HIGH AUTHORITY
OF THE EUROPEAN COAL AND STEEL
COMMUNITY

STEEL CONGRESS

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The High Authority
of the
European Coal and Steel Community

Steel Congress 1965

Progress in Steel Processing

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CLOSING SESSION

1 *Official Opening of the Congress*

in the Presence of their Royal Highnesses the Grand Duke and Grand Duchess of Luxembourg

Dino DEL BO

President of the High Authority

Your Royal Highnesses, your presence here at this second Congress organized by the High Authority of the European Coal and Steel Community to promote steel utilization is for us a very clear sign of your interest in this initiative taken for the first time last year.

Your Royal Highnesses, Ladies and Gentlemen, it seems to me that this is the moment to stress the links between the subjects to be treated at this year's Congress and those examined last year.

The chief aim remains the same. It is to render steel, one of the principal basic industries, ever more competitive in face of new competing industrial products and in particular to help it to contribute increasingly to raising living standards and to the creation of new activities — in short, to make it the main motor of collaboration between peoples, of a work of peace and progress.

Last year we concentrated our efforts on the possibilities of increasing steel utilization in the building and construction sector. In this context the chief problem to be tackled was to accelerate the rate of construction of houses and other buildings in the Community through the use of steel and in particular trough a much greater recourse to prefabrication methods. The studies carried out by the Congress have helped to identify the means which should make it possible for the building industry to become more industrialized and to develop beyond its present artisanal methods. The construction industry could thus join the ranks of the major industries, on an equal footing with other production sectors.

However, last year's Congress, at which certain fundamental aspects of steel utilization were examined, made it clear that other problems remained to be solved. In particular the ways of employing steel in an industry such as building which, like many others, can be considered as in effect a steel processing industry. This is why we have thought it necessary to hold this Congress on a subject which logically should perhaps be considered preliminary to last year's discussions, even though chronologically it is taking place after them.

What are the basic characteristics of steel? What are the possibilities for it in the construction of industrial installations, of capital goods and of consumer goods? How can steel not only defend the position it has already achieved but also in the future maintain the primacy which today classes it as the basic material for processing in most industrial sectors?

Such is the theme which is today submitted to the scientists, technicians, representatives of public utilities and administration, architects and all those, directly or indirectly concerned with the production or the use of steel, who have responded in such large numbers to our invitation to take part in this second Congress.

We give you all a warm welcome and thank you for coming.

We would like to greet and to express our thanks in particular, now at the beginning of this second Steel Congress, to the representatives of the Press — representatives of the political Press as well as those from the technical Press — who by their invaluable support have once more shown the interest they attach to the High Authority's initiative of last year, now renewed today.

The Steel Utilization Congress is on the way of becoming the most important single public meeting held by the High Authority. To give it still greater significance and importance, the High Authority has this year decided to ask Mr. Etzel to act as President of the Congress. As member and Vice-President of the High Authority in the past who still today holds important public responsibilities, Mr. Etzel has given more than ample proof of his qualifications to act as President of this Congress. In accepting he shows once more his support for the High Authority as well as bringing us the benefit of his intelligence and experience.

We are very grateful to Mr. Etzel for having accepted our invitation and very pleased that he has been able to take the Chair at this second Steel Congress.

In conclusion, I may permit myself to make some general remarks of a political nature. It should be known that, at an uncertain stage in Europe's economic integration, the High Authority is concerned to show by this second Steel Congress that it, like the two other Commissions in Brussels, is of the opinion that the best way to contribute effectively to solving the vital problems which face Europeans today is to respect scrupulously both the letter and the spirit of the Treaties which govern us. This second Steel Congress is wholly in line both with the letter and the spirit of the Treaty of Paris which requires the High Authority to promote amongst public opinion in the Community and throughout the world an interest in all the new utilizations for the products for which we are responsible.

Henry CRAVATTE

Deputy Prime Minister of the Grand Duchy of Luxembourg

Your Royal Highnesses, Mr. President of the High Authority, Mr. President of the European Parliament, Your Excellencies, Ladies and Gentlemen, first of all, I must convey to you the apologies of our Prime Minister, Mr. Pierre Werner, who very much regrets that he is not able to be present to address the official Opening Session of your Congress as he had intended. Since he has had to travel to a neighbouring capital to attend an important European meeting, he has asked me to welcome you on behalf of the Government.

This is the second time that the High Authority of the European Coal and Steel Community has organized in our city a great Congress of this kind, an outstanding occasion as regards both its general theme and the standing and number of those taking part.

Our cordial respects to you all, our most welcome guests. A special word of greeting to your Chairman, Mr. Etzel, who has frequently given token of his sincere friendship for this country. His presence in the Chair will undoubtedly shed additional lustre on your proceedings; possessed as he is of all the attributes of a first-class chairman: authority, ability, experience and adroitness, he will ensure that all goes to perfection.

Ladies and gentlemen, I have no wish to make us sound presumptuous, but I do feel that no other country could more reasonably aspire than ours to the honour of serving as the venue for your Congress. Our economy was for many decades based entirely on the production of iron and steel, and despite the fairly marked industrial diversification of recent years this sector is still, and will remain, easily the most important. It is pre-eminently the socio-economic factor on which depends not only the level of employment of a large part of the population, but the general material wellbeing of the country. The whole Luxembourg community is affected, immediately or less immediately, by variations in the volume and conditions of steel production and steel sales.

No country can be more keenly concerned than ours with the theme of your Congress. No country can more ardently trust that your deliberations will be followed by the opening-up of new uses for steel, that aristocrat among materials, the combined product of raw metal, technological ingenuity, enterprise and human toil.

A still more cogent argument for regarding Luxembourg as the right place for the International Steel Congress is the fact that the European Coal and Steel Community has had its headquarters here since its inception.

Your Congress is one of the Community's most notable efforts of recent years.

Faced with many difficult problems, the Community has drawn its strength not only from the Treaty on which it is based and the powers vested in its supranational Institutions, but also on indisputable successes which have caught the attention of Europe and the world. It has been duly mindful of one of the dominant elements in the Treaty of Paris in seeking to promote and expand steel consumption and to popularize the use of steel, with the aim of raising the standard of living of the 180 million Europeans for whose benefit it was set up. The slogan of your Congress, "Steel Creates the Future", has grown to be a positive obsession with the emergent countries of the world.

I pay this tribute to the work of the High Authority in order to emphasize how much we welcome the growing-up around this important Institution of a great corpus of activity, thought, study and research.

Last year's Congress had a special, individual character of its own. The present Congress has one likewise, in two regards.

First, the technological and economic matters you will be discussing are placed against a very wide international background which is given a distinctive touch by the special links with Europe. I feel your recognition of this will be a source of inspiration to you and will add a particular and powerful momentum to your discussions.

The other point about the Congress is its broad and varied composition. There are among your number not only technologists and scientists from plants and laboratories, but also engineers, designers, architects, economists—all fellow-workers with whom you can exchange your findings. This communication and exchange of knowledge will throw up new ideas leading to the evolvement of new uses for steel in all kinds of fields.

Another thing: this Congress is, I feel, a major contribution to *rapprochement* among our countries and peoples. The series of developments during the second half of this year have made it clear that Europe is at present passing through a crisis. The immediate outlook is regarded by many as gloomy.

Yet surely we have reason to continue confident in the sense and realism of the men who at this juncture have the heaviest responsibilities to bear.

For this Congress, the countries represented at which extend so far beyond the confines of Little Europe, offers a striking glimpse of the realities of to-day and of to-morrow. It is, after all, embarking on the study of matters of the highest importance to our countries, which can be successfully dealt with only on a basis of close international co-operation.

For its ultimate objective is to institute a co-operation and understanding ranging well beyond the Europe of the Six, which, let us hope, will be succeeded at no very distant date by a wider Europe still more in line with the underlying desires of our peoples.

Your debates will find an echo outside this continent of ours, since among other subjects you are to discuss the problems of steel utilization in the emergent countries.

Political oppositions and contradictions cannot persist for ever in the teeth of economic realities. It is economic realities that ensure human wellbeing by extending to mankind the benefits of a production with a tremendous future before it.

In conclusion, I wish your Congress the fullest success in achieving the aims of its organizers. And above and beyond that, so far from giving rise to barren rivalries and jealousies, may it open the way to further expansion in the paths of peace.

Franz ETZEL
Chairman of the Congress

Steel for the World of tomorrow

Your Royal Highnesses, Mr. President of the High Authority, Mr. President of the European Parliament, Your Excellencies, Honorable Members of the Government of the Grand Duchy of Luxembourg, Ladies and Gentlemen, the science-fiction kings have up to now usually placed their previews of the future in the year 2000, a date they reckoned to be still far away, well beyond their readers' lifetimes. But we have now reached a point where only 34 years lie between us and the onset of the twenty-first century. Not all of us, but a good many, will see the turn of the millennium, though only as, I trust, hale and heartly old-age pensioners.

The course of human affairs as the second millennium draws to its close is like the course of an individual human life. The later years are harder going, fuller, more crowded and eventful than the earlier, and they slide by more swiftly. The originators of the science-fiction genre, the Jules Vernes and the Hans Dominiks, writing for entertainment and not as serious prophets, have turned out—unlike so many weather and economic forecasters—to be pretty well right. Though we shall not, even by 2000—or probably ever—subdue the whole universe, we very likely shall be masters of interplanetary space. Incidentally, the term "space ship" was not coined by our contemporary technologists, but by those imaginative authors of early science fiction. Since their day, their dim conception of splitting the atom has evolved into a new source of energy, a great industry, and, alas, a sword of Damocles over the head of human kind.

By the year 2000 the whole aspect of our cities and countryside will have changed. The earth will have become smaller, and, let us hope, the sense of human interdependence greater. Transport, and particularly travel, as a vital human activity in the industrial mass society, will need to be organized at several superimposed levels for the volume of traffic to be contained. Intercontinental rocket vessels will fly about our planet, artificial satellites will keep the airways safe and provide a world network of instant telecommunications. Exploration and exploitation of the sea and the abyssal regions will open up new sources of raw materials and nutrition, of fresh water for the consumption of the great agglomerations and for the irrigation of arid deserts.

These are just a few of the more salient changes in the world of the early twenty-first century. We cannot know their full impact and complexity, for the three and a half decades still to come probably hold as much as the three and a half centuries behind us. I hope and trust that medical science will have succeeded in the course of these 34 years in ridding humanity of one of its greatest scourges, cancer. I dare say by that time a remedy will have been found against the common cold. At all events, means will have had to be found of feeding an enormously expanded human population and meeting its multifarious needs. The emergent countries in Asia, Africa and South America, already long murmuring, will begin to clamour: their cry must be heard and their demand to eat from the amply-stocked table with the rest accepted, for better and for worse.

The challenge to our generation is the economic and ethical conquest of a future which, as we know, has already begun. Economics and ethics, theWestern *ora et labora*, man's material and spiritual weal, cannot stand in one another's stead. They are the twin poles of a world which, to live in peace and kindliness, must turn upon this axis, and not eternally upon the perilous axis of the ideological East-West antagonism.

I shall today be dealing only with the economic aspects, but I should like to suggest that at the next Congress a philosopher or theologian should be invited to speak on the world of tomorrow. As regards the economic side, its outstanding characteristic today is its fluidity. Between the economic structure and the swiftly-changing way of life in the industrial mass society there is close and constant interaction. In this process the function of the economy as a whole is to subserve and not to control. It is human nature to wrest advantage more forcibly and impetuously from constantly changing than from static circumstances. There are plenty of tumultuous historical movements to serve as lurid examples. As we well know, irresponsibility on the part of producers or consumers, buyers or sellers, employers or workers is exceedingly harmful even now: in a future economy, shifting, interwoven, intricate and sensitive, it could be doom to whoever may then be the weakest.

The world of tomorrow will produce practically everything industrially. A pair of boots Hans Sachs fashioned at his last, a folio volume from the hand press of Gutenberg will be at best obtainable only by eccentric wealthy collectors. Industrial production will be largely automated. But automation always involves investment. Industrial investment and financing in a fast-changing economic structure may become as hard as climbing the North Wall of the Eiger, unless we also have mechanization in management: I mean the systematic use of computers as an aid to business strategy.

The data stored for processing in these machines must be so prepared as to lend themselves to conversion into mathematical equations and patterns in accordance with the principles of operations research: the results can then be employed as a reliable basis for enterprise policy. The computer's work does not itself constitute policy decision, but it facilitates it enormously, since it affords the management fuller and more dependable intelligence to act on. The art of management is coming to consist not so much in solving the difficult problems involved direct, as in simply asking the right question at the right time. Though responsibility, of course, the computer cannot take over from the human individual.

Historians are accustomed on occasion—thereby showing that they recognize the economic associations of history—to designate periods of time according to the basic material of human society: the Stone Age, the Bronze Age, the Iron Age, the Steel Age. What lies ahead? Will steel still be the basic material of the twenty-first century? The answer hinges on the exertions which the steel-producing and—as will emerge in the proceedings of the next few days—the steel-processing industries are prepared to make.

Very considerable progress has been made by now in metallurgical research to improve the mechanical and technological properties of the different steel qualities: perhaps the most important advances for practical purposes have been the increases in mechanical resistance, as for instance the achievement of higher yield points, and in suitability for processing, for example better weldability. I am told that one outstanding success in this connection is the new weldable martensite hardenable steels with resistances of up to 200 kg. per sq. mm. and yield points as high as 185 kg. per sq. mm. But there have been other improvements too, in resistance to corrosion and in mechanical properties such as toughness and insensitivity to ultra-low temperatures. At the other extreme, for jet engines and gas turbines, for metal-cutting tools and high-temperature techniques heat-resistant materials are now used, in the form of high-alloy steels and ceramals. For nuclear reactors steel's natural imperviousness to radiation is an additional advantage—a property which can moreover be intensified by appropriate treatment. Other tangible results in this field include the artificial satellites now circling the earth.

Present research suggests that the thermal and mechanical efficiency of these "super-alloys" can be still further increased.What is currently feasible is not enough, for progress on supersonic flight, for instance, is still held up by the thermal behaviour of the materials. There is still plenty of scope for stepping up the resistance of steel: physicists have recently been claiming that steel's maximum possible resistance is incomparably greater than anything achievable today.

Alongside improvements to steel qualities there must go improvements to the forms and shapes in which steel is employed. Latterly we have seen silk-slender steel fibres a few thousands of a millimetre thick, and india-paper-fine steel foil a few hundredths. And as you all know there are other forms too, less striking, but just as valuable and efficient—elaborately-conceived products such as the cold-rolled sections, the extrusion profiles, the Euronorm sections, the galvanized and plastic-coated strip. All the same, we must not rest on our laurels: we must achieve the unachievable to offer steel tallying with the received ideas of it yet embodying what appear on the face of things contradictory properties—resistant yet malleable, wear-and-tear-proof yet not brittle, at the same time non-reverberant, light-admitting, colourful, gay and glamorous, warm and friendly and alive, hardly like a metal any more, and, on the top of it all, cheap.

The tasks ahead of us are so vast and many-sided that the steelmakers alone cannot hope to master them. What is needed is close co-operation and detailed comparing of notes with the processing industries—and the greater the amount of design and processing work in relation to the amount of steel used, that is to say the higher the degree of technicization, the more vital that co-operation becomes.

Experts are agreed that as time goes on there will be fewer and fewer persons employed on mechanized production and a higher and higher proportion in the tertiary sector, and that, in parallel, the distribution of goods will be more and more linked with tertiary activities. As has been said, the consumer does not in reality need either a material, or a product, or a good of any kind: what he needs is solutions to problems. Which means that in the world of tomorrow, the marketing of steel and steel products will entail comprehensive and really competent services, in the form of technical counselling, research on new products and processes, and regular consumer consultation.

The ancients and the Middle Ages saw the world as a trhee-tier unit, earth, heaven and hell. With the progress of science and technology in the nineteenth and twentieth centuries this conception was superseded. But the idea of a tiered world does seem to me to be a pointer to the future. We cannot appreciably increase the earth's habitable surface to make room for an expanding humanity. But we can organize such basic manifestations of human activity as home life, work and travel to take place at several levels one above the other. What was first done in the huge urban agglomerations of New York and Chicago—the building of soaring skyscrapers and the running of transport on overhead roads and underground—will have to be done elsewhere, with up-to-the-minute improvements, in many places in the world of tomorrow. And tomorrow's tiered world cannot be built without the aid of steel.

To feed a human race by then numbering several thousands of millions we shall need intensified and mechanized agriculture. Agriculture without steel equipment and machinery is unimaginable even now, and still more so for the future.

Steel used in the past to be regarded as a typical capital-goods material. Machinery, buildings, vehicles and installations were mainly of steel. But already it is apparent that large quantities of steel are also being used to manufacture for the consumer-goods market—kitchen utensils, furniture, gardening implements, camping and sports equipment, cans and other containers, motor cars and toys. If we make a real push it should surely be possible to stimulate this growing market to take even more steel.

At the High Authority's first Steel Congress here last year, the Chairman, Prof. Jeanneney, posed the question at the opening session whether competing materials—principally concrete, aluminium and plastics—were likely seriously to affect steel's future prospects. With an intelligence such as his, he declined to answer Yes or No: he said it would depend on the effort we were prepared to deploy, now and later, on the competence and diligence of our personnel, and on the vision of our leaders. Prof. Jeanneney went on to refer to "saving inventions"—the big breakthroughs that one after another must open up the future. This shrewd comment is, I feel, highly relevant to the world of tomorrow.

I may perhaps be apposite to quote here the Schuman Declaration of May 9, 1950. "Europe," Schuman said, "will be built through concrete achievements, which first create a *de facto* solidarity." It was in this spirit that the Coal and Steel Treaty was conceived fifteen years ago. Today that *de facto* solidarity has been established in the coal and steel sectors: the Congress for which we are now met bears witness to it. But the Treaty's object is not merely solidarity among producers. Those present at the Congress are, in the best sense of the term, a mixed company of consumers, processers and producers; we feel, too, the fullest solidarity with our friends from the non-Community countries, whose presence clearly demonstrates that a mixed company is the reverse of a closed shop.We are looking, all of us, to the world of tomorrow and its altered economy. One of the great features of that future will be co-operation, horizontal and vertical and world-wide.

Today's, and still more tomorrow's market is becoming unmistakably the cause and production the effect. All the same, that is not to say we should wait for the impetus towards innovation to come from the end-consumer, and work back, slowly and time-wastingly, via the processer to the producer. No, the end-consumer, the processer and the producer must form a common front in the van of production progress, to anticipate the customer's wishes: vertical co-operation for this purpose will become an integral part of the market strategy of the future.

The true task of this second High Authority Steel Congress, on "Progress in Steel Processing," must therefore be to acquaint both partners in the field of steel technology, the producers and the processers, with the latest developments in processing techniques, and to stimulate debate between them. In taking this task upon itself, the High Authority is discharging a duty laid upon it by its establishing Treaty. The basic Articles of the Treaty require it to promote "the expansion of the economy, the development of employment and the improvement of the standard of living", together with "the regular expansion and the modernization of production and the improvement of quality." By holding this series of Congresses, it is creating a forum for the exchange of views and a starting-point for further progress and research.

The subjects for the four Working Parties—Industrial Design, Surface Treatment, Cold Forming and Jointing and Assembly Techniques—are, I think, happily chosen. They represent areas of steel processing which considerably influence steel utilization, and in which new advances both in pure and in applied research have recently been achieved.

The principles of industrial design can do much to make the industrial products, and hence the world, of tomorrow a pleasanter and happier place to live in. This is true not only of the consumer goods in man's immediate personal surroundings, but also of the capital goods he employs, or even merely looks at. As we all know, iron and steel tend from past history to have grim associations with war and violence. But here I see a possibility of giving them a kindlier connotation, of ennobling their image among the public. Then again, for purely business reasons, we should pay more attention to industrial design, for sheer ugliness finds few takers.

Much the same applies with regard to surface treatment. In an age when summer after summer sees mass migrations to the Mediterranean beaches for the surface treatment of the human body, steel can hardly escape the trend! Some highly promising beginnings have already been made, of which we shall learn more from the specialist papers. But there is another reason why surface treatment is becoming indispensable—the trend towards lightweight steel construction. For lightweight building, as you know, the components are having to be manufactured thinner and thinner: any weakening of load-bearing members by corrosion could very quickly cause their collapse.

The themes of cold forming and assembly are also closely allied. The main problems relate to economic fabrications, that is, to lowering costs in processing. Suitability for cold forming and weldability are perhaps the two most important properties of steel from the processing standpoint, and it has long been the aim of metallurgists to increase them and increase them again. Technologically, both cold forming and welding are processes which lend themselves readily, and advantageously, to mechanization and automation. As we shall be shown in the course of the Congress, considerable progress has been made of late in this direction also. Working Parties III and IV will thus be dealing with questions needing to be approached from two angles, that of the material and that of the method.

As we have seen, in the world of tomorrow the emergent countries will be playing a very prominent role vis-à-vis ourselves. I am therefore particularly glad to know that the High Authority has taken account of this, and has arranged for the first time that the present Congress should include a discussion on the significance of steel in the developing countries.

May I say how much I hope that this second High Authority Steel Congress will come up to the expectations of us all—the High Authority itself as organizer, the rapporteurs who have so kindly agreed to serve, and last but not least yourselves, ladies and gentlemen, who have many of you come long distances in token of your interest.

For myself, I am deeply conscious of the honour done me in inviting me to be Chairman of this Congress. As the High Authority's one-time Vice-President, I have already a close connection with it and its aims, and am therefore particularly happy at this further opportunity to do it service.

May the results of the Congress help not only to afford fresh stimuli to steel utilization, not only to make possible further economic achievements, but ultimately to make the world of today and the world of tomorrow a better and a happier place.

I hereby declare the second Steel Congress of the High Authority, on Progress in Steel Processing, officially open.

Roger REYNAUD
Member of the High Authority

Technical and Economic Aspects of Steel Processing

Your Royal Highnesses, Mr. President of the European Parliament, Your Excellencies, Honorable Members of the Government of the Grand Duchy of Luxembourg, Ladies and Gentlemen, in asking me to address the Opening Session of this second Luxembourg Steel Congress, the High Authority has done me an honour, but an honour of whose attendant risks I am well aware.

Whereas our first Congress dealt with progress in steel construction, a subject closely related in several respects to our every day concerns and considerations, the programme of this second Congress bears a different and at first glance indeed somewhat surprising aspect, that of a mosaic of extremely varied and highly specialized studies.

This stems from the very nature of the steel-processing industry, which covers a great many different production lines and an enormous variety of techniques and processes.

In point of fact, our programme comprises three separate groups of questions. The first concern a number of processes and techniques, most of them of recent development and some of them daring new departures, selected from the immense range in use in the steel-processing industries. This is the portion of the Congress dealing with:

—surface treatment,

—cold-forming, and

—assembly methods.

The second group are centred on the concept of industrial design, usually though perhaps not quite accurately rendered in French as "esthétique industrielle."

The last category are connected more particularly with the manner of application of the techniques and processes to very specific situations—the use of steel in the emergent countries.

I make no claim to offer a general conspectus of such a mixture of subjects, but I should like, if you will allow me, to make a few points concerning them, taking as my basic theme the extraordinary variety of means that can be employed to achieve the same end.

The range of materials, techniques, processes, agents and forces that can be deployed with technological satisfactoriness is now so wide, so flexible and so varied as to be positively disconcerting.

Whether the problem is to give a product the geometrical shape best suited to its technical, economic or aesthetic function, to give its surface the strength and finish needed for it to do its job reliably and well while remaining attractive to see and handle, or to assemble the components of a product technically or economically impossible to design or make initially as a single whole—whatever the problem, there are all manner of possible answers, necessitating constant imaginative thought and objective study in order to make a choice. Three general criteria may be mentioned as having to be borne in mind in this regard—economic remunerativeness, aesthetic appreciation and the time factor as regards ultimate introduction.

To take the first criterion first. Given alternative means of achieving a single end, the criterion of remunerativeness is a matter, basically, of the comparative costs of different raw materials, different techniques, different methods and different combinations of them. There is, of course, a certain choice. This does not depend only on time and progress: it also depends at any given stage in technological development, on the characteristics of the product and on local economic conditions.

Take first of all the equipment product relation. In this connection I may perhaps try to analyse broadly some of the groups of processes to be discussed during the Congress.

Choice among the different cold-forming techniques, for instance, would seem to be dominated primarily by three parameters—the length of the production run concerned, the size of the product, and the degree of precision required.

Thus cold forming by explosive shockwaves is a discontinuous process, and hence in the final analysis a slow one. On the other hand, it can be used to form large-sized products, and is therefore suitable for short production runs, in which the equipment must not be too costly in relation to the product.

Magnetic-pulse and electric-discharge forming resemble shockwave forming in many respects, but they do allow to some extent of automation, which makes the process speedier and more suitable for use on longer production runs, though even these runs will be a good deal shorter than in the peculiarly favoured field of die-stamping. At the same time, this does mean that only products of smaller size can be made.

The specific capital expenditure involved is considerably lower than for the traditional die-stamping process, but higher than for explosive-shockwave forming.

Machining by electrical discharge allows of still more advanced automation: it can be employed for long production runs, and has the advantage of comparatively low initial capital outlay, particularly in respect of equipment. However, though products of highly complex form can be turned out by this method, it does not seem capable of affording any great degree of precision.

Up to a point, the comparison of these three processes corresponds to the traditional comparison between manual, reversible and continuous rolling, with length of production run replacing hourly or yearly production as a factor in the calculation. As both increase, the employment of differently-designed plant, larger and larger, dearer and dearer in relation to the product, but more and more productive, is successively seen to be the economically most appropriate answer to a given technical problem.

It would be mistaken, therefore, to attempt to establish a definite merit rating as among different processes. This would conflict with the relativity I referred to a moment ago.What I have just been saying was rather intended to outline the fields of application for the different methods. As the technologists present are aware, technical descriptions of processes are incomplete unless accompanied by a few brief economic indications.

It would therefore be worth-while for those sections of the Congress dealing with the surface treatment of steel and with methods of assembly also to dwell a little on these technico-economic aspects. Some attempt to do so has been made on other occasions for the more usual machining, forging and casting techniques.

This approach would have the further advantage of bringing out also the effects of local circumstances.

Admittedly, as in the cases I have instanced, a technique suited for short production runs and large product sizes is economically unsuited for long production runs and smaller product sizes. Nevertheless, the choice among techniques is not absolute, either for the basic or for the processing industries, since it is influenced by the costs of the production factors, namely raw materials, energy, labour and capital, which themselves vary according to local availabilities.

So I am particularly glad that the Congress is being attended by specialists from countries where the cost structure is quite different from that in the industrialized areas of Western Europe.

This aspect will doubtless be the focal point of the Special Committee's discussions. Now there are two potential difficulties to be overcome in this connection. The first is the idea that the arrangements that have turned out best in the wealthy countries—for industry in general and the metal-producing and metal-processing industries in particular—are ipso facto suitable for direct transplantation to the emergent countries. In the emergent countries, for the most part, capital is scarce and there is a glut of unskilled, together with a shortage of skilled labour, in addition to varying degrees of poverty in foreign exchange and in energy resources.

On the other hand, it would be equally wrong to suppose that the emergent countries should disregard modern techniques which are commonly, though not invariably, bound up with a high degree of capitalization and technological development. There would be no sense whatever in expecting them to traverse the same long and stony road to industrialization as our own did, starting from rough-and-ready techniques and only adopting new ones after many years of research, development and assimilation.

On the contrary, it will be quickness in taking over techniques, and the fact of being in a position to make an informed choice in line with local conditions from among a wide variety of alternative possibilities, that will offer the emergent countries one of their chances to speed up their process of industrialization and enrichment.

The criterion of which I have been speaking amounts in effect to seeking the lowest cost. This is the economic aspect in the narrowest and most restrictive sense of the term. Nevertheless, in certain of the coming discussions, particularly in Working Party I and doubtless also in Working Parties II and IV, there is by hypothesis another criterion, the criterion of aesthetic appreciation.

Aesthetic appreciation is of its nature intuitive and subjective. Intuitive in that, notwithstanding the canons of a particular time or fashion, beauty has never yet been pinpointed by equation: it is something that is happening afresh all the time, always showing a new face, appearing in a hundred different incarnations. And the multiplicity of personal tastes, expressive of subjectivity, is the other pole of the aesthetic approach. Surely this dual character is the inherent riddle of aesthetics.

Any tendency to over-abstraction in the purely rational and mathematical attempt to raise material well-being to the highest possible level is thus corrected by reference to human sensitivity. Though design does have a market price, the aesthetic criterion cannot be measured. It is because it touches the deeper chords in the spirit of man that I am pleased to see the subject of *l'esthétique industrielle*, industrial design, placed at the top of the Congress agenda.

This dualism between the concern for cheapness and the concern for pleasing design has too long been regarded as a conflict. Let us trust that a feeling for attractiveness will set limits to the concessions creative thought must make to the question of profitability associated with mass production.Well-being amid ugliness is but a barren postulate.

Whether opposed or aligned, the criterion of remunerativeness and the criterion of pleasing design are indissolubly linked in the continuous striving for perfection. It is the technologist's duty to satisfy both.Where the pleasing and the rational do coincide, is this the exception, the effect of chance? Is it not rather the result of inspiration, that inspiration that itself springs from a committed, absorbed approach? The answer is obvious. Yet nothing can ever be taken for granted: the evolution of motor-car design is an interesting case in point, in which the calculations of the technologist and the market specialist are continually sustained, and occasionally disrupted, by the ever-changing movement of consumer preferences.

In this connection, I was struck by the point made in one of the first papers on industrial design, urging that the extractive and the processing industries combine, despite their apparently conflicting interests, to support research on industrial design for the purpose of opening up new fields of utilization for all materials generally.

It may be that this suggestion will be taken up: may I say that, if so, steel has nothing to fear, for two reasons. First, steel is not expensive. Doubtless for a particular purpose another material or combination of materials may well be used instead, but, though this arrangement may in some cases be more satisfactory if the cost factor is ignored, it will usually work out pretty dear. Secondly, as the importance of the design criterion increases, steel's prospects become still more promising, in view of the unlimited variety of jobs it can perform and shapes it can take. For, in Valery's incisive phrase, steel will "whet, cut, split, drill, bind, file, pierce, grip, plane, saw, thread, bore; it vibrates, it magnetizes, it tautens and slackens; contains; retains, sustains..." What infinite scope for steel!

But industrial design must extend beyond the product to industrial equipment in the most comprehensive sense. The first stage of the Industrial Revolution suggested that the machine in bringing new material satisfaction might at the same time maim human life. It is time to react, to put our received ideas and habits through a searching examination.

Are we doomed to monstrous industrial overgrowth as the outcome of unjustified confidence in the omnipotence of economies of scale?

Is out-and-out standardization really inevitable?

The great majority of the techniques with which the Congress will principally be dealing are advanced techniques Many of them were devised only a few decades or even a few years ago, and some are even now only in the blueprint or the semi-industrial stage. How long will it be before they are everywhere known and employed, those of them which prove worth introducing?

It is hard to say, but in all probability the time needed for their development, publicization, financing and adoption will be shorter than it was for their predecessors, not only by reason of better methods of communication and dissemination, of larger capital resources and of the stimulus of international competition, but also because those in charge, in their different capacities, of the production process and its future course are more alive to the importance of innovation, research and development.

From this brief commentary on the subjects which the Congress is to discuss, it will be clear that we have with us the time factor in a new form, a speeding-up of inventions and of the structural changes resulting from them. Technique improvement, economic development, aesthetic resurgence, geographical diversification are proceeding so rapidly that we are living in a world in permanent flux.

This quickening of the pace of progress, this broadening of the range of alternative possibilities for the producer, the designer and the planner, raise a number of problems which I should like to mention for your attention.

First, there is the difficulty posed by the existence of older and newer techniques side by side. How is it to be overcome with the purpose, not of pointlessly seeking to preserve the past, but of avoiding waste and overlapping in capital investment and so ensuring that the passage from the old to the new goes through as economically as possible? In a free-market economy, the answer is the price mechanism and competition. But the nub of the problem is to settle the climate and framework in which competition can afford the optimum results for society as a whole. This difficult task needs to be tackled with due consideration for the technical and economic conditions pertaining to the different possible production points, based on a careful analysis of the various factors of which I have been speaking.

Secondly, there is the question of the region or town. This involves a different kind of juxtaposition, for the changes produced by this progress in the location and patterns of production, distribution and demand must be reconciled with the workers' right to security, stability and status. You are familiar with the High Authority's responsibilities and activities in connection with the industrial redevelopment necessitated by the structural changes which have been taking place in the last few years in the coalmining and iron and steel industries. The adoption of new techniques which are to be discussed at this Congress will involve perhaps less spectacular but quite as awkward problems with regard to industrial redevelopment and to resettlement and retraining of industrial personnel.

Thirdly, there is the problem of the adjustment of the individual.With the rapid changes in the degree and kind of knowledge and skills required and in patterns of employment, ever-increasing importance will be to education and training, and in particular to occupational retraining with a view to redeployment.

It seems probable that the proportion of the working population which will have to change from one industry or speciality to another in the future in the course of a career will rise. And it is more than probable that the proportion of those, at whatever level, who will have more than once during their adult lives to absorb new knowledge, to learn techniques which did not exist in their early days, will rise steeply, to become indeed the large majority. From being the odd try-out here and there, retraining will become the general rule, one of the customary practices necessary to and made possible by the rapid spread of automated production.

So far from being an additional burden to man, this change in requirements as to knowledge and experience will come to be a source of enrichment, variety and satisfaction, as well as at the same time serving more and more to create leisure.

These three points seem to me essential, since man, while guiding the acts of choice as consumer, is affected by them as producer. Just as his intuition, his inventive faculties and his aesthetic appreciation play a pre-eminent role with respect to matter and to calculation, so his ability to adapt as a user of techniques is a determining factor in progress.

It is agreed by all that many of these problems will be easier to resolve in the Europe we are now building, which as it advances towards greater cohesion among its different component elements nevertheless aims at maintaining and developing their several endowments and heritages.

That Europe—more varied, I might even say more "dialectical" than the giant continent-wide nations, richer than the newly-developing countries—is achieving a harmonious balance between the organized efficiency of the former and the passionate aspirations of the latter. It may stand as an example to many countries. It could be a pole of attraction to those who have to work out among themselves the paths to unity and prosperity. And it could be a powerful factor in promoting the development of a sounder and stabler world.

2 *Proceedings of the Congress*

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and

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Recent Steel Developments in Supersonic Aircraft

Man's abilities to predict new markets, to visualize new product requirements, and to temper these with the realities of the market place in terms of competition, costs, and profits, have always determined our technical growth and our economic vigor. It is therefore imperative that we constantly evaluate these abilities, and diligently strive to improve them.

The evaluation of what has been done in the past is accepted by historians as a valuable guide to the future, and such an evaluation can be made in a logical, methodical way. The evaluation of what can be done in the future is not so prosaic, and requires that the ingredients of imagination and courage be added to our historical knowledge. Perhaps the greatest test of all is not understanding what has been done, not understanding what can be done, but understanding what should and must be done.

Our participation in this, the Second European Coal and Steel Community Congress, will contribute, at least in some small way, to each of these three areas of understanding.

The discussion of the significance of recent steel developments in supersonic aircraft will be based on the experience of North American Aviation with the XB-70A supersonic research aircraft program. The presentation will include major design considerations for the XB-70A, a discussion of stainless steel sheet, the application of stainless steel bar products, and will cover the selection and use of high-strength alloy steel, H-11. An attempt will be made to relate the discussion to the steel producer interests, and to point out areas where specific XB-70A developments are being used in other new systems.

The XB-70A program

The XB-70A is a research program encompassing a multitude of technical developments which have culminated in two flying aircraft, designed to fly at 2000 miles per hour at an altitude of 70,000 feet. Like an iceberg, the significance of the program is not obvious from the visible portion of the two vehicles. The real importance is the contribution made to the technology in many areas for future progress. This program, in many ways, is a new generation in research, following the X-15 program, described by the American National Aeronautics and Space Administration as the most successful research program of its type ever conducted.

The first XB-70A was flown on 21 September 1964, and by August 1965 the two XB-70A aircraft had made 19 test flights. More than half of this time was at supersonic speed, including seven flights in which supersonic speed was sustained for more than an hour. Continuous speeds of Mach 2 and above were maintained for 50 minutes on three different flights. Maximum speed and altitude achieved in the test program thus far are Mach 2.85 (about 1,900 miles per hour) and 67,000 feet.

After many refinements, the design became a delta wing configuration with a forward canard, and six side-by-side, aft-mounted jet engines with a combined thrust of about 180,000 pounds (fig. 1, p. 51). To feed the engines required a fuel capacity equal to two railroad tank cars of kerosene-like fuel.

The XB-70A has a length of 180 feet and a span of 110 feet. The 250-ton craft is constructed of 80,000 pounds of stainless steel, 20,000 pounds of alloy steel, and 12,000 pounds of titanium alloy. The stainless steel is utilized in a unique structure of 22,000 square feet of honeycomb panels, combined into a fuel-containing unit by 9 miles of fusion welds.

The developments required to achieve the multitude of technical goals in the program were at first rather staggering to the imagination, and many of those who knew the problems first hand shouted that it could never be done.

A proper measure of the significance of any research program requires an historical evaluation, but already, XB-70A developments have made a significant impact on other new programs. Examples can be cited in the fields of environmental control, lightweight engines, lightweight hydraulic systems, new fabrication techniques, nondestructive inspection, new materials, new types of structure, and many others. Several specific examples in the field of materials and processes are of particular interest.

Steel honeycomb panels were developed which exhibit very high structural efficiencies up to 630° F. These panels are comprised of facing sheets brazed to a honeycomb core formed from foil, (fig. 2, p. 51). This development has led to the application of similar panels on the Lockheed C-141, the Boeing 727, Apollo, and Saturn.

Metal removal by electricity and by chemical immersion has been developed which has made great advances in our abilities to fabricate parts from steel, nickel, and titanium alloys. These processes have been useful on the Apollo, the F-111 Aircraft, atomic reactors, and rocket engine components.

In the area of lightweight hydraulic systems, H-11 high-strength actuators, high-strength stainless steel tubing, and minimum-weight brazed and welded tube joints were developed to operate at 4000 psi and a temperature of 600° F. These are finding many uses in space vehicles and marine applications, as well as in proposed aircraft designs, such as supersonic transports.

The nickel alloy Rene' 41 fabricated into the XB-70A engine shrouds and into structural fuselage areas surrounding the engines which has resulted in the development and refinement of forming, welding, heat treatment and chemical milling processes. These developments will be of value to many future space and aircraft programs where heat resistant structures are needed.

Among many XB-70A developments in the technology of the fabrication of ultra-light titanium structure is the burnthrough welding process which efficiently joins thin caps and webs to form spars and beams. In this process, the welding head is automated to follow a predetermined path, melting through the cap of the assembly to fuse with the web. This development is already in use for the F-111 Aircraft and for the Saturn test stand.

The impressive list of nonmetallic developments made for the XB-70A includes the windshield. Its several panels total nearly 100 square feet in area, with the largest individual panel over six feet long. It is optical quality tempered plate glass, capable of withstanding a temperature of 500° F. It is laminated with a newly developed silicone interlayer. The developments made in heat resistance, optical quality, and methods of attachment will benefit many new programs.

The list of developments goes on and on, but the few examples given serve to explain the nature of the XB-70A program in the area of material and process developments.

Design considerations

Although the XB-70A is principally a steel airplane, the original purpose was not to design and build a steel airplane, or a titanium airplane, or an aluminium airplane, but to design and build a craft with an intercontinental range, and the capability of carrying a useful payload. These requirements of range and payload brought the conclusion that an optimum choice of conditions would be a speed of Mach 3 and a flying altitude of about 70,000 feet.With these parameters established, the problems of aerodynamic heating, efficient fuel containment, the control of personnel environment, and many others could be defined.

The speed of Mach 3 at an altitude of 70,000 feet was found by analysis and experiment to produce skin temperatures ranging from 450° F to 630° F, with temperatures up to about 1000° F in the structural areas surrounding the engines. These temperatures virtually eliminated the use of aluminium alloys for construction of the airframe, and our attention was drawn to steel and titanium alloys.

The containment of very large quantities of fuel as a major requirement made the use of fuel bladders and other types of separate tankage schemes far too inefficient from a weight standpoint. This directed the design to fuel-containing structure, and made weldable and brazeable materials essential for these areas.

An evaluation of the structural requirements for the airframe revealed that the compressive strength, tensile strength, stiffness, fracture toughness, and corrosion resistance were also important factors in the selection of materials. Because of the flight load spectrum for the design mission, it was found that once the static strength and stiffness requirements were met, that adequate fatigue resistance was also achieved.

A detailed analysis of the temperature problems pointed up two basic requirements. One was that the fuel had to be kept below a temperature of 300° F for proper engine operation, and that this could be done by the use of a paneltype construction with thermal insulating properties. Mechanical refrigeration was not feasible for this purpose. The second point was that in the forward fuselage, a suitable temperature for the crew and the electronic components could not be achieved by insulation alone, but would require mechanical refrigeration. The studies also indicated that once committed to refrigeration in the forward fuselage, that insulating panel construction was not weight benefit.

The design envolved to one requiring insulating panel construction for fuel-containing areas and skin and frame construction for refrigerated areas. Other areas of the airframe where the control of temperature was not required incorporated either panel construction or skin and frame construction based on the minimum weights obtainable.

For supporting structure and for landing gear, stiffness and high static strength at the various temperatures mentioned were primary design parameters. Again, fatigue strength was adequate when these other performance values were satisfied.

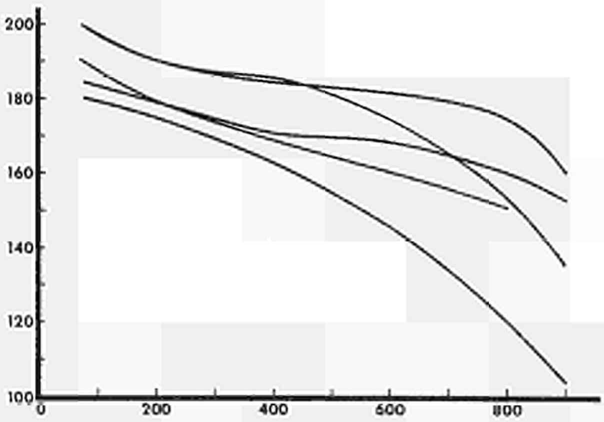
Material selection

Early in the design definition phase, it became apparent that the panel construction should be brazed honeycomb and that the core and facing material should be a high-strength stainless steel. Several alloys of the general type were available, but none which retained a high-strength up to the anticipated flight temperatures for the panel areas of 630° F. At this time, steel producers and research organizations were consulted, and were asked to develop a material to do the job, and also to predict the strength values which they felt could be met if the alloy developments were successful. Although this approach probably seems quite impertinent, the entire program was sufficiently advanced in concept that the approach to materials and process development was approximately parallel to the methods used to solve the unknowns in aerodynamics, structural characteristics, human factors, and other fields.

The stainless steel proposed for panels was assigned a target room temperature tensile strength of 240,000 psi as a design minimum value, and several candidate alloys were developed and evaluated. The best of the new alloys were Armco Steel Corporation's PH15-7Mo and Allegheny Ludlum alloys AM 350 and AM 355. The PH15-7Mo material appeared to most nearly meet the stringent requirements for sheet and foil. This alloy was not suitable as a bar and forging alloy, and, since the honeycomb panel designs beginning to come off the design boards required detail parts made from bar forgings as well as from sheet and foil, a major obstacle was reached. Understandably, it was difficult to find a bar alloy which could be welded to the sheet alloy, and which, after processing, would offer the required strength and corrosion resistance.With some compromise, the AM 355 alloy could be used for this application, and it was selected as the best candidate. Alloy development continued beyond this point in time, resulting in three new alloys: 15-5PH, PH13-8Mo, and PH14-8Mo. These developments, although not widely used for the XB-70A, were a direct result of XB-70A and will have an important impact in future steel applications. A comparison of several stainless steels is shown in the table below, "Common Product Forms". The following figure shows "Tensile Strength Versus Temperature."

Common Product Forms

	Sheet & plate	Foil	Bar & extrusion	Tubing	Castings	Forgings	Wire
Stainless W	—						
17-7PH	—	—					—
17-4PH	—		—		—	—	
PH15-7Mo	—	—	—	—			—
AM350	—	—		—			
AM355	—		—		—	—	
15-5PH			—			—	
PH13-8Mo			—			—	
PH14-8Mo	—	—					



Tensile Strength Versus Temperature

For landing gear and various types of substructure, alloy steels with tensile strength levels approaching 300,000 psi with elastic moduli of about 30,000,000 psi had been in use for applications similar to those for the XB-70A, with one major difference—service temperatures had always been well below the commonly used tempering temperatures of about 500° F to 700° F. A search for a suitable alloy was made, with target properties of 300,000 psi tensile strength, a modulus of elasticity of 30,000,000 psi, and good hot strength up to 1000° F. The search led to H-11 tool steel, a 0.40-percent carbon—5 percent chromium grade offering nearly all of the target attributes when tempered in the range of 1050° F.

Although our interests in this discussion are directed to steel, some comments regarding the applications of titanium may be of interest for comparison purposes. The forward 60 feet of the fuselage are characterized by comparatively light loads, crew containment, and electronic system containment. These factors indicate that the temperature levels required cannot be achieved by insulation alone, as mentioned earlier, and must be air conditioned. The light load level indicated that, from a structural standpoint, neither the strength of steel sandwich nor the strength of steel skin and frame were required. Titanium, with a tensile strength level of about 170,000 psi and a modulus of elasticity of about 16,000,000 psi, then becomes the optimum choice of material, using a skin and frame construction with glass wool insulation,. It was found that the titanium 6A1-4V in use at that time could be heat treated to provide the properties required, as could the newly developed alloy titanium 4A1-3Mo-1V. Much of the titanium alloy development leading to these choices was accomplished in a major titanium sheet rolling development effort sponsored by the United States Government.

Stainless steel sheet and foil—Fracture toughness

One of the major factors in the selection of a stainless steel alloy for brazed honeycomb panels was the capability of reliably providing high strength with adequate fracture toughness. The PH15-7Mo composition is a precipitation hardening grade designed to be capable of heat treatment to tensile strengths up to about 250,000 psi. The heat treating cycle consists of cooling from above 1400° F to obtain the transformation to martensite, followed by reheating above 900° F to obtain the precipitation hardening reaction. The hardening mechanism of the alloy is based on the precipitation of Ni3Al and NiAl intermetallic compounds in a low-carbon matensitic matrix (bibliographic reference 1). The composition includes chromium for corrosion resistance and molybdenum for hot strength in the hardened condition. It is balanced with carbon and nickel to provide the desired austenite to martensite transformation characteristics. This alloy development was based partly on an alloy that has been in production for many years, 17-7PH. The following table shows the compositions of 17-7PH and PH15-7Mo.

Chemical Compositions of 17-7PH and PH15-7Mo Stainless Steels

Element	17-7PH %	PH15-7Mo %
Carbon	0.09 Max	0.09 Max
Manganese	1.00 Max	1.00 Max
Phosphorus	0.04 Max	0.04 Max
Sulfur	0.04 Max	0.04 Max
Silicon	1.00 Max	1.00 Max
Chromium	16.00-18.00	14.00-16.00
Nickel	6.50-7.75	6.50-7.75
Aluminium	0.75-1.50	0.75-1.50
Molybdenum	—	2.00-3.00

The evaluation of many production-sized heats of the PH15-7Mo alloy showed a remarkably reproducible response to heat treatment. For any of several selected heat treating cycles, it was found that the tensile strength range could be controlled to within 30,000 psi, and that varying the precipitation'hardening temperature by 10° F provided a sensitive control.

It was found that material heat treated to the higher tensile strengths, over about 220,000 psi, displayed a reduced resistance to stress corrosion cracking and a lower fracture toughness.

The fracture toughness requirements for the PH15-7Mo panel facesheets were established by first evaluating the capability to detect cracks by methods most likely to be used in service depots. It was found that cracks shorter than one-fourth inch were not readily detected, so an assumption was made that such defects could be present in flying panels. Test panels were then fabricated, and one-fourth inch long cracks were induced in them. The aircraft load spectrum was applied to these panels, and it was learned that panels heat treated to a tensile strength over 220,000 psi failed at some number of cycles short of the anticipated aircraft life. Test panels at tensile strenght levels at or below 220,000 psi successfully withstood the required cycle life without failure. The maximum permissible tensile strength was therefore established at the 220,000 psi value.

For structural analysis not involving fracture toughness, some minimum predicted tensile strength was also needed, and the value closest to the 220,000 psi maximum value would be, of course, the most efficient. With the capability to adjust the strength level by varying the precipitation hardening temperature, the question became how narrow a range in tensile strength could be predicted and achieved, considering that the answer is influenced by the variation in chemistry from heat to heat of steel, the variations in the heating equipment and controllers used in panel processing, and the differences in cooling rates caused by a variety of panel configurations. Here, the remarkable chemistry and process control achieved by the steel producer, and the great versatility of this composition became apparent. It was decided that the control of tensile strength under all foreseen conditions could be controlled within a total spread of 30,000 psi, permitting the range to be established at 190,000 to 220,000 psi. The alloy is a metastable composition with a complex hardening mechanism, produced in 70-ton electric furnaces. It is believed that the achievements of its development and production to such precise limits is an outstanding accomplishment in the field of metallurgy and steel production.

Stainless steel sheet—Corrosion resistance

The corrosion resistance of the PH15-7Mo was carefully examined because the chromium content is lower than that in alloys such as the 18 chromium 8 nickel family where the resistance to atmospheric corrosion is well known. In the precipitation hardening types, chromium suppresses the martensitic transformation temperature and, therefore, must be balanced with the elements which tend to stabilize the austenite (carbon, nickel, manganese, nitrogen, and copper). The alloy designer made a very critical selection of the chromium content, knowing that perhaps 18 percent chromium was desired for corrosion resistance, but that something less had to be selected to provide the desired transformation characteristics. The selection of the 14-16 chromium percent range for PH15-7Mo seems to be an ideal compromise.

Corrosion resistance is a relative thing, and its discussion should include the specific corrosive media involved, the time over which the corrosion occurs, the stress in the material, and the unit of measurement of the corrosion. Three types of corrosion are of specific interest, namely, stress corrosion, cracking, pitting corrosion and general rusting. It was felt that the best way to evaluate the corrosion resistance of this material was to compare it with a similar material which has exhibited satisfactory service life. This comparison can be based on a number of accelerated tests, such as beach exposure, salt spray cabinet exposure, alternate immersion into liquids, and others. For aircraft applications, 17-7PH sheet makes an excellent baseline for comparison, since it has given satisfactory service life for well over 10 years. For marine service 17-4PH has served well, and makes a good reference material. Interpretation of accelerated test-results requires a great deal of judgement, since the test conditions are arbitrary, and may not properly simulate service conditions. It should also be recognized that a material which appears to be inferior to a known material based on accelerated test-results may still be adequate for the intended application.

To illustrate a stress corrosion comparison, the table below shows PH15-7Mo in two conditions, compared to 17-7PH. Here, the materials were under a continual stress of 60 percent of their respective yield strengths, and exposed at both the 80-foot lot and the 800-foot lot at Kure Beach. This comparison shows that PH15-7Mo precipitation-hardened at 1050° F is equivalent to 17-7PH, and that PH15-7Mo precipitation-hardened at 950° F is inferior to 17-7PH.

Kure Beach Stress Corrosion Tests - Stress Level - 60% Fty

Material	Days to failure	
	80 ft Lot	800 ft Lot
17-7PH (precip hard. at 1050° F)	71-N.F.	N.F.
PH15-7Mo (precip hard. at 950° F)	25	72-N.F.
PH15-7Mo (precip hard. at 1050° F)	78-N.F.	N.F.

Note : "N.F." indicates no failure after 226 days.

Stainless steel sheet and foil—Tolerances

The use of steel in aircraft structure immediately focuses our attention on the greatly increased density of the material over that of the conventionally used aluminium alloys. This in turn means that thickness tolerances become more critical because the design must be based on the minimum thickness of the material, and any tolerance over this figure is unwanted weight. An example of this factor can be shown by assuming an increase in tolerance of 0.001 inch for steel honeycomb facesheets for the XB-70A panels. This results in an increase in skin weight of 2000 pounds. Experience shows that such a weight would become several times greater in the actual vehicle weight because of its influence on structural factors, engine performance, and fuel consumption.

Means to achieve the smallest possible thickness tolerances were studied in detail. For sheet products the best available tolerances wereone-half Al-Si values, produced by conventional cold finishing and roller or stretcher leveling. Since these tolerances were unacceptable, a thorough study of methods to reduce thickness tolerances was made. Belt grinding chemical milling and precision rolling were the possibilities with the most promise. As a result of the study, belt grinding was selected as the method to be used because chemical milling could not meet the tolerances needed, and equipment for precision rolling sheet widths was not available. Subsequently, a sudden development changed the situation. The successful operation of a newly installed 50-inch Sendzimir mill was announced and PH15-7Mo precision-rolled sheet in widths up to 36 inches became available. This width capability was later increased to 44 inches. The rather remarkable tolerances guaranteed and met for the entire XB-70A program are shown in the following table.

Thickness Tolerances—PH15-7Mo Sheet (in inches)

Gage	Tolerance
0.006 through 0.009	± 10 %
0.010 through 0.019	± 0.001
0.20 through 0.100	± 0.000 / 0.002
Note: For widths up to 44 inches.	

The honeycomb core required the use of PH15-7Mo foil in nominal thicknesses of 0.001 to 0.004, with 0.0015 the most often used. A weight tolerance for honeycomb blankets was necessary, and this was established at ± 8 percent. To meet this, allowing for variations in cell geometry, and overall dimensions, it was necessary to assign a foil thickness tolerance of ± 5 percent. Sendzimir mills were routinely producing various alloy foils with a ± 10 percent tolerance, to gages down to 0.002 inch.

The new requirement of producing foils down to 0.001 inch with a ± 5 percent thickness tolerance required an intensive development effort by the foil producers. Although a maximum width of about 4 inches would satisfy the requirement for core height, the foil has been supplied 24 inches wide. This has been accomplished by pregrinding cold-rolled strip to remove nearly all of the crown, and rolling to tolerance on a Sendzimir mill, using a dry hydrogen annealing operation. The effect of tolerance on core weight is shown in the following table, where it can be seen that for a specific cell size a few ten thousandths in foil thickness, makes a significant difference in core density in terms of pounds (Biblio. 2).

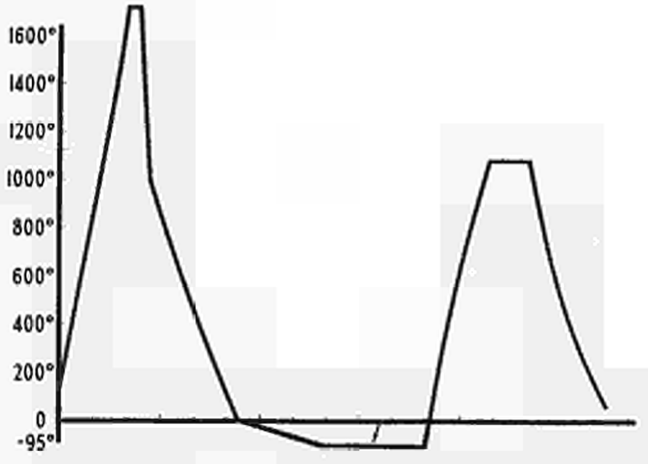
The Effect of Foil Thickness on PH Steel Honeycomb Core Density

Cell Size (Inch)	Foil Thickness (Inch)	Core Density (Pound Per Cu.Ft.)
1/8	0.0010	8.3
1/8	0.0015	12.5
1/8	0.002	16.6
3/16	0.00075	4.2
3/16	0.001	5.6
3/16	0.0012	6.7
3/16	0.0015	8.3
3/16	0.002	11.2

As a matter of general interest, approximately 750,000 pounds of PH15-7Mo foil were produced for this program.

Brazing of honeycomb panels

Precipitation hardening PH15-7Mo stainless steel is particularly well suited to the fabrication of high-strength brazed assemblies. In these applications, thermal cycles are adjusted to permit concurrent brazing and heat treatment (bibliographic reference 3). The standardized process for heat treating this grade calls for austenite conditioning at 1750° F, air cooling, transforming at —100° F, and precipitation hardening in the range of 900° F to 1100° F. Two brazing alloys, a silver-copper and a copper-manganese-nickel, were developed which permits concurrent brazing and austenite conditioning in the range of 1715° F to 1765° F. The tooling mass required for panel brazing varies with panel size and, of course, does not permit the cooling rate achieved in air cooling a sheet metal part. Various cooling rates are used depending upon panel size. Cooling rates from the brazing temperature down to about 1000° F affect the response to heat treatment because of carbide precipitation. In this temperature range, cooling times to 1000° F as long as 150 minutes are used. Slight adjustments in precipitation-hardening temperatures and times are used to compensate for the effects of these various cooling rates. Slower cooling rates also reduce the austenite stability and simplify the processing somewhat. For example, panels cooled to 1000° F within 30 minutes must be cooled to about — 100° F to produce transformation, while panels cooled to 1000° F in 150 minutes transform when cooled below + 50° F. A typical brazing cycle for a panel cooled in a relatively short time is shown in the following figure.

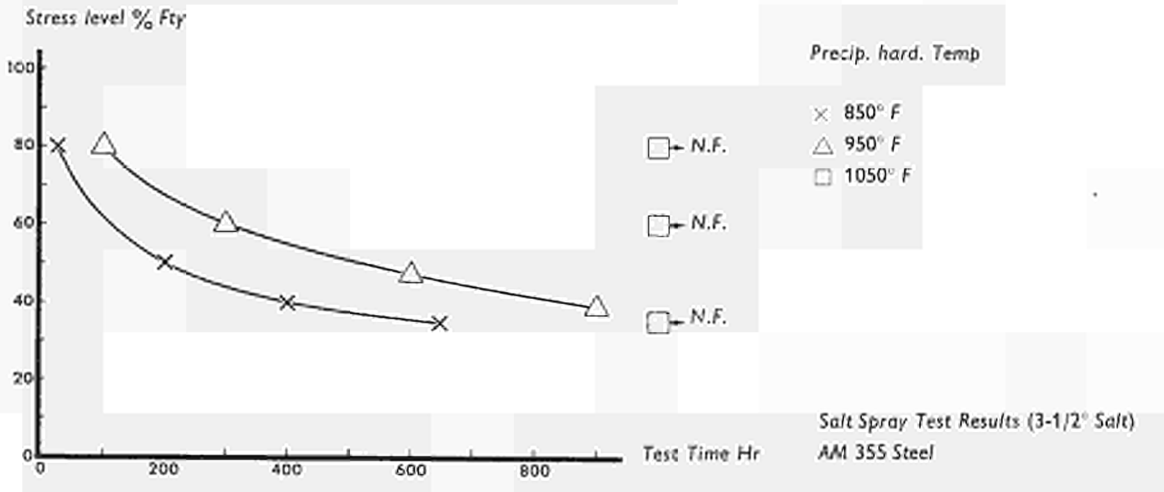


Typical brazing cycle

Tensile strengths are controlled within the range of 190,000 to 220, 000 psi by this process, and fracture toughness is controlled to close limits. Test bars run with each panel have shown that in producing several thousand panels, comprising many mill heats of material, reliable and reproducible response to heat treatment can be predicted. A typical example of a brazed honeycomb panel is shown in figure 3, p. 51. This panel has been chemically milled after brazing to remove weight from areas of lower stress.

Stainless steel bars and forgings

The applications of stainless steel bars and forgings were very specialized, because it was necessary to have high-strength detail parts which could be brazed as an integral part of honeycomb panels, to which subsequent weldments could later be made, and which, for other applications, could be welded in the fully heat treated condition to brazed honeycomb panels. Of course, the various other necessary characteristics, such as fracture toughness and corrosion resistance, concurrently had to be achieved in the weldments as well as in the parent metal. It was learned that the AM 355 material was marginal in its resistance to stress corrosion cracking when heat treated to strength levels above about 200,000 psi, accomplished by precipitation hardening at temperatures ranging from 850° F to 950° F. At a more modest strength level, about 180,000 psi, accomplished by precipitation hardening at 1050° F, improved resistance to stress corrosion cracking was obtained. The following figure demonstrates this behaviour in a salt spray environment. Emphasis on the development of stainless steel bar alloys toward two specific goals was continued. One was to develop a bar alloy which could be heat treated or brazed with PH15-7Mo sheet material, while producing strength and corrosion resistance superior to that of AM 355. It should be pointed out that the PH15-7Mo composition is not suitable for bars and forgings because of inadequate ductility in the transverse direction. This problem is associated with the delta ferrite phase present. The second goal attacked was to develop a bar and forging alloy with a transverse ductility superior to that of 17-4PH in heavy sections. The problem in the 17-4PH is also associated with the delta ferrite content of the alloy.



After a concerted effort, both objectives were achieved, and PH13-8Mo became the new companion alloy for PH15-7Mo sheet, and 15-5PH became the improved version of the 17-4PH grade. Both new alloys demand an extremely close balance of ferrite forming elements and austenite stabilizing elements, and require that conventional arc melting be replaced by vacuum induction melting (Biblio. 4). The nominal chemical compositions of the four stainless steel bar alloys mentioned are shown in the following table.

Chemical Compositions—Stainless Steel Bar and Forging Alloys

Alloy Element-Percent	17-4PH	15-5PH	PH13-8Mo	AM 355
Carbon (1)	0.05	0.04	0.04	0.12
Manganese (1)	0.8	0.8	0.8	0.9
Silicon (2)	0.8	0.8	0.8	0.3
Chromium (2)	16.5	14.5	12.8	15.5
Nickel (1)	4.0	4.5	8.0	4.5
Aluminium (2)	—	—	1.0	—
Molybdenum (2)	—	—	2.0	2.9
Others	4.0 Cu (1) 0.3 Cb (2) + Ta (2)	3.5 Cu (1) 0.3 Cb (2) + Ta (2)	—	0.1 N (1)

(1) Austenite Stabilizers
(2) Ferrite Formers

High strength alloy steel

The adaptation of H-11 as a high-strength structural alloy for the XB-70A was a blend of two areas of technology. Our structural and producibility knowledge of this type of material was based upon 5 years of usage of 4340, and similar compositions, heat treated to tensile strength levels up to 280,000 psi. Our knowledge of high-strength, heat-resistant steels came from many years of experience with tool steels. The family of tool steels which appeared to best fit our structural and producibility requirements appeared to be the AI-Si H-11 chromium hot work tool steel. This grade is a 0.40 carbon, 5.0 chromium, air-hardening type.

The criteria for selection, in addition to the resistance to high temperature were: (1) high strength, (2) high stiffness, (3) good weldability, and (4) adequate toughness. The H-11 steel was being produced by conventional air melting practices in ingots up to about 9 inches in diameter for wrought tools and die blocks, and as-cast die blocks. Its obvious shortcoming for structural applications was the very poor toughness when loaded in any direction except compression. No one knew how much improvement in toughness might be achieved. Since no other alternate approaches to a new material were found, a determined effort was launched to improve the toughness of the H-11 grade, while maintaining a tensile strength range of 280,000 to 300,000 psi.

Early evaluations of consumable electrode vacuum-melted material indicated that a large improvement in toughness was feasible. The controlling factors were found to be close chemistry limits, reduced freezing segregation in the ingot, and improved cleanliness. Additional experience showed that our selected course of action was sound, and that consumable electrode vacuum melting could produce a toughness in H-11 equal to or better than that of the 4340 type alloys used previously. A comparison of the minimum guaranteed properties established and achieved in consumable electrode vacuum melted forgings and air melted forgings as shown in the following table.

Guaranteed Minimum Properties—H-11 Alloy Steel

	Die Forgings	
	Vacuum Melt	Air Melt
Tensile Ultimate	280,000 psi	280,000 psi
Tensile Yield	245,000 psi	236,000 psi
Elongation	10.0 %	4.5 %
Red. in Area	30.0 %	7.5 %

The availability of vacuum melted H-11 was at first nonexistent, but in the period of two years, changed a great deal. The status for three specific years indicating this improvement, all based on XB-70A requirements, is shown in the following table.

H-11 Vacuum Melted Stock Availability

	1959	1960	1961
Sources	2	5	9
Mill Production (Lb/Yr)	25,000	800,000	Over 1,000,000
Useable Billet Size (Max)	8000 Lb	16,000 Lb	24,000 Lb
Cost/Pound	$ 2.05	$ 1.55	$ 1.20

The H-11 steel landing gear of the XB-70 is comprised of two main struts, each fitted with a main beam carrying four wheels, and a forward strut carrying two wheels. One of the most spectacular applications of H-11 steel is the main beam which is machined to precision dimensions from a 13,000 pound forging. The forging and the finish-machined parts are shown in figure 4, p. 52.

A major structural application of a sophisticated nature is the H-11 truss section, which carries wing loads through the fuselage. This truss is comprised of streamlined tube sections welded to machined end fittings. Analyses showed that this structure is lighter than the alternate design in titanium. The H-11 steel truss is shown in figure 5, p. 52 .

The successful application of H-11 at this strength level demands careful attention to many detail characteristics of the alloy, and inattention to them would invite unexpected fabrication costs and structural failures.

The H-11 structure includes many types of parts, among which are large welded frames with thin webs and caps. Many parts require threading, straightening or grinding. Each process is a potential source of trouble. A few of the necessary limitations are given below:

(1) Threads — when made to the Specification MIL-S-7742 configuration, they must be rolled. Acme, Whitworth, or "radius root" threads may be rolled or ground.

(2) Welding — preheat and postheat treatments are required. Welds are made while the part is maintained at 600° F. Weldments must be fully annealed before heat treating.

(3) Cold straightening — when applied to heat treated parts, cold straightening must be followed by stress-relieving at 925° F for 2 hours.

(4) Rough edges — burrs, deep scratches, and rough edges must be removed before the part is heat treated.

(5) Grinding — care is required to prevent checking, and all grinding must be followed by stress- relieving at 925° F for 2 hours.

Corrosion protection is provided in several ways, depending upon function of the part and service temperature. Sprayed aluminium coated with a silicone resin is used for some parts with service temperatures up to 900° F. A nickel-zinc electroplate coated with a silicon resin protects other parts for the same service temperatures. Vacuum-deposited cadmium is used for some applications where service temperatures do not exceed 500° F.

Today, consumable electrode vacuum melted H-11 is being produced in ingot sizes up to 32 inches in diameter, mainly for applications as tools and die blocks. It has been learned that the H-11 product developed for the XB-70 gives tools with increased life, and has resulted in the production of other tool grades as a vacuum melted product. The improved performance of these tools is attributable to the improvements in chemistry control, reduced segregation, and improved cleanliness, the same reasons for the improved toughness for the XB-70 applications.

In summary, it can be said that the XB-70A H-11 developments have given us the capability to design and use structural parts at tensile strength levels up to 300,000 psi, and have led to the production and use of improved dies and tools from greatly increased ingot sizes. Most human achievements bring us to a plateau from which we can reach upward, and so it is with H-11. The successes reviewed here have provided a basis to push on, equipped, we hope, with the wisdom to approach new problems with the proper balance of ingenuity and caution.

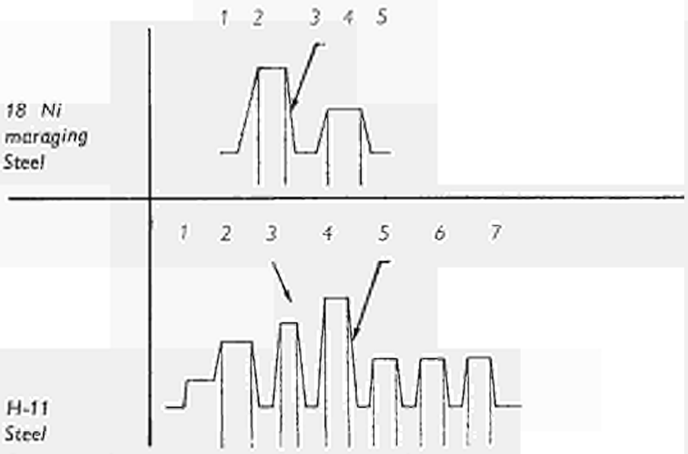
The future of high-strength alloy steels

In the area of improved fabrication characteristics, the high strength 18 nickel maraging steels should be mentioned. These grades are strengthened by a simple aging process, and have many of the attributes of H-11. A comparison of the design properties of the 300 grade maraging steel was made with H-11 for the XB-70A, and where a penalty in both modulus (E) and shear strength (F_{tu}) could be accepted, it very nearly met or exceeded the H-11 capabilities, as shown in the table below. Had the 18 nickel maraging steels been available sooner, a number of H-11 parts for the XB-70A would have been changed to take advantage of the simpler processing and the greater fracture toughness.

Properties of 18Ni Maraging Steel and H-11 steel at 650° F.

Property	H-11 (psi)	18Ni (Maraging) (psi)	% Change
F_{tu}	247,000	234,000	— 5
F_{ty}	200,000	209,000	+ 4
F_{cy}	227,000	235,000	+ 3
F_{su}	164,000	130,000	— 20
E	27.0×10^6	24.0×10^6	— 11
Elongation	8 % (Typical)	7 % (Typical)	— 12
Reduction in Area	20 % (Typical)	35 % (Typical)	+ 75

A comparison of the processing sequences required for welded assemblies in H-11 and 18 nickel maraging steel, as shown in the following figure, demonstrates the processing advantages of the maraging grade.



Processing Sequence — H-11 and Maraging Steels

18 Ni maraging Steel:

1 Weld
2 Anneal 1500° F. (½ HR.)
3 Air quench
4 Age 900° F. (3 HR.)
5 Room Temperature

Hours total process time

Can be repair welded after final heat treatment

H-11 Steel:

1 Weld 600° F.
2 Stress relieve 1100° F. (2HR.)
3 Postwell anneal 1600° F. (½ HR.)
4 Harden 1850° F. (½ HR.)
5 Air quench
6 Temp. 990, 990, 990-1050°F. (2 HR.)
7 Room temperature

15½ hours total process time

Can not be repair welded after final heat treatment

The next goal in high-strength steels is beginning to take shape in the 400,000 psi tensile strength range, demonstrated by the development of the matrix alloys by the Vasco Metals Corporation (bibliographic reference 5). Typical properties for two of these grades are reported to be as shown in the following table.

Matrix Steel Properties

	M-A	Matrix II
Tensile Strength, 1000 psi	361	404
0.2 Percent Offset Yield Strength, 1000 psi	292	363
Elongation, Percent	6	6
Reduction of Area, Percent	20	18
V-Notch Charpy Impact, Ft-Lb	9	5

Other developments such as ausforming and shock hardening are also gaining in importance, but all share two major limitations, which are the difficulties in fabricating useful parts, and the means to achieve adequate toughness.

Generally speaking, the very-high-strength steels do not have the required fatigue life for many designs. For applications such as a supersonic transport landing gear, for example, better fatigue resistance can be obtained from conventional alloy steels heat treated to lower tensile strength levels.

Our knowledge of the factors controlling toughness and fatigue, and our abilities in new ways to fabricate parts, are rapidly increasing. Keeping pace is our knowledge of better steel melting and mill processing. These factors, combined with the greatly increasing need for high-performance materials, will lead to higher strength steels in the future, and an ever growing usage.

Conclusion

Our discussion has described the XB-70A program, and has outlined the more important aspects of design materials and types of construction. The applications of stainless steels were discussed, and the design features and fabrication methods for brazed honeycomb panels were covered. The structural use of H-11 high-strength steel was explained, and examples of parts were given.

The importance of the many technical developments in this program was emphasized, and examples of new programs benefitting from them were given. A repetitive theme occurs in the discussion to emphasize that new markets for steel products in high-performance vehicle construction are based upon the abilities of the supplier to meet exacting and very specialized requirements.

A logical conclusion from a review of steel developments is that certain technical advancements have easily recognized impacts on new markets. One of these is increased ingot size, such as that achieved with vacuum melted H-11 steel. Larger ingots result in removing many limitations on the sizes of finished products, thus expanding the market for a product into new applications. Larger ingots likewise reduce production, inspection, and handling costs which again expand the market because of the improved cost effectiveness of the mill forms offered to potential users.

Perhaps some technical developments have somewhat less easily recognized impacts on market expansion. In this category is what we might call "alloy engineering". We have discussed the precise balances of chemical compositions required to meet specific performance objectives. To achieve this precise balance we have developed new skills in melting methods and equipment, new skills in the very close control of the content of critical chemical elements, and new methods in analytically determining our success in controlling this alloy balance. Further, we have demonstrated that the steel producers and users can develop the technical skills to exploit these melting advancements by the use of precisely controlled processes in developing mill forms and vehicle components with sophisticated properties. Each factor in the improvement in alloy engineering increases our abilities to develop new generations of alloys with even higher performance capabilities and better cost effectiveness, increasingly expanding the market boundaries.

Another example in this category is the attainment of very close thickness tolerances. This can result in the elimination of processing steps otherwise required of the user which can reduce costs and flow time for part fabrication, placing a product in a better competitive position. Such improvements can open new markets, as well, by making a product applicable to a greater number of processes and products than would otherwise be possible.

The challenge to the steel industry is clear. New technical developments, singlely and in combination, are the key to market development, and if approached with vigour and imagination can result in an explosion of steel market boundaries.

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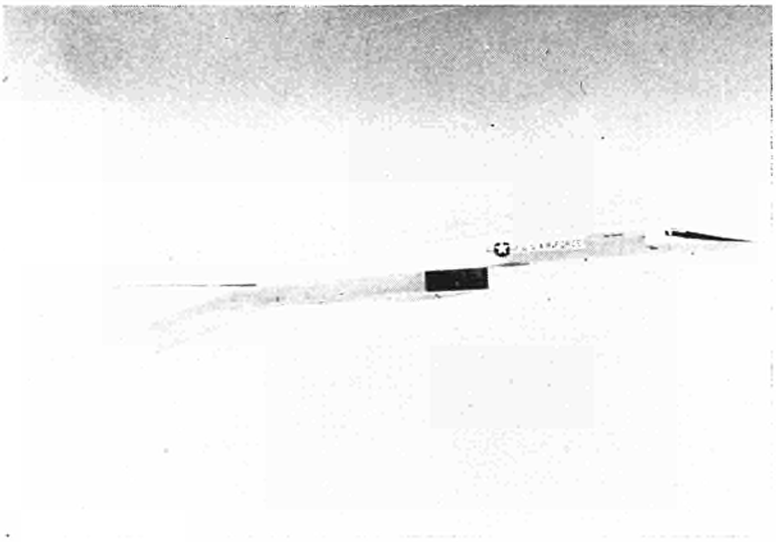
List of illustrations



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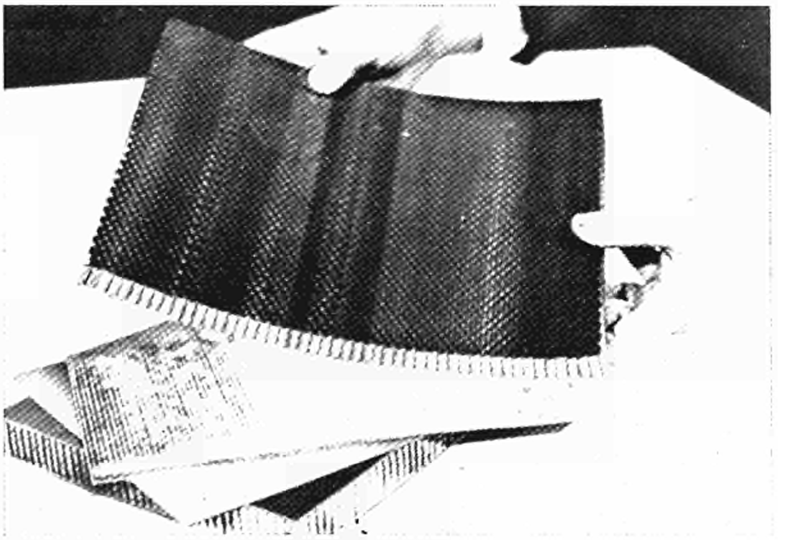

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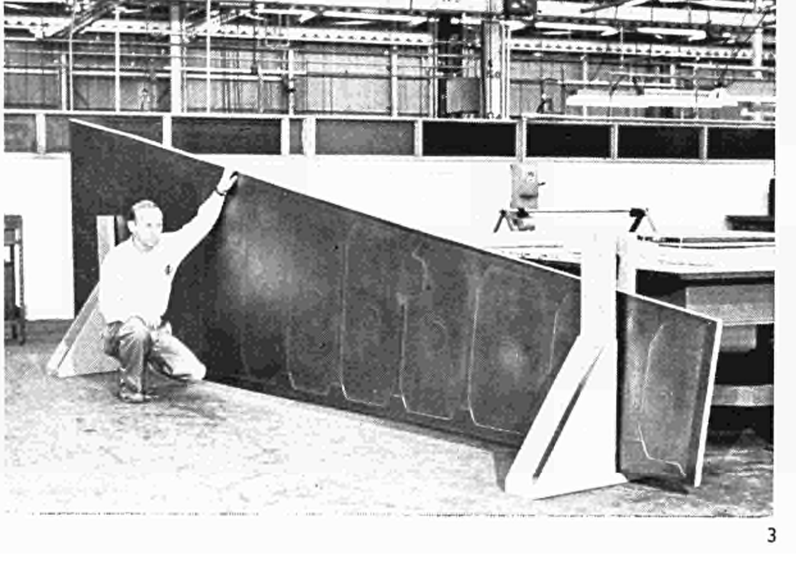

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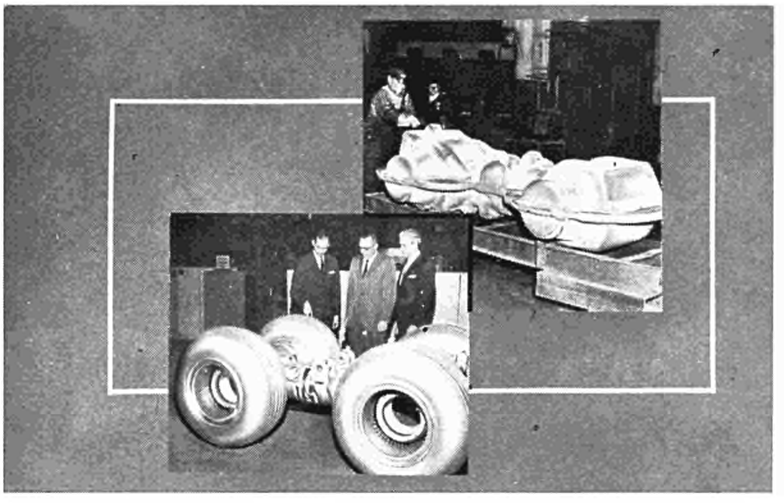
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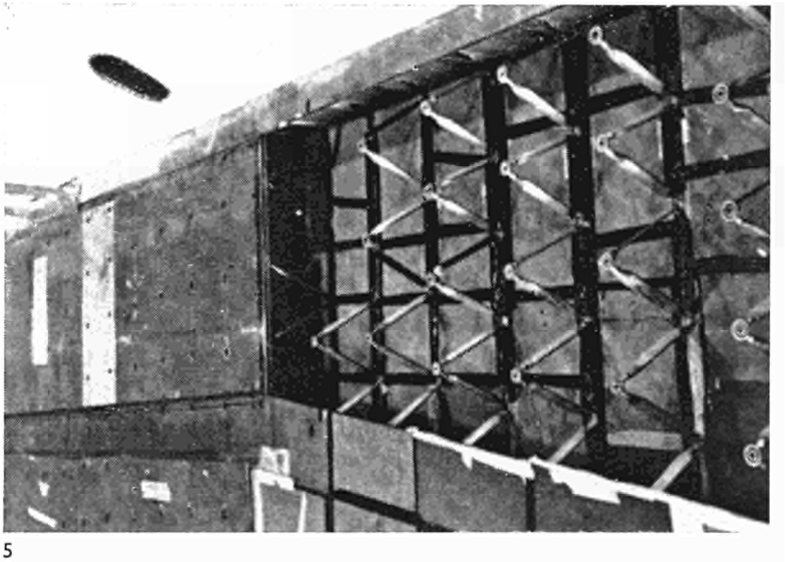
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WORKING PARTY I

Steel and Industrial Design

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Introduction

The Working Party has been considering the part played by industrial design in the process of bringing industrial products into being and of constantly adapting them to the consumer's requirements.

As a comparative newcomer, the design profession is now trying to see how it can fit most smoothly into the cycle of the creation, manufacture and use of industrial products. One point which has emerged from the Working Party's proceedings is that the industrial designer can only give of his best when he forms one of a team with the engineer and the management; within that team, he is responsible more especially for studying the relations between product and consumer, looking at the product from the point of view of its end consumer so as to make it more pleasing, more useful and so more likely to attract.

At present, the designer is still one of the team of research workers on product planning for the future, and assists with studies on new uses for industrial products.

The many practical instances which have been cited to the Working Party have significantly illustrated the role of industrial design in regard to steel products.

Tomàs MALDONADO

The Role of the Industrial Designer in the Steel Industry

(Translated from French)

What the English-speaking countries call "industrial design" — an Anglicism which has found its way into nearly every language — is not a profession the aims of which we can take for granted as being sufficiently known or recognized. For this reason, any theoretical consideration of the subject must be preceded by a definition of what industrial design is and what it sets out to attain.

Though somewhat unsophisticated in its thoroughness, this method offers a number of incontestable advantages, the first of which is that it considerably lessens the risk of misapprehensions. Another advantage, perhaps the most important, is implicit in that any need for definition presupposes an opportunity for redefinition, or more precisely for revision.

This is especially so in the case of industrial design. In fact nothing is more important for industrial design at the moment than that the premises on which it has been based since 1930 should be subjected to discussion. The subject, for example, on which I have been invited to speak, "The Role of the Designer in the Steel Industry", cannot be usefully discussed without to some extent dissenting from these premises. In a world of perpetual change, industrial design must itself be perpetually changing, not only in order to keep pace with that world, but also, and primarily, to function as a factor of change and a factor of innovation.

This view of industrial design as a profession in perpetual change, a dynamic, developing profession, has not many supporters. It is criticized above all as being starry-eyed and as failing to be sufficiently down to earth. Industry may have changed in many ways, it is argued, but not as regards the patterns of thought and action which have conditioned its economic behaviour for the last thirty-five years.

For this reason it would be absurd, the argument goes on, to suppose that the basic premises of industrial design, springing from and working by these patterns, could be reconsidered or superseded: there is no sense in urging a new economic role for industrial design which would confine itself, as hitherto, to interpreting, reflecting and faithfully serving the status quo of the industry.

No doubt, an argument of this kind may seem convincing at first, but a more detailed analysis immediately reveals the fallacy. It is not true for example, that the traditional patterns of thought and action in industry are still regarded by industry itself as unchangeable. In very considerable sectors, a revisionist tendency has begun to gain ground. Narrow utilitarianism and cultural and social nihilism are giving way to a new kind of rationalism, a scientific rationalism. Premises once sacred are now no longer so: it has come to be seen that they filled only a particular time and place. Since there are no more taboos, there is no more sacrilege. There is now no hesitation in denouncing as fallible and vulnerable what was regarded only yesterday as law, whether in the field of production, distribution or sales.

Industry itself is changing its patterns of thought and action, not for reasons of doctrine, but because only by doing so can it break free from its present immobility, and indeed survive. The call for a new departure in industrial design is not, as might be supposed simply unwarranted interference — on the contrary: it reflects a strong momentum towards renewal in industry.

I shall now venture a few reflections on the subject of possible conditions for new developments in industrial design, endeavouring to define, or redefine, or revise its function. At the same time, I hope to show how industrial design can be of service to this movement towards renewal in industry in general, and in the steel industry in particular.

Perhaps the most serious criticism that could be made of our technological civilization is that it does nothing to promote, either in breadth or in depth, recognition of the processes going on within it. Fundamentally, this means that our civilization is obscurantist. However we may feel about this, there is one thing that cannot be denied: in the technological civilization of today, our production and consumption are greater than our comprehension. In other words, we have not yet arrived at a full awareness of either production or consumption.

In both spheres, there is only particularized awareness, which is submerged and stifled in the immediate reality of producing and consuming the object concerned. There is no generalized awareness of the processes going on around the object to be produced and consumed. This state of hypertrophied particularized awareness and atrophied generalized awareness is no longer a matter of concern only to the critics of our civilization. Many responsible economists are wondering, not without anxiety, just how long the industrial world can continue to drift in this way, not knowing where it is heading, producing haphazardly for haphazard consumption.

Fortunately, some salutary reactions against this state of affairs have become apparent in the last few years. The growing influence of methods of scientific programming in industry is doing much to develop generalized awareness. All the same, even that awareness is generalized only with regard to production interests.

This nuance is important, for it can help us to a better understanding of the function of industrial design. In my opinion, what industrial design ought to do is to encourage generalized awareness of consumption interests, or rather, to be accurate, of the interests of the consumer, the user of industrial products. Because of the narrow utilitarianism I have mentioned, industry has always been unwilling in the past to accept that industrial design can legitimately have such a function. Until now, it has preferred to consider industrial design as the most effective way of stimulating specific awareness — exclusively, of course, from the point of view of production interests. The designer cannot go on for ever as the man who is brought in only when it is intended to launch a supposed novelty on to the market, or when it is deemed necessary to create a specially attractive form or one that cannot fail to sell. In the future, industrial design will need to be a factor in planning — a factor in socially responsible planning.

I know this concept of "social responsibility" is highly suspect; it has a sort of missionary flavour; and we have come to consider it, as the saying goes, "transeconomic." But from this point of view too matters are changing. Basically, I feel that, in the long run, irresponsibility is a very bad thing. It is possible for a time to carry on business without any regard for social interests, perhaps even against them, but it is nonsense to suppose that this can continue indefinitely.

Industry cannot continue for much longer to evade the concept of responsibility. Its responsibility will be chiefly in regard to man's environment. That environment has never been more full of original objects or more empty of a consistent, orderly pattern. Sooner or later, whether we like it or not, industry will have to do something towards changing this state of affairs.

Man's environment can no longer go on as it is at present, a mere juxtaposition of isolated objects, it will have to become the product of organic growth connected by a unifying purpose. To be capable however of dealing with such a task, we shall have to equip ourselves with experience and knowledge which we at present almost entirely lack. We shall have to broaden our present experience and knowledge in the field of industrial design. In my opinion, it will be necessary to carry on a comprehensive programme of research. I am fully aware that the idea of research, let alone of fundamental research on industrial design will appear extraordinary. Nevertheless, for an industry that prepares its decisions scientifically, as industries will more and more in the future, only industrial design based on research will be able to produce new contributions of value.

Among the subjects for research on industrial design that will have to be tackled at once should be mentioned first of all the development of systematized product planning methods. Unlike the methods now coming into use in some companies, these will have to give more or less precise information on the properties of the products as regards form and shape, that is to say, on what may be termed a combinative theory or a systematic analysis of the forms and shapes of the products. In reality, there can be no methodology in the planning of products without a study of the practical details involved in blending and dovetailing the products with one another.

Another item in the fundamental research programme, and closely related to the preceding one, would be a study of the structural and functional complexity of technical objects. The intensification of work in this field (which was begun a good many years ago by Abraham Moles in France and Herbert A. Simon in the United States), will undoubtedly open up new opportunities for the designer to innovate, that is, to create products that not only appear to be new, as so often happens, but really are structurally and functionally new.

The problems inherent in communal services also form a very important field of research. While luxury articles and weapons of destruction can count on the most advanced and elaborate resources of present-day technology, communal services get only the most elementary assistance. All the same, the measures adopted in this field cannot consist only in the mechanical application of technological advances achieved in other fields that are in varying degrees either trivial or terrifying. The problem of the under-development of communal services is not purely a technical one; it is also relevant to the under-development of industrial design. Here even more than elsewhere improvisation just will not do. No progress can be made without complete evaluation of different operational behaviours in the use of communal services. In other words, only by means of fundamental research on industrial design can the right conditions be established for its radical improvement.

The mining industries, such as coal, and the processing industries, such as steel, are in my opinion the most suited to appreciate the new function of industrial design. I would even say — somewhat paradoxically — that they are better placed to do so, because up to now they have had less to do with its earlier function than other industries. We must bear in mind that the form and shape to be given to consumer products is the concern of the manufacturing industries, the works doing the final processing, not of the industries that extract the raw materials or make semi-finished products. Whereas for the former consumption is a concrete, ever-present and immediate reality, for the latter it is abstract, remote and indirect. The steel industry, for example, has never felt itself responsible for the finished products that are launched on to the market by the companies which it has merely supplied with semi-finished products.

I know that there are exceptions, for example the branches of the steel industry directly concerned in the manufacture of finished products like locomotives, cranes, machine tools and the intricate components used in building. Nevertheless, given the nature of these products, these exceptions are not really relevant to what I have just been saying. The mining and processing industries, far removed if not altogether divorced from the world of the consumer, have on the one hand lost contact with the user of the finished product, the ultimate target of the entire economic process, while on the other they have been able to avoid the distortions and contortions of the industries that have to concern themselves with the consumer's real or supposed desires. In a word, they have detached themselves from the situation, yet remain able to see it. This is no bad thing. For in the final analysis, it is not hard to apprehend a situation if you can still see it.

For this reason I venture to contend that the new function of industrial design can be better grasped by the mining and processing industries. I am convinced that, without claiming to take over the tasks that belong to the manufacturing industries, they could and should lend their support to fundamental research on industrial design.

In the next few decades the world will have to face tasks of unprecedented magnitude and complexity. These tasks will be directly or indirectly connected with the ambitious plan to provide basic equipment for more than two thousand million human beings. The preparation of the most appropriate methods of industrial design to tackle these new tasks must be carried out in the mining and processing industries. The manufacturing industries are too much committed to the principles of industrial design as they now are, to be able to study new ones for adoption in the future.

Nevertheless, I must point out that the mining and processing industries are at present also finding it difficult to assume this responsibility. The trouble is mainly the line taken regarding the problems involved.

Each time these industries have come out in favour of industrial design, they have shown undue preference for a particular material; in other words, they wanted to know how far industrial design could serve to open up new fields of utilization for the material they themselves produced.

A very characteristic instance is the drive by the plastics and aluminium industries, and the steel industry would seem to be doing much the same. The very fact that designers have been invited to take part in this Congress suggests that this is so. I hope nevertheless that our presence here will help the steel industry to avoid the mistakes committed by the industries I have just mentioned.

I do honestly feel that the designer's job is not simply to boost one particular material. The world of tomorrow will not be all plastic, or all aluminium, or all steel. It is nonsense to suppose that any one material can be the destined material for the technology of the future.

Until quite recently most designers did have rather this idea, a very old one in the history of industrial design the idea of *Materialgerechtigkeit*, that is, roughly, non-interchangeability of material.

What the precursors of industrial design meant basically by *Materialgerechtigkeit* was that one material could not do duty for another, as regards either appearance or function. Another rather less widely accepted interpretation went further: a product of quality, it was maintained, should be made entirely from one material. However even though designers of our time today unite in disliking, and hence avoiding, imitation, no-one would accept any longer the so-called principle that perfection can only be found in articles made entirely from the same material. The idea, for example, of making a sanitary block entirely of plastic or steel in one piece, is as dead as the dodo. I do not say it is not possible in theory, or even in practice — is has been done — but it is the sort of virtuosity that does not really pay, either technically, economically or functionally.

It looks, so far as one can predict technological developments, as if the future tendency will be, as today, to make free use of whatever materials are best for each purpose or part of a purpose. The consequence will be that beyond a certain degree of complexity, products will need progressively greater structural and functional differentiation, which in turn of course means greater diversity in the materials used. There is no indication that the material composition of technical products will become more homogeneous: on the contrary, everything suggests, at present, that it will become less so.

It sometimes appears that the market strategy of the steel industry — as well as of the plastic and aluminium industries — is considerably influenced by the same sort of misconceptions as were entertained by the precursors of industrial design. Here too though for different reasons, it is contended that one material — steel — can work independently of the rest. Doubtless, by this means it is hoped to enhance the competitive supremacy of steel. But the obstinacy and even apparent conviction with which this is maintained leads us to wonder whether the reasons are not perhaps purely economic. Probably they also derive from a certain traditional way of thought deeply engrained in the industry, the element of myth that is a constant in the older metal industries. In reality this intransigent "pan-metallism" is not very far removed from what Gaston Bachelard called *les rêves de la ferréité* or *le rêve métallique*.

When there is outright prejudice in favour of a particular material, there are very few openings for constructive co-operation between industrial designers and either the steel industry or any of the processing industries. On the other hand if this attitude could once be discarded, a whole host of new opportunities would be opened up.

In conclusion, I should like to hazard a suggestion, although I realize that to this Congress it will sound pretty much like sacrilege. I suggest that the mining and processing industries, despite their opposing interests, should jointly sponsor fundamental research on industrial design, with a view to finding new fields of utilization, not for any material in particular, but for all materials in general. In other words, I ask you to consider industrial design as a field, not for divergence but for convergence.

The mining and processing industries should make every effort to evolve a joint plan for the future. For although today their concerns are different and their fortunes opposed, in all probability before long they will be the same.

Erich GEYER

Design as a Subject for Special Study

(Translated from German)

In commenting on the points which have been raised in regard to industrial design, I should like first of all to say how impressed I have been by the papers we have heard, ranging from the philosophy of design to a series of practical examples. It seems to me a pity that we have so far had too little discussion and argument on the burning problems of industrial design in practice.

I am myself neither a designer nor an engineer: I am a member of a research association which was started about two years ago; a co-operative body on which some 25 firms are represented. Our feeling is that in recent years there has been a great deal of philosophizing about the aim of design as such. For the past two years therefore we have been trying to work out ways of helping to implement that aim in a number of practical enterprises.

To put it provocatively, here again there has been too much intrusion of aesthetic and social argument without sufficient realization that the aim of design can only be achieved by sober considerations of rational economics. Yet it is there — in the enterprise itself — that the problems to be tackled really lie. Many unsolved problems of industrial design are rooted, as you know from your own practical experience, in the question of how the new product will make out in the market of tomorrow. That is the question our firms are mainly concerned with, and very often we do not know how we are to apply industrial design as a sales promotion factor.

Our association has sought to establish on the basis of industrial experience in recent years, whether a firm could be said to be doing the right thing economically by simply employing a top-flight designer without creating the necessary background conditions for his work as regards enterprise organization. The answer was very definitely "No."

Accordingly, our study group of engineers, designers and economists has worked out an organizational basis. In our opinion the whole essence of this is product planning as the means of integrating and co-ordinating all the product-determining factors of industrial design. We regard design primarily as a process taking place in the form of a co-operative activity at the point of intersection of the subjects traditionally taught at college. We feel that when this is accepted the designer will not be in the position of working on his own.

A further difficulty has been that the psychological make-up and professional qualifications of technicians, development engineers, planners and marketing experts were not such as to make for rational co-operation with the designer. We therefore pressed for systematic advanced training in product design and product planning, to be given in "at-work" seminars. There are now more than 50 such seminars in existence. Our object is to inculcate a new mental approach on a broader range of topics in all managerial and specialist personnel — an approach wich I do not think we have all of us absorbed at college.

We consider the function of our study-group as regards fundamental research to be to compile useful educational material on design, an activity in which we have received valuable assistance from the Hochschule für Gestaltung in Ulm. We have already been able to pass on teaching methods and illustrations of this kind through guest lecturers at technical colleges and universities, with the aim of familiarizing engineers of the future with the subject of design even during their basic studies.

The work of our group is helping to create the intellectual level to which so far reference has been made at this present Congress. Given this, team work is no longer a difficulty for the designer.

Admittedly not all the designers have altogether welcomed this scheme of giving special training to technicians and to development and sales engineers. Many accept that our association is helping to smooth their path, but some regard us, wrongly, as a source of competition, because possibly one engineer out of a thousand might turn out to have talent as a designer. From our experience, however, there is no other solution but systematic instruction in the form of "at works" exposition of design problems. By this means we are helping our firms to organize more efficiently the planning, development and design of new products for the market of tomorrow.

I trust these remarks have shed some little light on the practical problems of design.

Gerhard OEHLER

The Role of the Industrial Designer in the Steel-Using Industries

(Translated from German)

The steel sheet processing industry, one of the main branches of which is car body manufacture, has for many years been disturbed to find designers often clinging obstinately to proposals for forms which are not conducive to economic production. I have experience of one case where a washing machine with rounded corners was changed to a sharp-edged design merely on the strength of the designer's wishes. This necessitated five drawing operations instead of two certain components, and led to a 150 % increase in tool costs and production wages at the deep drawing press. In general, many industrial designers appear to be completely unfamiliar with the technique of forming by deep drawing, or there would be far fewer forms diverging from simple cylindrical shapes on the market. After all, ease of cleaning, ease of repair and accessibility for repair all contribute to economic efficiency. If companies submit their draft plans to a designer or if they commission designs from him, then the production expert should afterwards be given an opportunity to express criticism. In the final analysis the sales expert must decide whether they should be guided by public taste and the designers' proposals, or by considerations of economy in production techniques.

Mosche KOHEN

Some Remarks on the Relations between Industrial Design and the Steel Industry

(Translated from German)

What has impressed me most at this Congress was the point made by the Chairman, Mr. Etzel, in his opening address, when he urged that steel be offered as a material that is "warm, friendly and alive," in order "not only to make possible further economic achievements, but ultimately to make the world of today and the world of tomorrow a better and happier place." That was a greater inspiration than the astounding technical feats of the XB 70A programme.

I had the opposite reaction a few hours later on hearing Mr. Odenhausen's arguments against Mr. Maldonado and Mr. Maldonado's reply (p. 62, 63 and 64). Mr. Odenhausen, with his concentration on competition, refuses to accept that the designer has any rightful function in the steel industry. I disagree, and I will give you my views on the subject in a moment. Mr. Odenhausen suggests only that the steel industry should materially assist industrial design, more or less out of sheer philantropy. I do feel this is a somewhat restricted approach. On the other hand, I do not support Mr. Maldonado's in itself quite legitimate plea for systematic fundamental research, simply because it is not a proper subject for the Congress's attention. Do please let us bear in mind that this is the very first confrontation between the steel industry and the designers in a European forum. We have to establish a primary basis for thinking in different terms before we can work out together just how the designer can actually help the steel industry. Hence I consider it somewhat pointless to urge terminological problems of design, or some esoteric aspect of industrial design that is not as it should be, upon the steel industry's attention at this Congress with a demand that something be done about it: at any rate it is no more relevant than the steel industry's private problems are for the designer. I have been sorry to see that some of the papers we have heard have tended to ignore the fact this is a Steel Congress and to treat it as a Design Congress.

Well, to get to my point. I consider that designers could do a great deal to improve the image of steel in the European mind. High-grade steel can not only be turned to technical account by scientists and technologists: it can be turned to human account by designers working on a psycho-physiological and sociological basis.

Amid the present efforts to unify Europe, we should not forget the part steel played in our destruction of each others cities and villages during the war and in the loss of millions of lives. The pictures we retain of the war are of guns, helmets, bayonets, machine-guns, murderous bullets and bombs. It was steel that was *the* war material, not wood or glass or aluminium. What practical action can the steel industry undertake now to give steel a kindlier, more human image? International architectural design competitions, laudable though they are, have at present only a minor impact. What we need is really large-scale action. The most convincing effect is produced by beginning at home, in the steelworks themselves. The only favourable impression I received at the steelworks was when I saw the metal in the unprocessed state, in the melting or blooming or hot-rolling stage: apart from that I felt the environment to be unpleasant, indeed often downright degrading.

In the first place I would suggest that the designers and architects be commissioned, in co-operation with other experts, to improve and where possible entirely remodel the industry's production premises themselves, starting with the blast-furnaces and working through the processing and fabricating shops, covering every little detail, right up to the main gate of the works. This would probably produce some really worth-while designs, quite apart from the opportunities for combining plain with coloured steel as visual elements in the design. Then at any rate steel production could go on in hygienic, cheerful, pleasing surroundings. This would enable the industry to stand out as genuinely progressive, demonstrating its steel to people in a striking, attractive manner. The drive for a united Europe can only succeed given parallel cultural development. In this connection designers have their contribution to make.

Secondly, the steel industry in selling its production should do a good deal more about steel's prestige in the manufacturing industries. It should try to ensure that its steel, whether it be used to make a bridge, a tractor or a tin-opener, is not so used without the services of a designer, for otherwise steel is liable to decline in human esteem. This will need thousands of highly-trained designers. Europe does not possess them: consequently it is high time for the steel industry — and others too, of course — to invest in facilities for training them. By so doing, the steel industry can give steel an assured future by reason of its increased appeal. The larger the number of designers, the greater the likelihood of new uses for steel being devised, over and above the strictly technical ones.

So far as the designer is concerned I cannot see any problem between industrial design and the steel industry as regards steel as a material: to him steel is just like any other material in civilization today. If the steel industry on its side has any problems or difficulties, now is the time to voice them.

Incidentally, I might add that the designer is not so advantageously placed as many other specialists. There is no professional institute of designers for him to have recourse to, and it is altogether too much to expect him in making his plans, or to expect a group engaged in planning, to assemble the relevant data personnally from a whole range of different sciences. It is not fair to find fault with the designer for frequently working by intuition in the absence of specialized knowledge. The importance of design should not be regarded by the steel industry solely from the restricted viewpoint of considerations of competition pure and simple. The industry should, in its own and in the general interest, try to ensure that designers are suitably qualified to do their job: the more facilities and data it gives them the more it can expect them to do to help make steel a humanly likeable and attractive material.

DISCUSSION

René MAILLIET

(Translated from French)

The High Authority might offer an incentive to industrial designers by offering for example a biennial prize for the steel industrial product deemed to be both the most attractively and most functionally designed. The winner would be selected by an independent panel of judges appointed by the High Authority, on the basis of criteria worked out in co-operation with industrial design specialists.

In the United States the American Iron and Steel Institute presents a biennial Steel Design Award. It might be an idea for the High Authority to initiate a similar award at international level.

Helmuth ODENHAUSEN

(Translated from German)

It is pleasing to see that Mr. Maldonado's paper is far from a colourless declamation, but on the contrary a refreshing challenge. I find that I can fully endorse his discerning remarks in many respects, but I must confess to some hesitation or disagreement about certain parts of his paper. As I have to be brief, I shall now only mention the points with which I disagree:

1. Mr. Maldonado speaks initially of the " role of a designer in the steel industry." Now in the steel industry itself the designer has no legitimate role. The steel industry makes rolled products, forgings and castings. Rolled products are made solely according to static, structural and technological considerations and forgings and castings are made according to the customer's drawings.

   Nevertheless the steel industry has a considerable interest — even though it may be an indirect one — in industrial design. It is interested in manufactured articles of steel produced by the steel-using industries. Because of this, the steel industry in many countries supports to the best of its ability and in a variety of ways the efforts of the steel-using industries as regards industrial design. It does so for two reasons: concern about competition and to meet its social responsibilities (or to use the words of our Chairman "to make this world more human").

Apart from this, I am firmly of the opinion that in the future the steel industry should do even more than in the past in the field of industrial design for manufactured articles of steel.

2. No one will seriously dispute the fact that systematic basic research has long been needed in the field of industrial design. Nevertheless, I consider Mr. Maldonado's suggestion that the costs should be met by the coalmining industry as misleading. Quite apart from the fact that coal-mining has other worries of its own at the moment, this fuel-producing industry cannot be expected to take on a responsibility completely outside the scope of its own economic interests and obligations. One would be as justified — or unjustified — in expecting coal to provide for the establishment and upkeep of zoological gardens.

3. Mr. Maldonado said: "The human environment... must... be governed by a uniform will." I am not sure whether the German translation is quite correct here. However, assuming this version to be correct, I for my part must say that I do not want a "governed environment" and certainly not one which is "governed by a uniform will," whatever the form this uniformity may take. Nor do I want to be manipulated or planned in my environment. I do not want a uniform environment at all. I prefer a many-sided, diversified and pluralistic one.

As far as planning in the industrial world is concerned, I would say: as much planning as necessary — as little planning as possible.

4. Mr. Maldonado mentioned the principle of the correct use of materials. This principle did not originate in industrial design, but emerged much earlier in the theory of construction. In both cases I consider it essential, because the more complex the demands, the more distinct are the functional properties of materials. I would mention in passing that the growing importance of the modulus of elasticity in light construction has given the principle of the correct use of materials new impetus.

I do not know whether the "rigid pan-metallism" mentioned by Mr. Maldonado has ever seriously existed as a claim to exclusivity for a metal or metals, but in any case it cannot be derived from the principle of the correct use of materials.

The claim itself is just as ridiculous as its execution is impracticable.

I should like to conclude with one fundamental comment which is not based on Mr. Maldonado's paper, but which I think may be useful here. With some concern I have noticed that industrial design is in some cases becoming fashionable; its principles are being made absolute or becoming an ideology and on occasion its demands are even being pronounced as dogmas. It seems to me that it is essential to keep a sense of proportion here. Therefore at this congress we should discuss not only the possibilities of industrial design, but also its limits. I should like to express my opinion that the industrial designer should not be overvalued in comparison with the design engineer, the technologist, the production engineer and the sales expert, nor should he be granted extra privileges.

I should like to remind you of our Chairman's words to the effect that the wellbeing of man and the salvation of man were not synonymous. Industrial design belongs to the field of human well-being. Neither art nor science nor industrial design can form the basis for a doctrine of salvation

Tomàs MALDONADO

(Translated from German)

I listened with much interest to Mr. Odenhausen's remarks on my paper. At the same time, I feel I must say that some of his criticisms seem to stem from a misunderstanding of my points, and others, I think, will not hold water.

I explained in some detail in my paper why I consider the steel industry has a special function to perform in connection with industrial design. Naturally, I know very well that the steel industry normally supplies raw materials and semi-finished products, not the manufactured article. But just because it is not directly concerned with manufacturing, it is able to adopt a much more independent position on matters of design than the industries which are constantly having to market new manufactured goods. I made the point in my paper that the steel industry both could and should provide financial support for pure research on industrial design. It may be very witty of Dr. Odenhausen to say that it might as well be expected to start and run a zoo, but I maintain that products made of steel, or partly of steel, and put on the market, do have some connection with the steel industry. And the top people in the steel industry definitely ought to realize that the sale of those products affects their own sales.

Mr. Odenhausen takes my remark that certain aspects of mankind's environment should be designed and planned with some eye to harmony as indicating that I am in favour of *dirigisme*. It is true that past history gives any number of examples of the extent to which that environment can be manipulated by planning. But he must also agree that the complete lack of planning now prevailing all over the world allows of just as serious manipulation.

I think Mr. Odenhausen's comments on my remarks concerning the use of the right material in the right place are very apposite. I also entirely agree that the designer must not be a Grand Inquisitor and industrial design must not be an ideology. When I referred in my paper to "the designer," I meant a team of assorted specialists, not one individual taking it upon himself to lay down the law to industry.

Henri VIENOT

The Function of Industrial Design in the Production of Capital Goods

(Translated from French)

I am particularly pleased to have this opportunity to give you my opinions and to present to you certain information on industrial design in the production of capital goods, since I believe that it is in this field that industrial design is most sensibly applied and best recommends itself, unaffected by futile stylistic trimmings, modish pretentiousness or superficial embellishment; baits used by many consumer goods manufacturers to attract buyers.

This subject appears particularly appropriate to this Congress since the manufacturers of industrial capital goods are unquestionably large users of steel and alloy steels.

French industrial capital goods manufacturers are only just beginning to devote attention to industrial design. The first time a designer was consulted on a machine tool was in 1955. That was 10 years ago and this collaboration remained an isolated case for several years. In the same year however this industrial designer co-operated on the design of a large gantry required for a hydro-electric station. It therefore appears that the interests of capital goods manufacturers in industrial design dates from about that time, and they are now beginning to make use of this discipline.

Nevertheless, the number of cases of such co-operation is only slowly increasing and the last 10 years have not brought about any significant change in the physiognomy of the industrial world.

The obstacles

It must be admitted that there are certain obstacles blocking the way, as regards both the principles involved and human relations.

One old principle, now outdated, stipulates that "function creates form". If this were so, our working party's efforts would be in vain, since engineers and technicians would, as in the past, remain solely responsible for the designs of industrial plant and also consumer goods. If the new discipline of industrial design is to take on and influence the creation of new plant, the fact that completely satisfactory results cannot be obtained by considering only the functional and technical factors must first win general acceptance. It is not enough to master the mechanical problems and have at one's fingertips all the available information on materials and ways of using them; one must also have the necessary talent to co-ordinate and harmonize such data. Engineering training does not include artistic instruction on industrial design; only rarely is the subject even briefly touched upon. Therefore others, industrial designers with adequate experience of production techniques, must be responsible for designing structures and parts of structures of pleasing form. If industry will not accept the state of mind implicit in industrial design; if it is considered that the engineer alone can produce plant pleasing to the eye and mind, then the way to industrial design is not yet open.

Psychologically, it is mainly a question of pre-conceived ideas which disappear once a relationship of normal co-operation is established. Before the engineer and designer get to know each other by working together on a problem, the former is often apprehensive of the latter, whom he considers an artist and thus unlikely. to have a sufficient grasp of the technical requirements to make a valid contribution to the work. He also fears that subjective considerations which he is not prepared to appreciate will be introduced into what was previously purely a technical sphere and this gives rise to a feeling of suspicion which is in fa ct unjustified The experienced industrial designer will have acquired a knowledge of manufacturing requirements; is familiar with materials and ways of using them; his language is based on that of the technicians since he expresses his ideas in models and plans. If men are to work together effectively on a creative project, they must learn to know each other. The successes already achieved in this field are numerous enough to abolish initial inhibitions. An attitude understandable 15 years ago is no longer so today, when the technician can acquaint himself with the designer's references.

These are artificial difficulties, but they are nevertheless retarding the development of industrial design, in particular in the field of highly technical products, such as capital goods.

The objectives

The manufacturers of industrial capital goods who call on the services of industrial designers do not all lay stress on the same results. However, the advantages of industrial design may be divided into three categories, which I shall illustrate by quoting the words of certain manufacturers.

The three types of results are social or cultural, commercial and technical.

Here is the opinion of a former milling machine operative, now head of his own firm producing 40 machine tools a month: "I know a man works better if he uses an attractive machine, because it is "his" machine; a machine on which he spends more than eight hours a day. He takes care of it like he takes care of his motor-bike or car. A worker's output depends not only on his personal potential, but also on the atmosphere in his workshop, the quality of the machine and its design."

I asked another manufacturer, one of the first supporters of industrial design in France, about the effect on his staff. He said: "Undoubtedly at any level the creation and manufacture of well designed products has a subconscious influence on some staff. The result is an undeniable tendency to strive for quality on the part of most employees. In a branch like ours, this quality in fact corresponds to an internal rather than external idea, the feeling that the external appearance would be an artificial disguise if it were not the result of a generally high standard of execution in the component elements of the machine. The research department is undoubtedly the section most influenced by the idea of design. Although it complains of the difficulties of fitting contacts with the industrial design office into a tight planning schedule, it would not think of undertaking a new project without giving due consideration to the design problems and consulting specialists."

Indeed, for this manufacturer, industrial design has become a dynamic internal force. When the industrial designer has built his model on the basis of the technical data received, and this has been approved, the whole firm has found its objective: the designers will try to find elegant solutions to the unresolved technical problems and the production departments will take great pains with the prototype and then with the production runs.

The commercial results of industrial design are the best known since they are the most spectacular, even if they cannot always be expressed in figures. Only very rarely is a new piece of equipment directly comparable with an old one, particularly in the case of production plant, since a change in model is almost always motivated by an improvement in the technical characteristics.

Nevertheless, the saying that one buys with one's eyes is almost as applicable to capital goods as to consumer goods. The technical buyer is as receptive to visual impressions as is the ordinary shopper. Obviously, this is not a field where an attractive appearance leads to immediate impulse buying; the phenomenon here is more of a subconscious nature. The observer is unconsciously impressed and influenced by a beautiful form, a clever solution which biases him in favour of the object. First impressions are very important in the selection and purchase of plant. An engineer visiting a machine tool exhibition such as the Biennale held recently in Brussels is faced with rival machines of similar characteristics and price. What then is the factor which influences his decision? It is the instinctive attraction he feels for one machine rather than for another, which gives him a desire to buy and a pride in having bought. When a technician examining a machine senses a subtle idea on the part of the designer, the presence of something more than mere technique; when he feels that there is nothing to be added and nothing superfluous in the design, the thinking technician will be persuaded that the manufacturer is reliable and anxious to give complete satisfaction.

The manufacturer who makes use of industrial design and pays attention to practical execution as well as design will always obtain good commercial results. The benefit he gains will vary according to circumstances, as will be shown in the examples we shall shortly examine.

These examples will also enable us to examine the contribution made by industrial design at technical level. This is both direct and indirect:

The designer who engages in research in depth tries to achieve a timeless form satisfactory in itself independent of any fad or fantasy. This aim is constantly receding since form is always linked with a certain level of technical development. In this respect industrial design is a continual recommencement. The search for harmonious form generally leads to sober lines easy to produce with inexpensive plant so that ipso facto good design leads to low production costs. Any industrial designer worthy of the name is also familiar with numerous methods, processes or materials which he manipulates in the course of his very varied work. He is thus able to put forward intelligent and economic proposals. The indirect influence of industrial design is no less beneficial: the technician's horizons are widened by contact with someone of another discipline who examines problems from a completely different point of view. Such contact promotes technical progress since it compels engineers and their teams to reconsider generally accepted methods. The designer first tackles the problems as a whole in order to define structures and parts of structures, and this attitude — unfamiliar to technicians — encourages original research and promotes progress even in technical matters. This is one of the results which is unanimously acknowledged and welcomed by all the manufacturers concerned.

Trends

In all the examples I shall give, steel is extensively used, though for several different reasons.

Steel, particularly in the form of sheet or plate, is an ideal material for both small scale and mass production. In the latter case, stamping techniques permit the production at low cost of an almost unlimited range of shapes. In medium and small scale production there are great possibilities in mechanical welding, and so steel sheet will be the first material considered, or will be reverted to after other materials have been examined.

There will be little variety in the processes for protecting or decorating capital goods. Enamelling is rarely used. Stainless steel with various finishes is sometimes used, but the use of plastic coated sheet is rare. Plate and sheet, in the field with which we are concerned, will generally be lacquered and it will be the forms which will introduce variety.

Some 10 years ago there was a movement, in which our design office was concerned, to replace girder structures by caissons of plate; for example in the 1955 gantry which I already mentioned and in handling equipment of all kinds. A perfect illustration of this trend is the large scale oxygen-cutting machine. The pantographs of these machines consist generally of angle frames braced by beams to prevent deformation. This metalwork collects dust and is inelegant. It was inconceivable to apply this principle of design to a large machine. I think you will agree with me that the use of a steel beam held rigid by triangulation carrying the devices which move the cutting torches represents a great advance. This beam is integrated with the caissons of plate which carry the slip joints of the gas lines. The use of plate is often seen in travelling cranes, gantry cranes and certain continuous belt elevators; this is certainly an irreversible trend.

It is for different reasons that welded steel plate has in recent years been used for machine frames. Generally this is in order to obtain more flexibility for plant subject to variations or limited production runs. This trend is expected to continue; particularly for specialized plant.

Practical examples

A few examples will give factual illustrations of the general considerations propounded above. They have been chosen from projects our design office has worked on, with the aim of showing as wide a variety of plant as possible.

Vices

The industrial designer tackles problems from new angles. He thinks more of the future than the past and encourages technicians to forge ahead. When a company commissioned our office to design a new vice, we were asked to eliminate an awkward machining operation consisting of slotting the housing to allow the passage of the slide. This was an operation in which it was difficult to obtain precision, so that assembly involved difficult adjustments.

The designer wanted to obtain a more slender shape, with a narrower housing, and he suggested a design containing a prismatic shaped slide which could bear on faces obtained in the housing by milling.

The technical department was immediately interested in this proposal which enabled it to take up an idea on which it had been working for some time. This was the origin of the new vice in which the slide bears on the end of screws put in place from the outside, which considerably facilitates assembly of the vice and enables wear to be taken up when necessary.

This method of construction was patented so that the company in question now has a much more attractive model which has improved functional characteristics and requires 15% less manpower.

Fork-lift trucks (fig. 1, p. 81)

In 1954 a company became aware of the need to improve the appearance of its fork-lift trucks and approached our Design Office for help. This co-operation is still continuing today in an attempt to make constant improvements to these machines. Before that time, no one had thought of applying the principles of industrial design to fork-lift trucks and the manufacturer soon realized that it was not just a superficial face-lift eliminating unnecessary complications or adding small embellishments to give character to the product. It was quite a different matter and consisted in tackling the actual architecture of the truck.

The trucks made in 1954 had numerous defects resulting from their form and the production processes used; each truck had to be "made to measure," which complicated production and made it impossible even to effect a simple replacement of a part of the bodywork in the customer's premises. Inevitably light gauge sheet was used and the bodywork was therefore very easily damaged, so that after a short period of use the truck had a battered appearance and became extremely noisy; the mechanical parts were not easily accessible and the truck had no architectural or artistic character; it was obvious that something was missing. The counterweight designed in 1955 was U-shaped to allow a high flow of cooling air. This determined the machine's general lines and the bodywork sheet metal was lined up to it. The upper bonnet lifted backwards on a hinge to give access to all the mechanical parts of the truck. At that time almost all fork lift trucks, like lorries, had bonnets which opened at the side, so that only a part of the engine could be seen and the interior remained dark. The new shape of the trucks was thought to be a great advance on the old type, both in world production and as regards that particular make.

But when the truck was put into service it became clear that we should have done much better. Firstly one body had merely been replaced by another: although the external appearance was greatly simplified, the body remained a complicated structure with rounded shapes which could only be obtained by hand because of the small production, and with numerous stiffeners, hinges, radiator grilles, etc. Also, the U-shaped counterweight was a headache since when it arrived from the foundry it was often found to be wider or narrower than its nominal dimension.

The next design concentrated on eliminating as much of the metal work as possible, simplifying shapes by simplifying structures and replacing narrow joints by very wide ones which thus permitted deviations of several milimetres in the mating of the bodywork components.

The U-shaped counterweight was abandoned and a solid one adopted: this gave no possibility of deformation apart from systematic and thus known shrinkage. At the same time it was lowered so as not to rise above the level of the cab floor. Since the company had installed large guillotines and folding presses for these changes, the chassis was made of heavy welded plate; the outer panels formed part of these caisson-type structures, as did the wings.

This meant that steel sheet was completely eliminated from the bottom part of the machine, without seriously complicating the structure of the chassis and with a considerable improvement in the rigidity of the truck. The chassis and counterweight together formed a plane at the upper part, which was the essential feature of this new design: the bonnets became simple shapes which could be produced very cheaply. When the old designs were abandoned, it was found possible to reduce labour in the sheet workshop by about fifteen men, while output was tripled.

The lowered form of the counterweight however was not without disadvantages as it meant that the trucks had to be somewhat longer and the turning circle was increased. In the fourth design stage the counterweight was shortened by cutting off the corners so as to reduce the turning circle and then it was raised above the level of the joint between the chassis and the bonnet. But there was no question of abandoning the advantages of the very simple bonnet and its junction with the chassis in one plane. The shape achieved in this new stage was very characteristic. The upper part of the counterweight is slightly narrower than the truck so that it fits under the bonnet, the basic idea of which has not changed, although it is designed to be stiffer.

What does the manufacturer think after these ten years of work and development? This is what he has to say :

> "One preliminary and very obvious result is that this work has made its mark on much of the world fork-lift truck industry. Some have based their designs very closely on the results described above; others, to their credit, have sought to adopt slightly different methods. Almost all manufacturers have shown that they were influenced by it; the movement is launched.
>
> Although the starting point for this work was a desire for research into design — or more accurately a reaction against ugliness — the horizon was soon widened, from which it may be concluded that form is not studied for itself, but must result from the overall concept of the product and its architecture. However, even with good architecture and a clear functional nature, in the long run the most advantageous solution can only be obtained in the embodiment of an artistic creation — and this cannot be the technician's responsibility since he is too absorbed in the analysis of his own problems.

Although the spheres of work may encroach on one another, the mental process is so different that the technician and the industrial designer are well aware that they complement each other. That is why collaboration between technicians and industrial designers has after all been found to be quite easy."

"Logatome" (fig. 2, p. 81)

This machine, to which I referred earlier, is intended to cut plate into strips 8 m wide. Originally designed for use in shipyards and then made more versatile, it has been adopted for numerous purposes even as far afield as Canada and Australia. Here too it was the industrial designer who planned its general architecture, which was then perfected with the company's technicians, and the management acknowledged that it had greatly exceeded the original commercial objectives. It is impossible to say exactly what part was played by industrial design in this success, but after hearing many people describe the Logatome as a "beautiful machine" the manufactur considers that its role was appreciable.

Machine tools (fig. 3,4 and 5, p. 81 and 82)

In five years the complete range of machine tools made by a well-know firm has been revised and each machine modelled on the basis of directives issued by our Design office, relating to both parts of the structure and the units as a whole, and to each detail, hand wheels, levers, control panels. This gave the machine tools a particularly integrated appearance at recent trade exhibitions.

The general line is based on the industrial designer's desire, as expressed in the first study, to simplify assembly and finishing processes by adopting steel plate and sheet with wide joints as used in the motor industry. Once the merits of this suggestion had been recognized, all the factory's departments showed great enthusiasm in producing a machine in every way corresponding to the basic model. The factory reaped the benefit of its efforts in the form of the great interest shown in its achievements, which opened up commercial outlets formerly inaccessible to it.

It is interesting to note that the general appearance of the machine designed in 1959 is now found in a certain number of rival machine tools produced more recently !

Shovel (fig. 6, p. 82)

Here too the essential team spirit was established in an atmosphere of mutual regard, with the technicians trying to find methods of putting the industrial designer's proposals into effect.

This shovel, the general purpose site machine, was warmly received in Europe and elsewhere. The company itself has in five years attained European stature, now has three times the manpower and is producing more than 10 shovels of this type a day. The users think of themselves as belonging to a family, an elite circle of owners of "beautiful machines", and the manufacturer considers that industrial design has fulfilled its purpose, first of all by guiding the technicians in their work, and then by creating the favourable first impression which in his opinion is so essential if the potential purchaser is to decide to buy.

I could give many similar examples, quoting the very words of manufacturers who call upon industrial designers and appreciate their contribution at commercial, technical and social levels. The opinions of these manufacturers may be summarized as follows: industrial design is essential for sales promotion and the expansion of the firm. Its cost is written off so rapidly that in fact a policy of industrial design is a very productive investment.

In conclusion I should like to say that industrial design is not an easy profession. It is not enough to possess a wide knowledge of materials and their use, the conditions for using, assembling and maintaining numerous types of plant, public taste and general trends in contemporary creative arts. In addition the industrial designer must be creative and have a most versatile creative abitility. What distinguishes a beautiful crane from a commonplace crane or a beautiful milling machine from an ordinary milling machine? It is the industrial designer's taste, intuition, inventive art and, let us not be afraid of the word, his talent.

Gino VALLE

The Function of Industrial Design

(Translated from Italian)

The designer has always existed, and it is almost superfluous to say that ever since man has been making things he has been using matter to form syntheses which have provided an answer to various needs.

To-day, the designer aims at expressing himself by using the cultural media at his disposal, and this has engendered the equivocal position in which he is enmeshed.

Let us try to explain this individual in concrete terms, and endeavour to ascertain whether he exists in the form in which he tends to describe himself, or in the form in which he is being accepted by the producer and consumer communities. If the designer tries to find self-expression in, or tries to become identified with, an aesthetic function, then he becomes the slave of the prejudices of academic critical culture. This concerns itself with the appearances of objects, and he no longer succeeds in referring the objects to his own qualitative or formal standards, this culture having been put into a state of crisis by the multiplicity of such standards in a world undergoing transformation.

On the other hand, industrial production has, since its very beginnings, created objects which have had to a greater or less degree a consciousness of form or structure; this consciousness has reflected the aesthetic prejudices of the maker or of the factory owner. At some stage, competition introduced a third element; this is the consumer, who has become a more or less determining factor according to the differing degree of development or involution of the community in which the process has been taking place.

More specifically, the object produced testimony to a creative relationship within society; this occurs not in the artistic or aesthetic sense, but simply because, as the object exists outside us, it can be used, described and assessed.

This has always happened in the history of mankind, and the testimonies concerned have been classified by conventional culture into fields which vary from primitive handicraft to town-planning.

The designer of to-day who finds his self-expression as an industrial designer has developed as a service to commerce when the market has become competitive, or as an element of prestige in certain non-competitive situations.

Now, the designer tries to acquire knowledge, and gain autonomy and professional dignity in the system outside or even against the system.

But let us try to keep matters simple. The world to-day varies from over-developed regions, where there exists a production-consumption involution which leads to complete anaesthesia, to under-developed regions which, in their communication with the other regions, receive from them products or communications in a way that is disconcerting and sometimes corrupting. But in these two different worlds, and in the intermediate ones, I think there are people who are beginning to be conscious of the problem; on the one hand, they are working to explain the large number of messages and pressures which are produced, and on the other hand, as outside observers, they see the dangers current in our industrial world, the enormous dissipation of human and economic energy which this world has experienced and which it will still have to experience to achieve a true balance.

The designer does not set out to be the creator of a new civilisation but to work with a clear-cut programme and definite tasks to be patiently accomplished, one by one. Incidentally, by the designer, I mean the person who is called to-day a product designer, architect or town-planner.

Having put this premise forward, I intend to set out the theme assigned to me by examining the evolutionary process of design within the bounds of my professional experience and narrowing it further in time and space. By the word "process", I mean a series of experiences, and examinations of subjective hypotheses, which tend to make themselves objective in becoming a testimony of the relationship between the community and the designer. To clarify the meaning of the expression "continuous process of design", it is necessary to make it clear that there does not come into being an intrinsic finality by the creation of an object; in general, it is conceived in the artistic or aesthetic sense and there exists only the volition for continuous examination and for adapting the object to the conditions of its use by the community.

The process, as such, is finalized; its aim is not that determined by the conditions of society in the way that such conditions can be recorded in terms of production, in the acritical production-consumption relationship, nor even as the creative projection of a vague moralism. The designer places himself realistically as a filter in the process, and aims to control it in accordance with the purposes and hypotheses of a function which is intrinsic to professional qualification.

What constitutes the professional qualification of designers is a problem that we are in the course of discussing (but the answer is not yet very clear).

Let us examine, then, the concept of subjective hypotheses. If we depart from a standard of work which is the verification of the hypothesis, in so far as it is a part of a process, it is evident that these hypotheses are subjective because they are postulated as hypotheses. But no theory exists which cannot be verified in reality; in as much as, if it cannot be verified, the theory fails.

Hence the process of verification tends to make such subjective hypotheses at least temporarily objective; that is to say, to make them become temporary theories by successive subjective verifications.

Hence it is only in time that the object achieves an objectivity; it achieves it when it is created, that is to say when it exists externally to the designer, to be judged on a basis of qualitative degree of function, that is to say its organic being.

Function is not qualified in temporal or formal terms of the classic type, but in structural terms within the community in transformation. The theme thus becomes very large, and it is time to bring it back to the empirical and practical plane by enunciating the possible arguments for verification of a subjective experience that has developed with a conscious objective finality. Such an experience manifests itself with various aspects of morphological and structural testimonies.

Going through the experience of design again, we find in the end a testimony of complete morphological transformation of a reality which had defined itself and finalized itself spontaneously and within its cultural limits. It is the result of successive adaptations of the cultural type, the technical and economic type, and the social and psychological type. What has been achieved is a complete substitution of the means and organs of production and programming of the investment resources.

Example: Transformation of the investment object — factory transformation of the object, a branch which has acquired a new content. Partial results of the design, obtainable in the development of the process.

Beyond this, there are the successive steps of design experience in building-scale, steps which are classified as architecture in the critical and conventional historical record, which tend towards the liberation of the academic education schemes, and which have verified the validity or otherwise of various consumer prejudices of critical culture, in the constant search for motives for the creation of objects.

(a) Administrative offices; metal structure designed to exploit the contructional material — load-bearing reinforced concrete, and surrounding structure in steel. Use of two basic materials having opposing characteristics, for their intrinsic qualities. (fig. 7, 8 and 9, p. 82 and 83).

(b) Transformation of the industrial surroundings by means of the replacement of the component elements. (fig. 10, p. 83)

(c) Transformation of the corporate image elements. (fig. 11 and 12,p. 83)

(d) Conscious contamination in surroundings historically defined in a manner which is organic and critically crystallized.

- Udine Savings Bank: Octet frame curtain and its technological and psychological motives. (fig. 13 and 14, p. 83 and 84)
- Offices: use of steel as a material of timeless characteristics and straightforward technology in surroundings formally crystallized, and implications of the experience. (fig. 15, p. 84)

Richard LATHAM

Industrial Design and the Use of Steel in American Products: Situation in 1965

Since the practice of Industrial Design and its relationship to industry in any country or culture is essentially that of bringing machine made artifacts into being, any discussion of the subject should deal primarily with specific products, and pictures are more appropriate than words in describing them. I intend to do exactly this by describing new products of American industry which have unique or innovative aspects in their use of materials such as steel.

However, as a preface to the accomplished fact, or product, I believe some explanation of what lies behind the process which produces it is necessary. The very function of Industrial Design in industry, its management, the use of the skill and the role it plays in bringing innovation into being is the heart of any progress, and the results always follow this train of understanding and logical use of the skill itself.

American designers have worked for clients and designed products both in Europe and the USA. I would like to discuss at the beginning some differences between these two areas in the use of Industrial Design as part of the industrial process.

Put simply, it has been our experience that the European industrialist views the designer as an artist, and a specific kind of artist who is responsible for the aesthetics of the final machine product. This may be oversimplifying an attitude and a relationship, but it has a direct bearing on the role the designer plays and the responsibility management places on him for the success of a product at the market level. As an Industrial Artist, the designer is supposed to be able to create aesthetic qualities for the product's appearance and to some extent its use function, that will assure its complete and final appropriateness in a society, once it is made. In short, "It looks right and it functions well in the hands of the ultimate owner and user."

This is a very clear and clean definition of the Industrial Designer. It makes for a logical relationship between management, engineering and the designer himself and in our viewpoint, it is good and in some ways better than the understanding that exists in the USA.

Let me clarify the word "better." It has been the practice of american industry for some time to use the designer as a stylist. There are many explanations of exactly what this word means, but the major results of the work itself indicate that industry believes the designer can manipulate the aesthetic appearance of a product in such a way as to make it look "newer", "more expensive or less expensive" or, put into other words that the design of the product can alter its actual value in the eyes of the consumer by creating an artificial style. The most obvious example of this would be the annual model change practice by our automobile industry, or the many and various manipulations of appearance practiced by our furniture industry. There has been enough written and spoken on already, let me say only that for the last five years this practice has been diminishing and there is a strong return to sanity, even our automotive industry has begun to carry longevity and continuity in the forms of the products they make, and with the exceptions of the fashion industries, such as ladies clothing, "styling" per say is no longer considered an effective tool of merchandising.

The difference between the designer as an Industrial Artist and the Stylist employed by marketing for selling reasons, as it is done in America, has been explored by both these groups on many occasions, and the general consensus seems always to resolve back to the fact that the "Artist" approach produces the best end result for both the manufacturer and the ultimate owner. I do not contest this point, rather I confirm it by the word "better".

There are, on the other hand, some significant differences in the US designer's relationship to marketing which quite possibly make the designer more effective or, at very least, give the industry which uses his talents access to different skills he may have and produce results of another, and possibly equally important kind.

The american industry, for instance, as most industry all over the world, has broken the management of itself into many separate and important functions. Among them are Engineering, Manufacturing and Selling. The two functions of Engineering and Manufacturing are quite separate in business. They are staffed by different kinds of men, with different skills, in short everyone knows the difference between an Engineer and a Salesman.

When an Industrial Designer functions as an Industrial Artist, he reports directly to Engineering and Manufacturing. When he reports directly to Sales, ("marketing" in the USA), he functions in different ways, and not just as a stylist.

If one examines the management charts of all the large US Industries and most small ones, one finds that since about 1950 Industrial Design has been moved on the chart from Engineering and Manufacturing to Marketing. In fact, the managers of Industrial Design in our large corporations without exception report either to the V.P. of Marketing or directly to the President of the company. It is interesting to note that. since 1950, there have been created more than 6 Vice-Presidents of Design in large industries.

What lies behind this change? What responsibilities are different? And what effect does it have on the products and use of materials in industry?

Probably the one most logical explanation for the shift of Industrial Design from Engineering to Marketing is rooted in the intense and fierce competition between US businesses in the marketplace today.

The marketing competition that exists between all manufacturers of consumer goods is well understood, but it should be kept in mind that in America this same kind of competition exists in all products from capital goods and transportation to commodities including coal and salt. There is more factory space, more trained labor, more engineering brains, more of almost everything including venture capital that the marketplace can support and in a competitive climate like this, it is not unusual for the biggest of business to go down the drain. I could name a few who have, but I won't bother. I can only add that when the President of a one billion dollar industry is written up by the Wall Street Journal and quoted as saying, "Don't believe the rumors that we are going out of the automobile business," it is certain that competition is genuinely fierce, that the stakes are equally high and that every technique at hand is used in any way possible to insure that this particular industry is not going down the drain.

In a business environment of this kind, Industrial Design was shifted to Marketing. When business found that more advertising, more merchandising and more of every kind of selling would not improve their market position, they turned their attention to new products, new services and innovation, and one of the first things they discovered was that new product ideas came essentially out of an understanding of the consumer or customers needs, rather than from sheer invention and the advance of technology. Certainly research and development continue to press back the frontiers of science and technology, but the trick is in the application of materials and techniques, you might say "end use" and always in terms of a product that a customer wants and needs.

Does this apply only to mundane consumer goods? No! Even Aero-Space and the aircraft industry have turned to this kind of planning. For instance, there has been a mock-up of the manned moon vehicle in the Industrial Design area of NASA for three years. All the human factors have been proved — we know where we want to go and "what" we have to go in — it remains to be seen if we can develop the materials, horsepower and technology to meet this clearly defined "product."

Much the same is true in Mock 2 transport aircraft. Certainly the problem is of a technical nature, but the result must deal with human beings who must reach their destination as comfortably as if they were in an easy chair at home. Here again, the mock ups on human factors are running far enough ahead of research to define the product.

And right here, I would like to point out that one of the most serious aspects of this product problem is metals, "steel" to be exact, that can withstand the temperatures of a 2,000 mile per hour ride. Technicians are better qualified than I to tell you of the developments in this area, but let me describe how the process of defining the competition, describing the problem and product and encouraging the development of new materials and techniques works at a much more mundane level.

An ordinary cooking pot. The sale of cookware in the US is approximately $100,000,000 per year. It has always been broken down into iron, porcelain enameled steel, stainless steel, aluminum, and since 1955, pyroceram. More than 25 manufacturers share this market and three to five divide the market for stainless steel among themselves. We work for one of these five.

Assume the following conditions. In 1950, aluminum has begun to fade as the prestige material in cookware and stainless steel has taken over. In order to remain competitive, technical developments continue. Copper plated stainless, Tripli — or carbon core stainless, and finally aluminum core stainless steel are developed to produce new products the housewife would prefer to cook on. In 1955, a company came to the market with a new material evolved from our Aero-Space program. It is essentially a glass, that by tempering becomes a new metallic type of material that is impervious to heat change and is easier to clean than regular stainless steel. It also does a little better baking job. Sounds simple and interesting, and it was so interesting to the American housewife that the sale of this material went from 0 to 37 million dollars by 1963. A big bite out of everybody's share of market.

Now enters an entirely new material in 1963. This is a coating of plastic which has non-stick cooking properties. In essence one does not have to use fats or grease as food will not stick to it, add the factor that it is very easy to clean. An interesting development, but in all probability just a passing fancy. This material is supplied by a firm of world-wide reputation who has no concern with any particular metal and only wants to limit its use to metals where it cannot fail under extreme conditions. They do just that, they limit it to stamped or cast aluminum. It so happens that the housewife likes the results so much that the sale of this so called "Teflon" coated ware reaches 30 % of the market and is still climbing. Can you imagine what this does to all of the manufacturers of stainless steel ware? I can tell you, because we work for one of the largest and we are confronted with the problem — it practically puts them out of business. You might be thinking to yourself, why doesn't the manufacturer of a cook-pot keep abreast of new developments and change to new materials — and I can only add, that is exactly what is happening. But then I ask you — what about the producer of stainless steel who enjoyed the biggest part of a 100 million market? What does he do?

There are many things he can do and will do, but essentially what I am trying to describe to you is a picture of business confronted with highly competitive problems from all sides and my point is that working in this kind of environment both the manufacturer of cookware, and the maker of stainless steel work with the Industrial Designers in quite a different way than as an Industrial Artist.

What are the ways? And some of the results?

There are many different ways that the US designer may work for marketing, other than as an artist. Product Planning is one typical title given to a procedure followed by our large industries. Under this format the designer's basic charge is that of visualizing products 3 to 5 years ahead of existing production. The work must take into account technology and engineering innovation available and most often it is used by management to try to predict what could happen to a product if time and money were spent on particular engineering development.

It is always dangerous to predict, but it remains a fact that with rare exception the mass produced product of three years from today can already be described — the basis for its engineering innovation must exist now if it is to be evolved into a manufacturing technique.

Quite often the problem is one of alternatives, for instance — with two innovations available, which one would be the more desirable to use ultimately and therefore the one to concentrate development on.

Such an example would be the knowledge that a certain kind of cooking surface could exist using plated circuiting. Obviously, such a cooking element would be a step forward. How much time and development is necessary to bring it about? Alongside this development, we have the ability to design an oven that cleans itself with heat, how much time and effort are needed to accomplish this? Then the two possibilities are visualized as future products and compared, a decision is made — in this case it was the latter, or self-cleaning oven and it is rapidly becoming standard for American cooking ranges across the board. The designer's role in visualizing future products of this kind is not one of blue sky — or evolving the kind of futuristic product one sees so often in American advertising, but rather that of evolving very practical down-to-earth products which demonstrate very clearly to many different people what the possibilities might mean to the company if it went ahead with the development.

These products, even though they are models, must look completely believable, and in some cases must work because they will be tested by the people who would buy them to determine if the ultimate owner prefers the result.

The same example may be demonstrated in TV, where the problem is simple. It costs about one million dollars an inch to shorten the neck of the tube — are the results worth it? — three to five years from now? Also in this area we may explore another product innovation of a different kind. At a time when all the products attempt to imitate wood boxes what would result if a product were designed to look like a machine — made from steel. The original steel case was painted, and the reaction on the part of the customer was, "I would like this product, but I'm uncertain of the surface finish." The question, then, is whether to substitute plastic. In the case before us a completely new technique was tried — that of laminating vinyl to steel sheet and drawing the whole into a finished product with integral surface. Needless to say, it was successful and the technique has been applied to pre-finished steel surfaces in many products since. Another way that the designer serves a new role is broadly termed Product Research. Although there are many different approaches, one thread of logic comes through. Examine the product historically, and specifically with reference to all developments in the field. What are its good points and bad points, who are its competitors and finally, what does the whole picture look like?

We have worked on many such projects ranging from studies of steel curtain wall applications which result in a report of the following nature to simple presentations which are really just a road map of a present and future comparison between an existing product or material, and all of its competitors — In every case the designer must show his results in terms of pictures or models of real products. It remains for others such as market research people to use words, but the designer must never lose sight of the fact that he is a visualizer of things.

Still another use of the designer in the capacity of visualizer and planner is the situation where a large producer of raw materials institutes a program aimed at the study of how his material might find new product applications.

American industry has used the designer for years to introduce new materials to potential users. The plastics people, in particular, developed this technique, and have developed internal design staffs and use outside consultants to make studies of new programs and products where the material might apply, or better yet, replaces another. One company even subsidizes student competitions for the use of their material as do many other material producers — why? — not just to encourage new ideas, but to indoctrinate the student in their material and get him in the frame of mind to design it into real goods when he is practicing professionally.

Nowadays, people know exactly what we designers are and so do all our clients, but they have also learned that because of the way we think and can visualize that we can be used by them as planners, as people who can suggest possible new uses for the material and finally as people who can visualize either through a model or drawing a new product three to five years from now, which does not exist in any form now.

All of this work has to do with the use of materials, the decision as to which material or process will produce the best final end result, and all of it is aimed at a product which can be sold.

I hope you have not concluded that I mean to imply the Industrial Designer can do all these things alone. He cannot! He is the partner of engineering, he depends completely on the scientist or development engineer to produce new technology and finally, maybe most important, he is the spokesman for the consumer or customer inside industry. His one basic concern in all matters should be that the end product will work best, look best and be the best thing possible for the ultimate owner.

If he can truly represent the end user in his work he then brings some assurance that the product or service under consideration will not only be desirable but successful for the customer.

What then is the position of the Industrial Designer and specifically in relation to new products and steel in these alternate roles I have described?

In 1961, in an advertisement that a US steel producer ran on work my office had done, I was quoted to the effect that steel was the life-blood of design for mass produced products. Certainly cast iron was one of the original processes which allowed the mass reproduction of parts and products and paved the way for mass production, but steel with its ability to be worked, drawn, stamped, welded, etc., became the really first flexible media for structure as well as sculptured envelope. The study of the advent and development of the automobile with all the attendant technology of automation and high production techniques reveals the whole story. The Industrial Designer and his manufacturing engineering partner is probably conversant with and works with more different kinds and qualities of steel than any other profession.

Other base metals and even plastics (fibre glass in particular) have replaced steel in certain basic goods, but in many cases where new technology in metal has occured, steel has moved back into the product as the most desirable material. One example from my own experience would be a series of vacuum sweepers my office designed for a large company this year. At the beginning of the project we made a study of competition which pointed out that plastics had moved into the field in the form of large housings and cases, especially in the case of the tank or floor vacuum. It was our mutual opinion that these plastic materials were wrong. We found certain new plastics that would serve the purpose, but in every case they were too expensive. In the end, after a long search and in the face of the fact that very successful companies had gone away from steel, we decided it was the right material and the product was designed for it, and in it.

It is our opinion as professional designers that one of the greatest areas for new developments in steel lies in finding ways to accomplish permanent finishes integral with the surface of the metal itself. The coatings, platings and laminates available for mass produced steel products are a technology in themselves, but with the exception of stainless steel, very little has been done in research in this area. We believe it will be done, because it has to be — to keep the material competitive.

I cited earlier the problem of integral non-stick finishes for stainless steel, and the process for anodizing the surface of the metal with glass. This is only a beginning in what may be the most significant thing that could occur in steel technology in the next 15 years. Cor-Ten, the self-rusting steel developed for architectural use, is an example of a beginning in that field. There is a joke that has been repeated for years to the effect that "Chromium is America's favorite color". Obviously this stems from our many automobiles with their massive chromium bumpers and details, to stores full of traffic appliances which are predominantly chrome plated. The actual fact is that recent research indicates most Americans do not necessarily prefer these masses of bright chromium — but the only practical alternatives are paint finishes which won't last, or stainless steels which are too expensive. The aluminum companies are trying to encroach on the automotive field by replacing many of these bright plated parts with their material. We believe steel is a better metal for that job, and it only remains to develop the itegral finishes necessary to make it more desirable once again.

The intense concentration on the part of the steel industry in the areas of structural integrity, drawing ability and zero tolerance casting techniques (powdered metal) have opened wide new horizons, both for the use of the material and for machines or products which were impossible before. But the fact remains, that the problems of protecting the material from the natural elements and even the corrosion attendant to controlled atmospheres is a continuing anachronism in an industry which prides itself on being as advanced as its competitors. These problems are attendant to all its application from bridges and massive capital goods to the smallest nut that holds a license plate onto a car. If it rusts it is not only useless as a fastener, but in attempting to remove it, all the parts it was intended to fasten together may be destroyed in the process.

I appreciate the fact that I was asked here to talk about and to show you some of the new developments that are being accomplished in the areas I work in, but I also feel strongly that, as a designer, I should be able to point out to the men who could accomplish the job, an opportunity for continuing developments that will increase the integrity and use opportunities for steel in an Industrial Society. The area of integral surface finish is only one of many, but I hope I have drawn attention to the fact that it could be a serious, fruitful area of development.

André Ernest MAHAIM

Motivations

(Translated from French)

One fact surprises us in examining the papers presented, namely that not a single speaker has suggested making a systematic study of motivations. Such a study would be interesting from several points of view

(1) the need for a list of guiding motivations to be drawn up by the industrial designer in co-operation with the engineer and the technical sales department;

(2) the recognition of plurality — an idea presented in masterly fashion by Mr. Maldonado — leading to the multiplicity of requirements, the variety of possible uses in combination with materials other than steel;

(3) the necessity for a debate, to take place, perhaps during a future Congress, between the industrial designer, the appropriate departments of E.C.S.C., the producers, manufacturers and distributors, in the field of psychological motivations connected with the utilization of steel.

These proposals are based on three concrete examples noted during the presentation of the papers:

(*a*) the example of the vice, quoted by Mr. Vienot, the corollary of which is the intensive promotion of the "do-it-yourself" Kit;

(*b*) Mr. Valle's example of industrial buildings of outstanding functional design on which the workers will be insisting more and more;

(*c*) the attractive design of domestic equipment proposed by Mr. Latham, which he suggests should be generally adopted in the home of tomorrow.

These ideas should be gone into more thoroughly. I would suggest the following slogan for industrial design:

"Steel is good because it makes a fine product;
Steel is best, because it is the most reliable product."

List of illustrations

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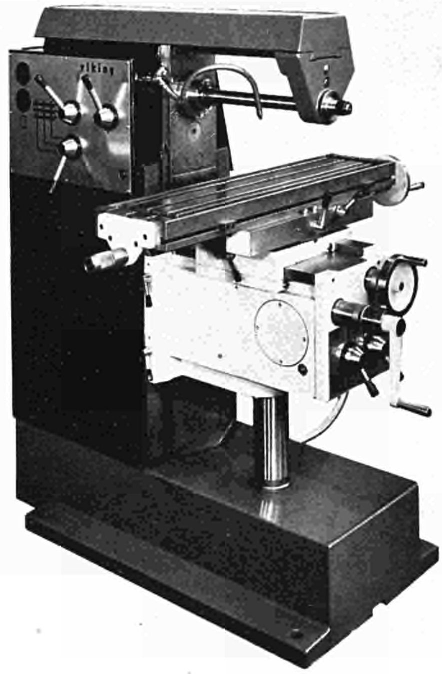

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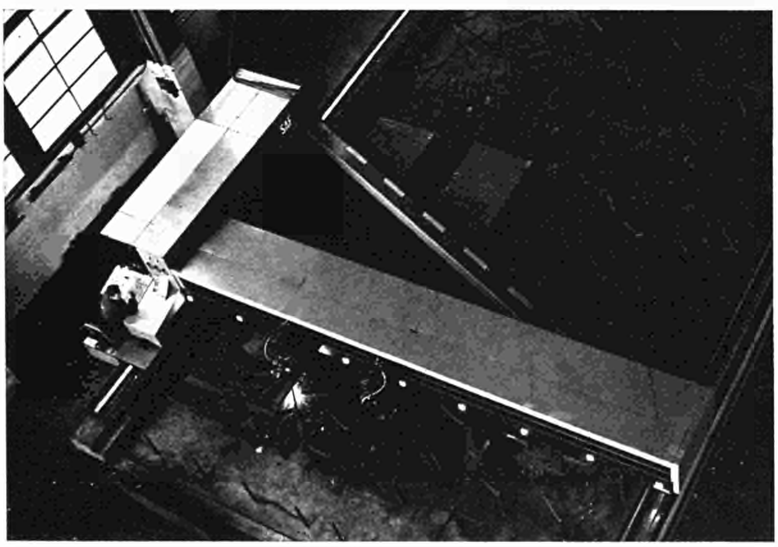

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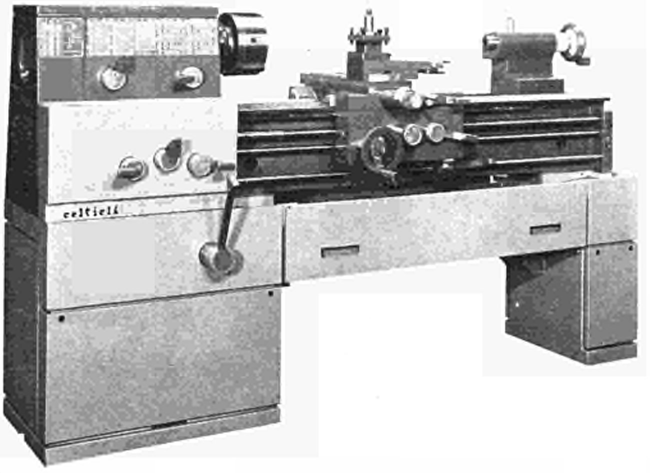

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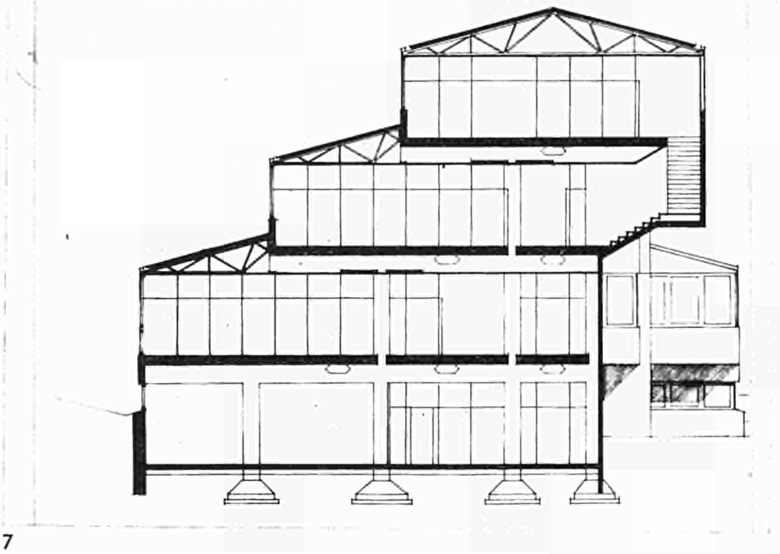

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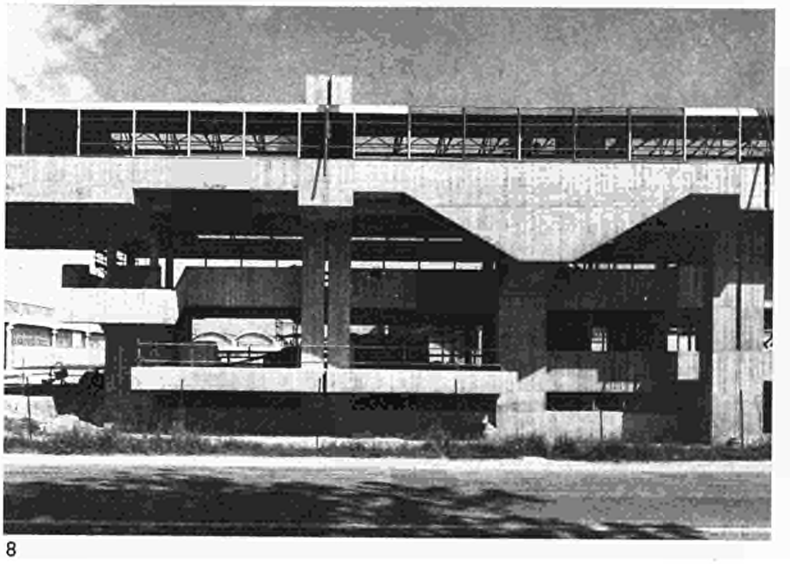

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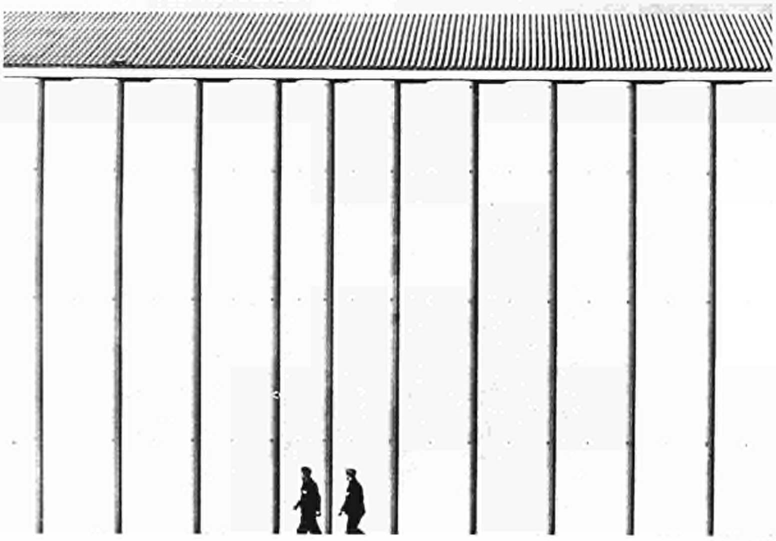

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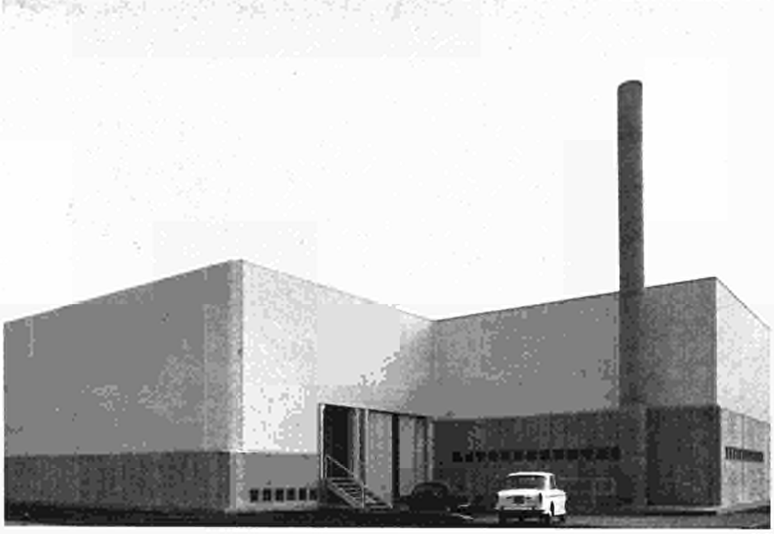

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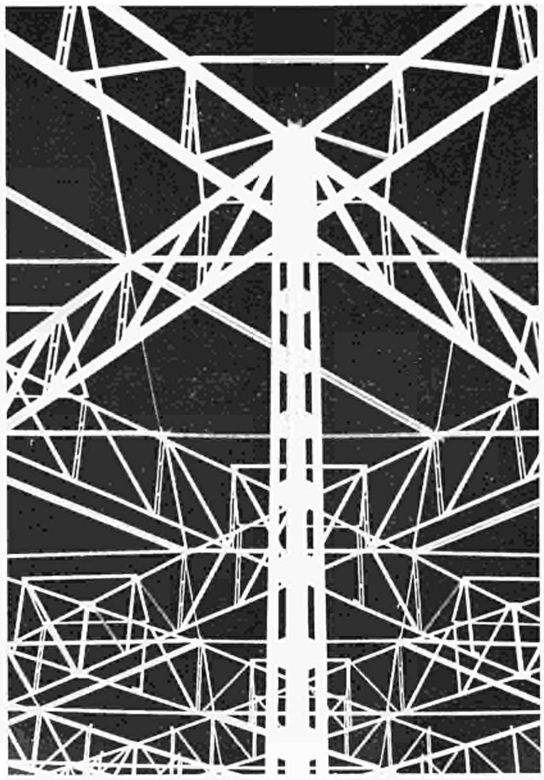

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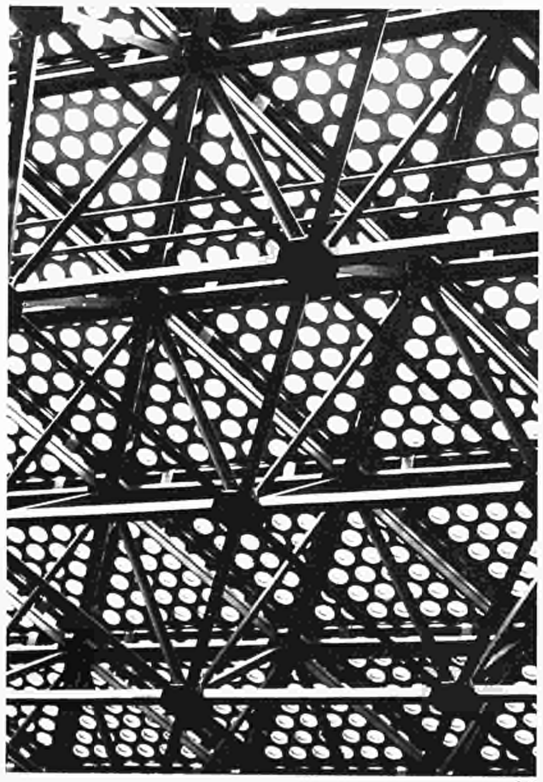

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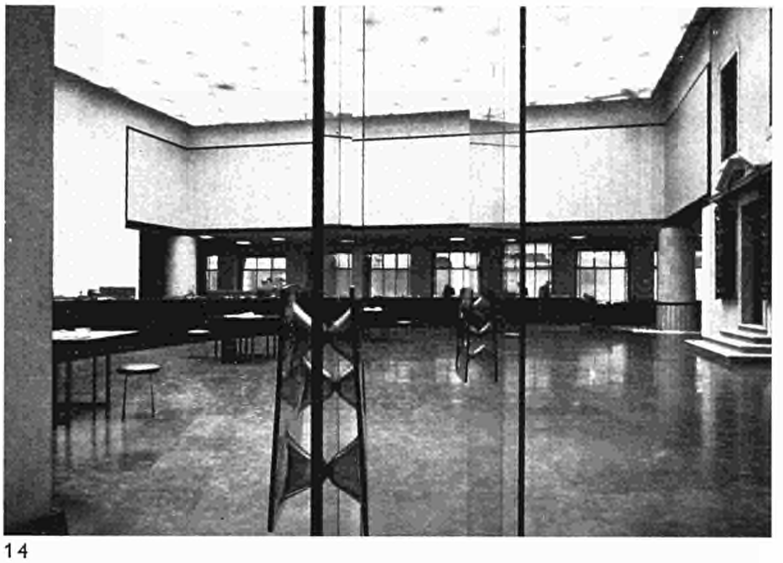

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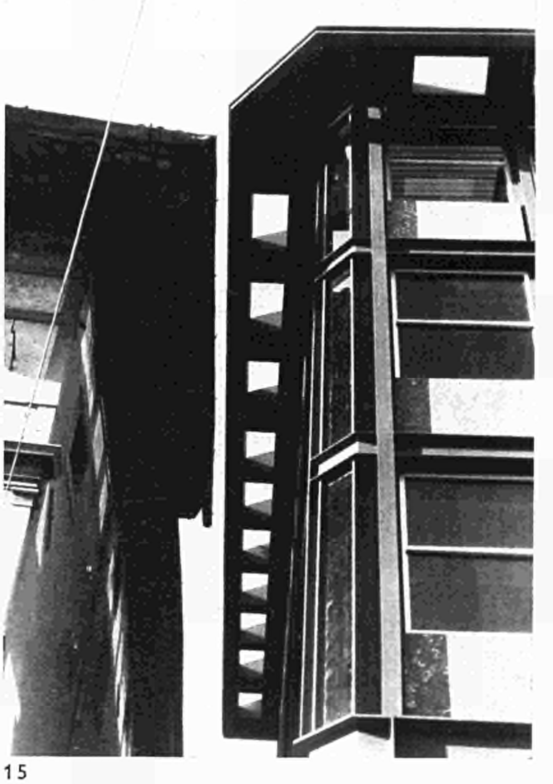


15

Sigvard BERNADOTTE

The Role of Industrial Design in the Production of Consumer Goods

At the risk of repeating something which has already been said I would like to, very briefly, explain what industrial design is and how to define it. The newness of this profession makes it inevitable that a lot of discussion around it arises and a lot of different opinions are voiced when trying to explain industrial design and the industrial designer. What an architect does or what an engineer works at is something which everybody knows or assumes to know, but what exactly does an industrial designer occupy himself with? Most people have a vague idea that he designs "things for industry," but how seriously he wrestles with problems only a very few people know.

There are about as many definitions as there are designers, but lately the international design organization ICSID (International Council of Societies of Industrial Design) has tried to propose and codify a definition which it is hoped once and for all will stop the discussion. This definition comes under three headings: the function, the method and the sphere of activity of the industrial designer.

The function of an industrial designer is to give form to the objects and services that render the conduct of human life efficient and satisfying.

The method of an industrial designer is to produce a hypothesis for a possible product, to work with other specialists in creating a practicable version of that hypothesis and to determine its final form.

The sphere of activity of an industrial designer at present embraces practically every type of human artifact, especially those that are massproduced and mechanically actuated. But rarely such large permanent structures as buildings and civil engineering works. There is little doubt that this sphere of activity will change as both industry and the profession of design progress.

This definition if and when accepted by 37 design societies in 25 countries will help enormously once and for all to dispel all misconceptions about industrial design. Maybe all this talk about definition and clarification has been too long, but I do not think you can discuss industrial design without doing this.

The function of industrial design in the production of consumer goods does not differ very much from that which is applicable to capital goods. It really is only a matter of the size and the scope of the work. It might be said that design is still more important in consumer goods, as those come into closer contact with the ultimate consumer and this is of course true, but from the designer's standpoint the problems are very similar.

Design has very little to do only with the outer shell, although this naturally also must be designed. Design should give the impression of the product's own individuality. There must never be any doubt of what the product is, no confusing of identities. It is bad when a consumer has to solve riddles when confronted with new articles. He must not have to ask himself: "What is this?" He must immediately see what it is. This sounds very self-evident, but as we daily are subjected to new impressions it is very important that the designer gives the new product a shape which at once associates it with its function and use.

Design must be in depth, an object must be designed from the inside and out, not the other way round. The designer must take into consideration the existing or planned construction but can naturally — if he is called in at an early enough stage of the product-planning — add his ideas to those of the engineers. It is often possible to come up with new unorthodox ideas, which the man in the factory simply has not thought of because he has become "blind" to new approaches.

Design is mainly two things:

1. Logical and sound thinking and

2. Team-work.

When given an assignment the first thing to do is to sit down and figure out what exactly is the problem that has to be solved. What are the difficulties? What is expected of us? What are the exact premises? What are the competitors doing? Through getting answers to these and other questions the problem becomes clearer and at the same time simpler. The sector wherein the solution lies narrows down and the work becomes easier, the chances of success increase, and the time element and with it the cost factor is cut down. All to the benefit of the client.

The actual time of "designing", drawing, is postponed and shortened and becomes much less hazardous. The more time you spend on thinking and planning the more accurate your designing becomes.

I would like to venture the thesis that design is teamwork. Alone the designer can do very little — together with the people from the construction- , sales- and distribution departments and the management he can add his little — but important — bit to the successful whole. He is, to be sure, only a small cog in the machinery that produces goods, but without this little cog the product would lack something. It might be well produced, excellently constructed, but it would not have that little additional something which makes it desirable to the consumer.

It is not always easy for the designer to establish the right contact with especially the construction department. The engineers will often feel that somebody from the outside is trying to meddle in his affairs. Therefore diplomacy and tact are two qualifications which are indispensable for the successful designer.

He must convince the constructor that he is not trying to take his place nor tell him what to do — but that he is solely interested in helping him in those parts of his job, where he unconsciously feels himself uncertain.

Somebody has always "designed" the products even before the advent of the industrial designer, but this somebody, either he was the constructor or the managing director or somebody else, has had very little or no experience in design of this kind, and he has always felt, very likely unconsciously, uncomfortable about this, because design was not his department.

When therefore the designer comes into the picture and finally has earned the respect and the understanding of the engineer he will find that the engineer is only too happy to place the responsibility on the designer with regards to design. And in this way the two experts will be able to work together, pulling the same way and helping each other for the benefit of the ultimate goal — a good product.

From a designer's stand-point and naturally also from the producer's, a good product is the same as an economically feasible product. The designer must therefore always be cost-conscious. When he suggests alterations and changes this must always be done with an eye to costs.

The attitude towards design as something which per se brings with it a heightening of expenses must be changed. In fact the use of a serious industrial designer should help to cut or at least reduce the inevitable rising of costs.

How important is design for the sale of a product? This of course varies very much, but let me take two examples: diametrically opposite each other — a spoon and a machine tool.

The function of a spoon is so firmly established and so clearly defined that any major deviation in this respect hardly is possible. All spoons are therefore basically the same. In this case the design plays a dominating part. To maintain that the spoon to 90 % is sold on its appearance is surely no exaggeration.

A machine tool on the other hand is basically just a machine. What it looks like is really rather insignificant. Here we have the opposite to the preceding example. The appearance of the machine tool maybe means 3 %. That a percentage is mentioned at all is due to the fact that there is always the possibility that a presumptive buyer is faced with two equivalent machines. Without a doubt he will choose the one that attracts him most. His choice can even be made entirely unconsciously and he would probably deny that esthetical motives have played a part. But when the choice stands between two possibilities where the technical data, quality, price and time of delivery are identical, but the appearance or design are different, an important reason for the decision to buy is the fact that one machine appeals more to the buyer than the other one. Why? Is it the colour-scheme, the shape or a combination of both? Nobody knows, but the attraction to one and the averseness to the other are without a doubt based on esthetical considerations.

Industrial Design as a profession is fairly young and like all youngsters it is often preposterous and irritating, but again like all young people this is something which disappears with age. And the profession is growing up or rather has grown up and is entirely prepared to stand on its own feet, and on its own merit. The times have passed, luckily, when a designer could come to his client with a smart rendering on black paper, the highlights twinkling like stars and the perspective making the object, whatever it is, look as if it were taking off into space at any moment.

Now the conscientious designer penetrates all the problems from research and analytical delving into the different aspects of the new product, to marketing and advertising before he even thinks of putting his pencil on paper. It is no longer a superficial smartening up of the product, but a thorough painstaking job. And this is why the designer in many ways has changed and matured. And the education of the industrial designer has thus taken on added importance. The finished designer is a man with a great responsibility. Responsibility towards his client. Responsibility towards the consumer and finally responsibility towards the community. (fig. 1 to 3, p. 105)

The last aspect is not the least important for after all today's world and the environment in which we live are formed by the designer. We are surrounded by things that have been shaped by him and without knowing it we are influenced by them for better or for worse. Therefore his aims must always be to heighten the standards of design and through them the standards of living and give man a more pleasing, a more comfortable and an easier place to live in.

The problem of educating the young designer is something which is being discussed everywhere. There are no definite rules what he must learn or how, but slowly, I think, there is emerging some semblance of international criteria, and I am sure that the next generation will know much better than we do how to educate the industrial designer.

The older generation of designers, the pioneers, were never trained to be industrial designers. They came from different walks of life. Some were stage designers, some silver designers. Others came from the advertising field or the world of fashion. But they all had a strong feeling for shape, colour, texture and of course for function. They worked with the trial-and-error method and it really is quite extraordinary that they achieved what they did.

The industrial designer today is or should be a blend of architect — engineer — craftsman. He must be something of a resarchman, a marketing man. He naturally cannot be a specialist in all the fields but he must be somebody that knows enough about these things to be able to ask the right questions and digest the answers.

It is easy to see how difficult it is to plan the training of such a man and how many different ways of doing this there are. Basically, however, there are two different aspects or directions to go. One is to start from the artistic side, to take for instance the architect or artisan and give him technical knowledge — the other is to take the technician, the engineer, and give him an esthetic education. Personally I think it is possible to do both, although I believe that to start from the esthetic end is a little more easy and satisfactory.

In the end it is only in practice that the designer develops and matures. There again we get into difficulties. at least in Europe, where big design offices are rare, because there are very few places where the designer, just out of school, can practice. He is therefore often tempted to start on his own too early and meets all the difficulties this bears with it. This is a problem which also will have to be solved.

But in spite of all this the design profession is growing in importance and is getting more accepted on the same level as the architect and the engineer, and its share in the development of new products is fast becoming self-evident and its work is becoming indispensable, a means to help the producer in getting the maximum sales result out of his products.

Carl AUBÖCK

The Contribution of Industrial Design in Developing New Products

(Translated from German)

Product development of today

In order to clarify my lecture, I should like to begin with a little story, which may be familiar to some of you:

> "There was once a master saddler, an able, thorough craftsman. He made saddles which were formed in such a way that they had nothing in common with the saddles of past centuries, or with the Turkish or the Japanese. Modern saddles you might say. But he did not know that. He only knew, that he made saddles as well as he could.
>
> Then, a remarkable movement came into the town. They called it secession. It demanded that only modern consumer goods be made.
>
> When the master saddler heard this, he took one of his best saddles and went with it to one of the leaders of the secession. And said to him: "Professor" — for that's what the man was, as the leaders of this movement were immediately made professors — "Professor I heard of your demands. I also am a modern man. I also want to work in a modern way. Tell me: is this saddle modern?"
>
> The professor inspected the saddle and gave a long lecture to the master saddler, from which he could only always hear words like "art in craftsmanship", "individuality", "modern", "Hermann Bahr," "Ruskin," "applied art," etc. But the conclusion was: no, that's no modern saddle.

The master saddler went away feeling quite ashamed and he thought, worked and thought again. But however hard he tried to meet the professor's requirements, he always produced his same old saddle!

Sorrowfully he went again to the professor and told him of his grief. The professor inspected the master saddler's attempts and he spoke: "Dear master saddler, you just don't have any imagination!"

Yes, that was it. He did not have any imagination! But he did not know at all that it was necessary for saddle making. If he had, he would have surely become a painter or a sculptor. Or a poet, or a composer.

But the professor said: "Come again tomorrow, that's what we are here for, to further the trade and to make it fruitful and rich with new ideas. I shall see what can be done for you."

And in his class he set the following competition: "project for a saddle." Next day, the master saddler came again. The professor was able to show him forty-nine projects for his saddles. Though he had but forty-four pupils, but five projects he had done himself. They belonged to the "studio." For they had feeling.

The master saddler looked at the drawings for a long time and his eyes became brighter and brighter.

Then he said: "Professor! If I knew as little as you do about riding, about the horse, about leather and about the work, then I also would have your imagination."

And he lives now happy and satisfied.

And makes saddles. Modern ones? He doesn't know. Just saddles."

This story, written by the Viennese Architect Adolf Loos in 1903 in his book "Trotzdem" depicts in an unequalled manner the mutual irrelevance of people more or less connected with production, just as it obtains even today in a slightly different form.

The starting point of our narrative is formed by the fact that in our pluralistic industrial society, production is characterized by an extensive division of labour. We appreciate, that on the whole, all production stages, starting from the initial motivation to the final sale, are rarely invested in one hand and in one person. Certainly, there may be certain types, mainly of crafts, where all work stages are invested in one hand, but even there this seldom applies.

We know therefore: In the case of product development, "lone decisions" are progressively less possible, and they will be surely even less possible in the future.

What is required, is a productive isolation of several people or groups of people, whereby the ability to exchange ideas and to work with various groups of people is the prerogative of the person entrusted with making responsible decisions.

So we come to another phenomenon: It has been established that tremendously rapid development during the past decades very often disturbed, if not made almost impossible, a common terminology in the sphere of Product Development. Where, as in the field of job allocation in Planned Production co-operation between various people or groups of people is necessary, and where it is desirable to achieve positive results, an essential condition for successful work seems to be, firstly to avoid as far as possible, misunderstanding in human expression and secondly, in spoken word, writing and optical expression, to arrive at a common basis. Of equal importance with a common language in design seems to be a genuine mental concept for all assignments in the field of Planned Production, from which alone a job allocation, appropriate to present-day conditions, can be worked out.

In this context it will be interesting, to examine briefly the question of systematic training. Apart from a few notable exceptions the training of designers for co-operation with Product Development in industry has at present no educational basis. By comparison with other departments in education, e.g. architecture, painting, plastic, commercial art, applied art etc., the training methods are usually still encumbered with the ballast of fragments from the teaching methods of other professions.

On the other hand the so-called training of designers lacks much of the basic knowledge which would enable them to have a hand in production. One may assume, however, with a certain justification, that in all probability, say within the next ten years, teaching methods may evolve which, on the one hand, will meet the actual demands of an industrial society and, on the other, offer the students in this sphere a general view of their future work at a higher level.

There can be no doubt that one can have too much of a good thing. Just as it would be wrong to question the necessity of Planned Production it would be equally wrong to overestimate its influence on the human surroundings. Economically speaking particularly there is a danger of misconception through an extreme and one-sided way of thinking.

Mentally speaking one often hears, usually in a rather pathetic way, of the expression of our time, the style of the epoch and the striving for such. I should like, if I may, again quote a pertinent remark by Adolf Loos from the beginning of this century:

> "The seeking and striving for a new style of our time is superfluous, for we have it, whether we want it or not. We are children of our time and everything we do, whatever it is, shall one day be regarded as a typical phenomenon of no other but our own time."

It is, by the way, very interesting to observe how topical Loos' reflections which, after all, date from two generations ago, sound in our time.

What we can and must seek, however, is a continual improvement and clarification of our possibilities to achieve satisfactory results for our human society. This may perhaps sound less attractive than a "striving for a new style" but, if I may say so, will be of more use to our time.

It is therefore of the utmost importance to recognize the positive use and potential of the role of Planned Production within the framework of general economic production, and carefully to consider how it is to be employed for the best possible success in development work and most realistically utilized.

It would be regrettable, in the consumer's interest, if the decisive factor in the choice of a product were to be its appearance. However important a part the outer form will play, it should never be used as camouflage for poor and faulty material. On the contrary, the appearance of a product should give a clear image of the entire technical, functional and economic efficiency of the proffered product, giving, already by its appearance, the customer truthful information about the product concerned. Thus he can be given, by virtue of its design, the necessary trust in a product which this, after purchase and subsequent use, will indeed justify.

As with all planning, so with Planned Production a perfectly organized progress control as well as the formation of an efficient team is of paramount importance. Despite the difference between individual practical cases, generally acceptable experiences and principles can be worked out, giving the persons responsible for production the opportunity to include, with some promise of success, Planned Production in the overall scheme. On the other hand it is important for the designer to become familiar with general principles concerning his work in the factory, and this will make co-operation with his employers easier. At this stage of the job it is of particular importance to lay down a suitably timed, optimum operational method for each case, or the development will come to a standstill. The designer's know-how, together with that of others must lead to true development. This represents a not insignificant part of the service to the employer, particularly where it envolves removing obstacles put up by traditional working methods etc. The greatest danger at this stage are the by now well known objections raised by plant organizations, with which the outside consultant is automatically confronted:

(a) We have always done it this way.

(b) We have never done it this way.

(c) Suppose everyone wanted to change things.

Again and again one comes to realize that experience gained in theory cannot always be equally applied in practice. Not that one should take the standpoint that either theory or practice is alone important for each development. Far from it. It is the task of an efficient working team in each case to strike a correct balance between theory and practice. We know that here too in the case of Product Development the role of the designer as co-ordinator between a diversity of efforts and factory interests is of great importance. His role as consultant, often drawn from outside, enables him rather than the firm's employees to act as, arbitrator in the development process. He can also draw from his manifold experiences gained through his contact with many other, often totally different, branches of production, putting them to advantageous use when working on any given project.

One has long recognized that an exchange of experiences, economic and technical, must be to the advantage of all concerned. In the field of Planned Production, however, the exchange of concrete experiences leaves much to be desired. Here genuine or sometimes imaginary economic considerations are often the cause of such information delays, and it would be extremely interesting to investigate, (although this would by far exceed the confines of this talk,), where the positively attainable use and the limits of a genuine information exchange would lie.

To speak in concrete terms: Industrial design offers a measure of increased service to distribution and the consumer which is by way of being a by-product of Product Development. Where conscientious and detailed preparatory work is done, various stages are dealt with which, purely from a commercial point of view, can greatly facilitate the job in hand. This gathering of data, e.g. market research, consumer research, planned production, packing, advertising, sales promotion and information also forms a most essential part of the whole service.

The conscientious activities within industrial design can therefore effectively contribute in overcoming the phenomenon of the reluctant buyer. This has many aspects, but it is worth-while to deal in some detail with some of the special difficulties.

We are all familiar with the reluctance of the public to use new products designed for ways of living which seemed at one time quite unattainable. To illustrate my point: All matters concerning living and eating habits today preoccupy an infinitely greater section of the public than only a few years ago where, sociologically speaking, understandable inhibitions arise, not to admit ignorance in this or that field, say table-manners. Here a carefully thought out product which comes on the market with the necessary information can have an instructional and educational effect and with that alone, that is by overcoming the barriers of the reluctant purchaser, can open new markets. Here too the importance of the right information and correct channeling of public opinion can not be overemphasized.

The social aspect of a well directed Planned Production with regard to a higher standard of living and improved service plays an important part in the successful presentation of new products. The success of Planned Production depends not least upon the organization of distribution and sales. The consumer, after all, becomes a far more conscious purchaser than was the case in former years. Here then, in the sociological structure, we recognize one of the most important phenomena; the importance of industrial design in the production of consumer goods is seen in a completely new light.

Let us not forget that one of the most pronounced characteristics of man is his ability to evolve. Within the constantly progressive development from generation to generation modern man is faced with a highly intensified pace of development, and it is this ability which helps him to understand more fully aspects and phenomena which he at one time simply ignored. Everything therefore which contributes to furthering this ability of man to evolve provides a genuine service and is worthy of praise. Well aimed Planned Production, if properly applied, is very well able to perform this service and thus to contribute to an improved standard of living. Therein lies its sociological and economic justification.

Many of you may have noticed that in an extremely interesting way products, often of totally different origin, can harmonize surprisingly well thus doubtless forming a coherent part in the cause of civilization even if, as already mentioned, one is dealing with products of completely different origin and function. To illustrate and to make clear this coherence, and to secure for the newly developed product its place in this industrial society, is an essential part of the task of industrial design. Let us, moreover, not forget that the changes in the sociological structure have had an extremely strong influence on Product Development.

An ever growing number of people are in the position to avail themselves of and to possess the new products, not to mention the latent consumer potential of the developing countries with their education and consumer vacuum. We know that here the consumer is morally entitled to a carefully prepared product and that he has the right to expect, for the price that he pays, an optimum service which includes the field of Product Development.

If, furthermore, we bear in mind that the importance of public bodies as a potential market is steadily increasing we recognize that here, to some extent, completely new tasks for Product Development present themselves. Both smaller and larger bodies in cities and countries have, during the past decades, become increasingly greater potential consumers. In consequence this creates in the mind of the citizen and ratepayer the demand that, in spending public funds, great value is set upon an optimum Planned Production of the product purchased, to ensure the most productive possible utilization of taxes. A request, as we all know, which has not always been observed giving rise, internationally, to so many questions and problems that the 1965 Congress of International Designer Associations chose as its theme the significant title: "Design and Community."

Let us not deceive ourselves however into thinking that the present recognizable situation, which leads to the creation of products, can be finally determined. We are caught up in a development process of the most vigorous kind, founded on totally new mental dimensions. Just as for example the new mathematics largely contribute to bringing processes and concepts from the subconscious into the conscious mind of men, thereby changing the image of the traditional conception of the world, the shaping of the human surroundings is decidedly influenced by processess which lead to the development of products.

With the genuine perception of the conditions of our time comes the task to do away with any dishonest form of living, whether antiquated or "modern." Unquestionably everything which serves to promote the conscious endeavour of man to attain the ability to advance, mentally and economically, is completely justified and for this reason has its technical and economic significance.

Therefore, if it is possible, by a conscious Product Development in our present time, to form a small building brick towards a better world, all the endeavours, however divergent these may seem, are justified and to be welcomed.

Marco ZANUSO

Two Examples of Industrial Design in the Production of Consumer Goods

(Translated from Italian)

Early in 1959, our office received a request for a design for a new type of kitchen-chair.

It was felt that the parts giving support to the body — the chair-back and the seat — could be made of laminated or compression-moulded plastics, and so the concept of a chair in a contemporary style was formulated in the initial stages of the design. The concept was the two plane surfaces mentioned, which could be made from plastic, together with an as yet undefined structural form for the joints and the supports.

A decision had been deferred so as not to limit the scope of the design to the extent that the solution would be a necessity rather than a choice. Limitations of this sort, defined and complied with right from the start, would undoubtedly have led to the conventional ideas which seem to be a constant difficulty in the development of a design for a chair. An example of this difficulty is the connection which has to be made between the body-supporting surfaces and whatever type of framework is chosen; this is the familiar confrontation between the linear and the two-dimensional.

The treatment of other practical details presented still more difficulty. It is worth-while considering one in particular which, in the case under review, led us to a completely new choice. We know that the edge of a plane surface can be somewhat fragile; it is liable to be bent, deformed or frayed. In the case under consideration, if the surfaces were made of plywood or laminated plastic the risk of splintering would necessitate some form of protection. We therefore considered providing the edges with a metal beading.

It will be clear that, at this stage, the problem of reconciling the two different geometrical forms was becoming better defined. Or rather, the contrast between the two systems, the surface and the line, was brought into relief — almost literally — by this metal beading and made us look for a new method of structural continuity.

In other words, the employment of the protective beading, in a design context, would probably mean continuing it over some or all of the length of the four legs of the chair.

It was at this stage that the attraction of investigating the possibilities of a completely integrated structure became evident. It would be an interesting course to pursue because we would be working on a theme which had never previously been studied in chair design.

The problem of connections between surfaces is of frequent occurrence in architecture, as exemplified in the method of convergence between roof surfaces and pillars.

Previously, in 1958 our office had been concerned with the scheme for an industrial complex at Sao Paolo, in Brazil. In this context, the possibility of using a design with a continuous outline for the connection between the two elements just mentioned had been considered. However, difficulties were presented by the need to simplify the mounting of the canopies on the columns; a simple solution was vital because of the large number of these elements.

This experience had strengthened our intention to extend research in a field where analysis was easier if conducted on a wide, unlimited basis.

The extension of the design possibilities, due to following a wider approach, and the intention to pursue the research to the extent of experimenting with the development of form from general physical principles, led to the decision to abandon the conventional professional approach that had been intended and to follow a more liberal policy of research.

The study of the chair had reached the point at which the edges and legs had been proposed as integrated components. The material for this sort of treatment was sheet metal, and so, extending the idea to the general structure of the whole chair, sheet metal became the material for the entire operation. Sheet metal is readily formed to the most suitable shape for dealing with the loads imposed upon it, and taking as a model the stress-bearing bodywork of the motor-car would provide us with first-class information.

In the initial application of these principles, a chair model of hand shaped sheet metal was used. The chair back and seat were formed from a single sheet of suitable thickness, with the seat part recessed at each of its four corners. The legs, tapered and ribbed to suit the design of the corner cut-outs, were welded on at these positions.

This model was, so to speak, the schematic or diagrammatic stage of all our reasoning, and it was, of course, subject to a large number of modifications both of static and of functional nature. However, despite its defects, it was a first tangible object; a definite starting point of a design approach, and a foundation for a long process of development. The connections between the legs and the seat were found to be inadequate for the higher stresses and so, in accordance with the principle we had adopted, the surface areas of the tops of the legs, were increased so that they became roughly funnel-shaped (fig. 4 to 10, p. 106 to 108)

The laws of physics and mechanics are laws of nature. It is not worth-while mentioning all the applications, in the vegetable and animal kingdoms, of the fundamental principle which we followed. However, we should mention at least one, which serves as an excellent example: in the leaves of many tropical plants, the development of the surface of the stem is like an open U-section, similar to that proposed for the legs of our chair.

To continue, then. The joint between the leg and the seat was made up of two parts, one being the leg of the original form welded direct to the seat, and the other, arranged around the first part, being a funnel-shaped gusset plate. The presence of this plate ensured the rigidity of the joint, and at the same time the seat was reinforced underneath by a sheet of metal, forming a secondary member, so as to make a box structure terminating halfway up to the chair back. From this position upwards, the sheet metal of the back was again of single construction.

All these modifications, integrated in a more exact design for the form of the chair, were reproduced in drawings showing every detail and numerous sections. The drawing then allowed us to specify the form and dimensions of several details. This opened the way to the reverse process, checking by means of models.

A wooden die was made of all the parts of the chair, and, by vacuum forming, an example of each was obtained which was suitable for our purpose, both in impact-resisting polystyrene and then in Araldite.

The plastic models indicated quite clearly that the sheet metal element underneath the seat should be designed as a unit with the four joints into which the legs were fitted, a proposal which derives quite naturally from the techniques of forming plastic materials.

The making of these models brought us once again to a stage where we carried out a large number of checks, this time mainly concerned with manufacture and shape. We now went a stage further by transferring our experiments from plastic to sheet metal. The first experiments with this material showed immediately that it was necessary to break down the one-piece reinforcing unit which conformed to our concept of a homogeneous element consisting of the four leg-joints and the supporting element below the seat.

Some 40 examples of an experimental chair were made by hand, and the experience accumulated in producing every one of them provided a running criticism of the method of assembly and, frequently, of the design details. All this development work had now occupied a year since the design had been requested; it was 1960, and the Triennale was approaching. This first series of chairs gave us cause to hope that the development of our ideas had progressed sufficiently to be exhibited.

The outcome of this first showing to the public and the experts was encouraging, as the chair gained the Silver Medal at the 12th Triennale at Milan.

Meanwhile, another practical experiment was being prepared to enable newly developed elements to be substituted for earlier ones during the course of our design work, and the idea of making another prototype of the chair was conceived. Its entire structure would be of stainless steel; the parts coming into contact with the chair's occupant would have a one-piece covering of hide. This "saddle" would be secured to the sheet metal by metal slips.

It must be confessed that the construction of this stainless-steel prototype was difficult; this is understandable because by the very nature of the experiment, the work was done by shop-floor methods. The very characteristics of this material resulted in a further important stage in the progress of our design. The line along which the double structure terminated halfway up the chair back was shown to be a source of weakness, and the possibility did not seem at all remote that, if the chair back was subjected to a sudden stress, it might bend and distort just where the support from the sheet metal below it ceased to be effective. For this reason, the double construction was extended to the whole of the chair back; this change naturally allowed a reduction in the thickness of all the sheet metal concerned.

Painting, which in the first examples consisted of stove-enamelling, was now done with nitrocellulose finishes.

At this point, the development of the design was once more advanced sufficiently for us to consider it opportune to construct another experimental series, more numerous than before and much more clearly specified. About a hundred chairs were subjected to the severe test of practical use; they had various types of trim.

Almost two years of testing, within the general framework of a continuous theoretical and practical investigation, allowed us to sum up the latest variations conclusively before establishing a basis for production and the preparation of the necessary dies.

The general form of the chair was modified by a different inclination of the seat/back unit with respect to the legs. To improve the static conditions of the seat by the exertion, at mid-point, of one force against another, we made a support by forming a concavity in the surface of the bottom shell.

In our office, production became our concern now that things were moving towards a final result.

Considering the large amount of research, it was natural that, in the examination of the production and commercial aspects, the attributes of the product were intended to be those applicable to general usage, and it was to this end that all our work was orientated right from the initial stages.

Before beginning work on the dies for the pressing and blanking of the parts, other improvements were introduced, namely a proportionate reduction of the length of the legs and of the height of the complete back.

Regular production started in 1964. The chair, in its present form, is composed of only a few elements, all made from the same material and by the same processes — two shell pieces constituting the seat; the four legs; and the four connections. The parts are all joined by spot welding, except for the leg connections, which are made by autogenous welding. The only parts forming an exception to this type of material and techniques are four rubber ends fitted into the legs at the points of contact with the floor.

With the attainment of the fundamental objective of a design — series production — the development of the idea and putting it into practice ought apparently to be at an end. In reality, the procedure followed cannot, by its very nature, admit of a true conclusion. If the last stage of progress can be defined, it is a continuous evolution, a synthesis which is repeated by the contribution of accumulated experience and which expresses itself in constant improvement.

From the successive design phases in this project, I think it is clear that it was a question of research rather than a normal professional application in the field of industrial design. In fact, the commission for the design of a chair quickly became a mere pretext which was abandoned as soon as technical interest guided research towards the study of the behaviour of the sheet metal and the shell connection.

The people who helped us in matters of technical and technological information were the technical information associations and the specialists consulted, while the craftsmen and technicians who prepare the mass-production patterns for automobile bodywork were indispensable to us in the preparation of the models and of the experimental series, which were of course made by hand.

This experience has convinced me that, in this field of technology a research project can become vast, particularly if it involves structures embodying shell and other types of construction. From work of this sort, one can obtain valuable results capable of developing, very considerably, the use of sheet steel in many consumer products.

In view of the difficulty in working this material, and of the high specialisation needed in its techniques, and in its technology, it would be very useful to have easily accessible arrangements for those interested in research to have the opportunity for extensive experimental work in the technical and aesthetic fields.

I am sure that well-directed work would have the greatest success both as regards production and sales, always bearing in mind the vastness of the field of application for these materials; a field still to be explored in the sector of furniture design and of prefabrication.

Ilmari TAPIOVAARA

The Function of Industrial Design in the Light of Increased Production

Almost all congresses dealing with industrial design, in which I have participated, have been characterized by one common feature: design has been approached like virgin soil — newly discovered, cleared and occupied, full of vitality, wild, progressive and promising. There has been no doubt of its existence. On the contrary — who could doubt land-clearing work? One could perhaps be doubtful about how the settler will face the obstacles — is the soil fertile, will the frost be damaging and how will relations between neighbours develop. One does not expect refined cultivation methods from a settler. In the same sense, the designer is not yet burdened with many theoretical research results. At present, he confines himself to basic creation work, pioneering in a new field in the belief that future development will bring with it more refined and effective "cultivation methods." The cultural image is expected to take shape with the pressure of progress. Design has, of course, existed since the beginning of time, but only since the turn of last century, has it become consciously observed. Some twenty years later, important theoretical discussions about design were first opened. From the present decade one expects, besides a strong boom in industrial design, an accurate definition of the concept itself. The clarification of design-philosophy is also required. Instinct and the simple knowledge possessed by the settler are no longer sufficient.

The object of this paper is to report on the present position of industrial design and its future prospects and the development of consumer goods production. In this development, a standard has already been reached where the national aspects are only a part of the problem, a standard that involves many new social, economic and technical aspects, and from which the progress can be expected to explode. Industrial design is a tool and reflector of this development.

It is just this standard or level of development that I would like to inspect with you and attempt to prognosticate its trend. Even though we are today all very "steel-minded", I'll extend my observations to cover other known raw materials.

I confess that I am an inseparable friend of steel as well as wood. In my own sphere of experience, I consider them as basic raw materials for industrial design. My relationship to them is similar to that of my young daughter to certain surroundings. When dreaming or thinking about two or more things, the first one is always a horse and the second the Beatles. After that are many empty meters of film before the following subjects come into focus.

Every designer has his own subjective fancy for certain raw materials and the solutions reached in his work are often dictated by these fancies. The majority of designers have a common fancy for steel, which has strongly encouraged widespread technical development of this product. As a contrasting example, I would mention wood technique, which has aroused interest mainly in countries with an abundance of woods. Consequently, technical progress in wood techniques is rather slow.

Hand-tool — Machine-tool

In the early years of this century, decorators and designers planned utility articles mainly for manual production. The present era of quantity consumer goods has relegated the hand-tools to museums or small workshops. Socially, technically and commercially, the machine-tool has created a new situation and greatly expanded design possibilities in general.

Let us view the situation prevailing in Europe during the last century. If we compare the present situation with that, we can see more clearly the trend in design. The designers' utility goods of that time were to be made mainly by hand-tools. In many cases he himself was a handicraftsman. A careful examination of his articles is similar to a study of handwriting. They reveal not only his handicraft skills, but also the advancement of the tools and their influence upon the shape of the article and also the living and educational standards of that period. Consumer goods were ordered and made exclusively for the customer.

Here I would like to tell you about Fridell, my Austrian teacher at the Helsinki Design Institute. According to his theory, Creco's vertical lines were due to his gout and the curved lines of rococo furniture were the consequence of the application of exotic wood-species and a type of chisel plane developed for their handling. He favoured the idea of playing Sherlock Holmes in the field of wood-carving, his specialty. He claimed that a 300 year old wooden altar cabinet in his home-town had been done by a one-handed and even a left-handed man. It was discovered that a wood-carver who, for some reason or another was without a right arm, was living around that time. This gentlemen could very well have been the maker of that cabinet. Yes, my respected teacher was in his theories always protected by a safe time margin!

Then — during the era of handicrafts — there were enough affluent people ordering specialized services, providing satisfactory earnings for a great many craftsmen and decorators. The majority of middle-class people could not afford to purchase more than the essential consumer goods because of the low standard of living. At that time the bulk of the national income was divided between a fairly small group. All artists reflected through their products the "green" state of the society of that time and the immature state of the technique and trade. But the same picture might also reflect the high standard of the skill in handicrafts.

Consumer goods take shape as the world progresses. The exchange of a hand-tool for a machine-tool is a consequence of profound social, economic and technical alterations. Industrial design has played a certain part in this development through the transition period and during later times. The natural influence of a hand-tool on the shape of an article has moved or is moving over to a machine-tool, the possibilities and qualifications of which a designer should know as well as the former artist knew his hand-tools.

The machine has created for the designer quite new contour possibilities. A machine should not be used for copying handicrafts but to explore the new unlimited world of forms which is open to it. A grotesque example of the machine's misuse is the rococo furniture produced in a plastics factory by a moulding method, the ice cold "flaming" fireplaces electrically lighted and the romantic atmosphere of an oil lamp with the oil light replaced by an authentic-appearing electric bulb. And how do you like a thick board material resembling marble in both appearance and application, or plastic "which looks more like leather than the leather itself." Imitation is a question of sense of style or education, but plagiarizing, with which it is sometimes confused, is a question of morality and criminality. Over a fairly long period in the early part of this century, when the inhabitants of the territory began to demand more and more quality consumer goods, the hand-tool gradually gave way to machines.

The road to progress has been paved with the transitional states of improved hand-tools and simple machines, the economic and reorganization of human labour power, the vulcanian liberation of technical progress combined with a more liberal economic way of thinking, the impulses of some smaller conflicts, and the dearly-paid-for World War I, and many many other aspects affecting development. It is only through great abstinence that the consumer has reached his present authoritative position. He is now in a key position to influence future progress.

A new trade — The designers

The development that took place simultaneously in all these fields created a new trade — designer-planned products for industrial production. The former "decorators" based their occupations on handicraft. Designers are representatives of the public, particularly in the consumer goods field. The fact is that the consumer can be in need of new products which the machine and the factory can produce and the merchants market, bu t no one knows exactly what. That is the designer's responsibility. To be able to find this "what", he must place himself spiritually near the consumer, try to understand his psyche, requirements and desires. When designing exclusively for the benefit of a factory, the artist represents the technical and economical requirements of production while if he feels himself a representative of the consumers, he takes the social responsibility of developing the requirements of hundreds and even thousands of people. By this attitude toward the consumer, he will be valuable to both the consumer and the factory. The designer's position is thus somewhere between the factory and the consumer.

Superficially thinking, this might sound like just "a way of saying," but actually it is not so. Let's take an example. If a writer sets about creating an artistically high standard "best-seller" commissioned by the publisher and a marketing man and tied up by their instructions, the result will very likely be a failure. But if he works independently on the basis of his own insight and feelings, without any compromises, he might succeed in creating a great story and perhaps also a best-seller of interest to the general public. And yet in both cases the physical situation is the same: the distance to the public and the publisher, the same typewriter, place, time, etc. Without their own thoughts and freedom of expression, what would the creations of Bach, Chopin, Chaplin, Mies van der Rohe, Charles Eames and many others have been. At least not art! And they are still best-sellers.

Division of Work

Let us have a look at the interests of each of the main parties in this process. From the marketing viewpoint, a consumer product is an object that should be sold in quantity. The aim is very clear — large scale sales. Yet marketing is anxious to get new and different products as often as possible.

The manufacturer, again, should develop sensible goods, which will be of interest to the marketing body. The price, quality and qualifications should be well-balanced and competitive with corresponding products. The factory aims at mass production and long-term models.

The designer is the main developer of consumer goods, his duty being to find out or to scent the requirements of the consumer and to design the products he desires. The pattern trend is the same as with the producer — large series and long-term models. To make something attractive to a great number of consumers is a sign of his success. The larger the consumer circle for a product, the better the chances to improve the quality, perhaps reducing the price, thus boosting distribution. In the designer's work, the co-ordination of consumers' requirements, economy and the gratification given by the product in correct relationship, forms the dial of the scale. To create articles for his requirements a designer should be interested in the total sphere of life of the consumer, both as an individual and as a community. A designer who lacks the sympathy for the public, is not a good designer.

Briefly and with some levity it can be said that the trade aims at millions in money, the factory at millions of production units and the designer at millions of souls. In the same way one could call this interest a circle, in which the designer smells and tastes the hunger, the producer makes the product and the marketing man serves it at a reasonable price to those who have the appetite.

I considered it necessary to point out the relationship between producer — designer — merchant, because the activity of all of them depends upon the capacity of the machinery. Regarding machines as quite natural tools of today, it would be unnecessary to waste your time, if it were not because the relationship between the designer and the machines seems to be a big problem. A designer always tends to underestimate the importance of a machine for new solutions, possibilities and variety. A designer is rather conservative regarding tools, like the producer and marketing man regarding the models: both prefer to choose from alternatives of new models the most familiar and the customary way of doing it "because it has been done before." One reason for the designers' caution might be his limited knowledge of machines. Customary one-sidedness is not sufficient in his work: it calls for many alternatives and an option of choice to create something new.

I must confess that certain situations between the manufacturer, merchant and designer seem a bit comical to me after it has been decided in quite mutual understanding simply that no large "revolution" in the collection of models will be made: the idea of new models must not deviate much from the old. Which means that an old and experienced model will be "touched up" and polished a bit.

The marketing man and the designer should attempt to attain a certain conventionality. Dissatisfaction with existing products causes constructive thinking, which in turn, produces improved products. The absence of bias, characteristic of an experimenter, should be made a custom of life. On top of that, a portion of world reformer spirit to add spice. If there is even one person with these qualifications among the leaders of the factory, his qualifications should be used to enrich the functions of the others.

But let's revert to the consumer product. Close co-operation among the main fields — design, production and marketing — is necessary. To this team can be added other members such as scientists, colour experts, tool experts, model makers or even, perhaps, a group of housewives, depending upon the nature of the task. It is natural for the designer, who is most responsible for the final product, to act as team captain and to hurl the developmental ball to each team member in turn who returns it always to the captain. Team-work, although proven useful in the development of consumer products, is not the only way of development. However, in the future, I expect that the most difficult and complicated production problems will be solved through team-work. Ideally then, each architect and designer will master a particular phase in his line. The increasing quantities in serial production make it necessary to divide responsibility, which results in more impersonal solutions. In the future, this division of responsibility will result in the elimination of the so-called "star" designers and the use of the more professional designers with good routine and high educational standards. The present era of "star" designers will evidently be finished with the now living designers. They will be replaced by team groups of specialized men with a designer as captain, better up to the requirements of progress, the members of which will be selected for each task separately. What will be the consequences of these future. changes? Smiles or tears?

What are the Costs Involved in Design?

There is no doubt that the general standard of consumer products' design will go up, but being anonymous products they will not have the character of those designed by a private artist. While the quality in general is improving, the costs of design are also increasing. The costs attributed to one noted designer can hardly be seen in the price while a team involves a new basis for compensation which can readily be seen in the price.

Design costs should not be so frightening as they generally seem to be. The main reason for this fright is evidently the suspense while awaiting the result. In more advanced industrial circles the designing of models is nowadays considered an investment, but in some cases necessary model expenses are being reduced by the utilization of second-class designers and sometimes even the development costs are evaded by stealing models The school of though which is today gaining a foothold in industrial design is that a certain goal for a new consumer product should be set and every effort made to attain it. A well-known German car was made this way and the famous spirit-stove can probably also be put in the same category. They were designed to cope with local requirements by means of far-sighted development. In marketing, the originating country's share is rather small.

My opinion is, that by working systematically, a universal consumer product can be planned. As an example from my own field, I am convinced that an all-purpose chair acceptable to the international market can be designed. Planning for such a chair would take some 12-18 months and the costs would be about $40-50,000. Distribution could be about 1/2-1 million chairs a year, bringing in an annual income of some $15-30 million. Such a chair could be in demand all over the world for 5-10 years. Even though the amount estimated for the development of such a model sounds quite high, it would not mean much in the total construction expense nor the final price for an item produced on such a large scale.

Models for Consumer Goods

Sufficiently great "planning costs" were surely caused by two research projects in the USA, one of which concerned "idea hunting" for the plastics industry and the other for the furniture industry. In both cases, the process was carried out through product analysis and marketing research up to the final production, purposely without the aid of a designer. As a result of this research, in the plastics industry only 13 of 1100 models and in the furniture industry 10 out of 120 models remained on the market. I know nothing about later developments, but I presume that these industries have reverted to the use of professional designers. Success is obviously bigger and costs better controlled when using designers. This has at least straightened out the trend of design policy to follow.

I can still mention a few ways of making models. Next to the method explained above are the "dayflies" of consumer goods. In good music, literature, theatre and the art of dancing and even in architecture, we know a respectable and high class — in its own way — sphere, folk art. Between good art and good folk art, there is the large group of crude singing, best sellers or so-called "dayflies." A typical example today is the "pop-world" of rock and roll music, but this money-hankering spirit has honked on to all forms of art and also to the applied arts. Among designers of consumer goods can also sometimes be found a similar eager money hunter who is not concerned with duration of his services or the interests of the consumer.

Another energetic group — small travelling manufacturers — collect foreign models, thus avoiding difficult design problems and risks. Some factories using this method might succeed in adding new features and, on this basis, offering something quite new. Cold hearted plagiarizers again utilize directly the creations of other manufacturers or private designers and their property.

Some kind of a new consumer product can thus be made by using a calculated best-seller-dayfly-pop technique, of assembling irresponsibly many elements appealing to the weakest points of consumers. Motifs are secured by "borrowing" one part here and one there, or quite simply, stealing. Also from the consumer or otherwise from outside the designing stage, spontaneous topics sometimes emerge which go mostly into the hands of professional designers for further development.

In most cases, however, a plan for a new product is a result of co-operation between the producer and designer. Whatever the product will be, the designer has to act like a radio-sounder with thousands of channels to receive impulses of requirements from all sides in order to arrange them in correct relation to each other in praxis. A good product — if such is made — is rather a synthesis than a result of compromises, a personal development rather than the mongrel of public opinion polls, and it is, above all, a product developed from the visual angle of the consumer, not of the producer.

Conclusion

From the thoughts explained above the following conclusions can be drawn.

A good consumer product is linked with experience, fulfills the present day requirements and possesses vital elements for future development.

A competent manufacturer masters the policy of industrial design from a wide visual angle, plans the programme years in advance, investing in planning and experimental activities.

A good marketing director should create a long-range price policy to determine the speed with which a new product can be launched. If there is no spontaneous demand for a product — he must create it. He should entrust the designing tasks to specialists. Public opinion polls and similar functions deal mainly with the present — not with the future. A good technical leader develops his system to satisfactorily meet the requirements of large consumer circles. He must not take advantage of the interests of the consumer to keep his production up, a pattern of thinkingwhich will also bestserve the progress of his factory.

A good designer is the consumer's representative even though his name is on the manufacturer's payroll. Without idealism and social alertness, he will have few chances of clearing long-range designing tasks. Composers, authors and designers have mutual similarities.

Just as the composition is not written by the orchestra, so a good factory does not try to design, but to produce functional and quality consumer goods.

A design-team group, well conscious of its task, forgets personal and formal orders of precedence. The team is free from social bias — and expresses through its work some reformer's dissatisfaction, developing the instinct of choosing the more unconventional of two alternatives.

A consumer cannot be expected to formulate shape or technical execution of an idea which is being born, but he can be and is unmerciful and unyielding in his criticism after its birth. And the continuous growth of his power of choice is guaranteed by the speed of progress, diminishing distances, rise in living standards and increasing free time. The average consumer previously demanded little, but in more recent years he has become a powerful force and is fully aware of this newfound power. His new and varying requirements must be met with responsibility.

The early art of handicrafts has developed into industrial design, accessible to the wide consumer circles and art characteristic of today. It finally reaches Mr. and Mrs. Smith in the form of consumer goods.

Günther HEBBEL

Problems of Design in the Production of Stainless Steel Consumer Goods

(Translated from German)

One of the largest manufacturers of stainless steel in Europe, realized that, particularly in the case of consumer goods made by small firms, there was a disquieting gap between workmanlike processing and good industrial design.

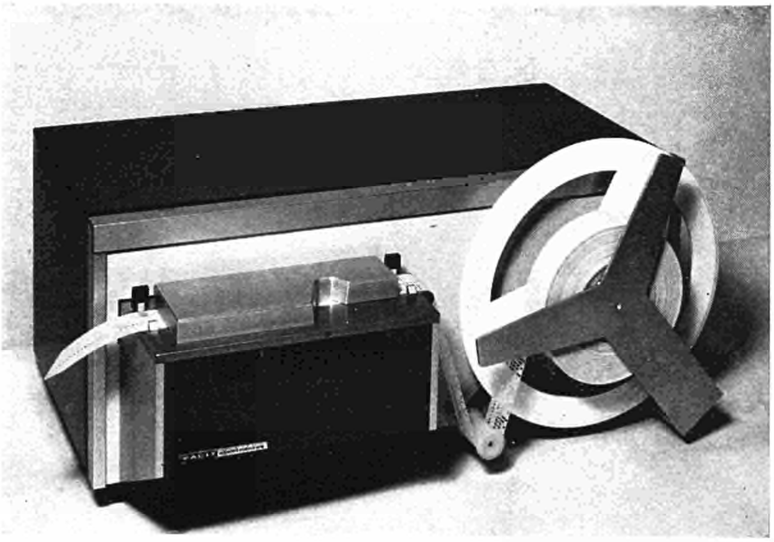
Cutlery in shapes taken over from the china industry and gift articles of sheet metal were and still are common place, and in order both to give the manufacturing customers a better idea of the technically correct use of stainless steels and of the forms to which the material is best suited, so as to enhance the competitive value of their goods, a team of architects, engineers and designers was formed to give the customer free technical advice in the solution of his problems. In addition to this team, a comprehensively equipped technical centre was established where the preliminary technical work involved in ensuring economic production of consumer goods could be carried out.

This novel type of co-operation between supplier and customer has already achieved considerable success in widely differing spheres of consumer goods production. To give only one example of the developments which were the result of fine teamwork, we would mention a set of door fittings (fig. 11, p. 108), which obtained the much sought-after qualification "Good Industrial Design" at the Hannover Fair. The work carried out on this article extended through all stages of industrial design, included market analysis, and the assessment of present trends and resulted in a series of constructional innovations and a more economic method of production which in turn ensured financial success for the manufacturing firm. This is only one of a large number of similar cases.

This is, as far as I am aware, the first time that a scheme of this type aiming at the improvement of industrial products has been undertaken by a basic industry in quite this form. The firm I am working for has of course, in this way involved itself in considerable extra work and responsibility, but the close connexion thus established between the works and smaller manufacturing firms in particular, who tend to shy away from the designers helps these firms to overcome their timidity in this respect; opening the door to more pleasing and efficient production. The readiness of fabricators to make use of this service is demonstrated by the fact that at the moment our team is working on a wide range of projects including the development of a stainless steel acoustic ceiling, lampstands and light fixtures, ashtrays, fittings for ships and cases for clocks.

All these products, like so many others in our time, make use of a material with meaningful application — stainless steel.

List of illustrations



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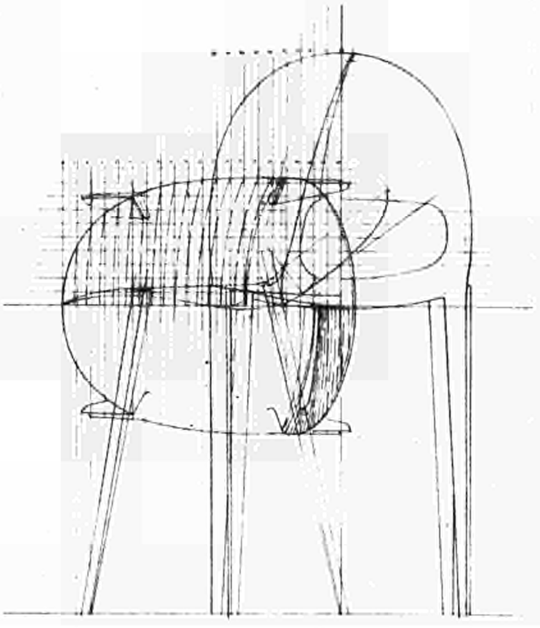

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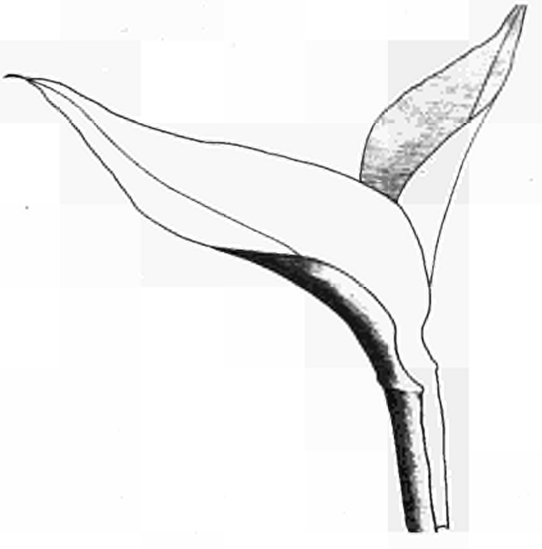

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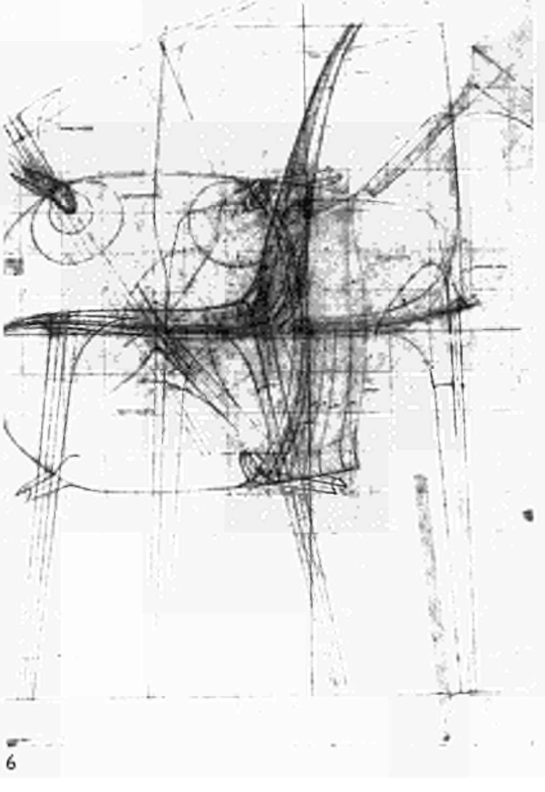

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Nuccio BERTONE

Industrial Design Applied to Car Bodies

(Translated from Italian)

This Congress is, I am sure, well acquainted with the part played by industrial design in modern industry and so I do not propose to dwell on general considerations. This paper is concerned with its applications in the motorcar industry, with particular reference to car bodies.

It will be appropriate first to review the conception and evolution of a new design before it is put into production, with only brief references to mechanical principles which combine with good body design to provide the best possible end product.

This is a subject I have been pursuing with dedication since my early days in my father's works, not only as a profession presenting many problems, but also because the work gives me so much pleasure.

I therefore hope you will excuse my harking back to my own experience in describing the birth and practical development of my ideal car body.

How is a new idea first conceived?

Careful preparation is essential, and in the first instance, close co-operation is necessary between those concerned with preparatory design and those occupied with its practical development. Ignoring special purpose designs such as competition and racing cars or research models, dream cars, and prestige versions for motor shows or publicity purposes which bear no relation to the rigid limitations affecting industrial design, let us consider the more complex problem of cars designed for mass production.

Design research is first initiated by the car manufacturer's top level Management, bearing in mind that design study, development, (instructive as these are in providing technical data for the incorporation of engineering advances in standard cars), production and sale of a given model, which we will call "ZX," must be achieved within three years to maintain or expand their business. Consideration must be given to the figures of cars sold, production costs, capital investment involved, and numbers of cars sold by competitors. All these factors must be constantly in the minds of those concerned, from the chairman, through the ranks of the departmental executives down to the lowliest operative, throughout this three-year period. Their constant preoccupation must be to justify their ideas at the press preview, and to the general public at the next motor show.

It is first necessary to establish the class of car to be presented, whether large, medium, small, or utility, and its engine capacity. This class definition is of fundamental importance, since it is impossible to adapt a given body design to different classes of vehicle. For example, it would be a gross error to seek to adapt a successful small car design to a large one and *vice versa*. Similarly, it is impossible to apply a successful utility design to a medium-size car, nor can compromises be made.

The importance of these factors must be clearly understood by the management, and after careful consideration of the various recommendations made by the research department, a decision must be made according to their judgement on the information provided. Such decisions are often best guided by the company's tradition.

There should be continuous contact and discussion between all departments concerned, piloted and coordinated by a product planning committee. Nothing should be omitted during this phase, when all concerned make their maximum contribution to the improvement of the end product. From the mechanical aspect, the engineers will make various proposals as to transmission for the same engine power, wheel base, track width, type of suspension, and will seek to establish agreement with the sales organisations as to the general performance to be offered. The weight of the car, speed, acceleration, fuel consumption and cruising range, are other factors to be considered, the economists stating what the production cost should be, and the accountants a possible selling price. All must prepare documented and itemized studies which are subjected to careful examination at joint meetings.

You may think that all this is irrelevant, but these are very important factors which the stylist must take into account, and the degree of his success is directly related to adherence to such basic principles. Nothing can be left to chance, and the board of directors are much concerned as to the final design form, and this inevitably creates some uncertainty, since it may be very difficult to reconcile contesting requirements.

Anxious moments may follow, not so much regarding the ultimate objective, as to the loss of basic programme time involved.

The strength of Management lies in the balanced judgment so essential to launching a new product. The large number of technicians concerned may form opposing groups, each supporting a specific styling theme, but this is a logical demonstration of determination and personality. Divergences of opinion also occur between the old and the young. It is the responsibility of Management, with the support of the Product Planning Committee, to reconcile such differences and to obtain general acceptance of their decisions by the weight of their authority and standing.

At this point, the basic idea of the car emerges, and form and body style must be conceived in line with definite objectives.

For a more realistic appreciation of the processes involved, I now propose to give you a practical example of the stylist's task, to demonstrate the guiding principles to be followed and the consequent demands on his creative ability.

Let us assume that the design study is concerned with a four-door car of medium power to be produced for a wide market. This type of vehicle is chosen for two sets of reasons, first because it represents a European objective which accords with the aims of this Congress, moreover, the average vehicle is that which European manufacturers consider the most suitable to meet Common Market requirements, and their present and future production programmes are based on such considerations. Increasing annual revenues, with consequent improvements in highway networks, including mountain passes and the ever increasing need for greater and speedier trade exchanges, all serve to stimulate manufacturers. Reduced production costs resulting in lower selling prices, together with greater safety assured by modern technology permit ownership of a better quality car. Such a car model encourages investment of large capital sums on plant and equipment for mass production. In this connection, it is interesting to note that present tendencies are not limited to providing specific production equipment, but to providing entirely new works specially designed for modern mass-production methods.

The model to be designed must be well conceived and, as I mentioned a moment ago, prospects of success depend as much on body design as on mechanical features. It would be true to say that manufacturers are today much more concerned with body design, that is, style and comfort for driver and passengers, than with other factors, for making an immediate appeal to the customer. Considering the degree of efficiency attained in the general development of technical service and the results achieved by experiments and tests and by their competitors, the manufacturers see no particular difficulty regarding normal mechanical performance. According to them, it is now quite normal for an engine of 16-1800 c.c. to develop 80-100 h.p., and for suspensions to be fully adequate in all conditions, with the car fully loaded, on wet, straight, winding and mountain roads, but if the body styling does not catch on, sales prospects would be adversely affected.

The manufacturer must then resort to other devices such as, more elaborate mechanical equipment where possible, better performance, or try to attract the customer by offering lower prices. This latter course is a very dangerous one from the Company's financial point of view. The problem is therefore one of good body design and finish. Having considered all these points, the stylist is psychologically prepared to review the general and specific objectives to be achieved as put to him by the Product Planning Committee.

General Objectives

For good external and internal style, the model "ZX" must be designed

(a) to meet the commonly accepted requirements as regards driver and passenger comfort and luggage space;

(b) to stimulate commercial interest as follows:

1. *Dimensions.* It must have the appearance of a large car and be both elegant and responsive. The car must obviously have a spacious interior and embody a degree of luxury commensurate with its price.

2. *Performance.* Styling should convey an impression of good effortless acceleration designed for sustained high cruising speeds. It should also reflect an air of importance and power rather than one of frivolity.

3. *Distinctive Features.* It should show a marked departure from the range of vehicles currently in production and from those of competitors, especially when compared with cars of lower engine capacity. There is invariably a contemporary style, and it is essential to aim at an appearance of quality and distinction presented by the best known existing models. The frontal appearance in particular should continue the manufacturers' tradition, since this identifies its individual character. In this connection, the Chairman of an important car-manufacturing firm told me:

   "Design me an absolutely new and original car — leave the front as before, perhaps a little more elegant, but make it more startling, more distinctive, anything you like, only it must be recognizable a mile away as one of ours. Our Company has a reputation for quality, and our customers would be disappointed if they felt they had bought a new car that looked cheaper than its predecessor on account of its inferior appearance."

4. *Smoothness and noiselessness*: The car should give visual promise of smooth, silent running and driving comfort. Body form should reduce wind noise to a minimum, even at high speeds, and at the same time

give the impression of effortless air-penetration capacity. It should suggest swift motion even when the car is standing at rest.

5. *Comfort.* Styling must emphasize motoring comfort. The interior must be generously spacious, luxurious, and graceful.

   The upholstery and internal trim of doors, panels, facia and dashboard, door posts, and roof lining should be tasteful and of the highest quality. Seats must be soft and have a well-tailored appearance.

6. *Compliance with International Regulations.* Every country has its own motoring and traffic regulations regarding the safety of passengers and third parties. The model considered must therefore conform to the prevailing rules of every country where it is to be sold, which means practically the whole world. Some of these present difficult problems to the stylist regarding headlights, sidelights, position and illumination of number plates and their dimensions. Internal and external projections which can cause injuries in the event of an accident must be avoided. Two separate international commissions are concerned with resolving safety problems, with the ultimate aim of standardization, but their studies will still take a long time. It is to be hoped that the experts will soon be able to offer some design proposals which will reduce the number of lives now lost in accidents.

   Regulations are becoming increasingly strict in all countries, both in regard to new vehicles put on the road and to granting driving licences to new motorists. Transport authorities today have to give, either full or partial approval for every single accessory and subsequently for the complete new vehicle. Strict compliance with the spirit of such legislation speeds up the procedure and makes it easier for the manufacturer to go ahead with production. In border-line cases, difficulties may be encountered which require design modifications. It will thus be seen that serious limitations are imposed on the stylist in his search for new designs.

7. *Prestige.* Car styling must provide assurance of a high degree of success considered as a symbol of social position and good taste. It must confer on its owner an air of dignity, maturity and distinction.

8. *Viability of Design.* The new model must be of advanced design to permit continued production for 4-5 years from its introduction and 7-8 years from its conception. During that period, it must withstand attack by competitors and thus maintain a high and, above all, constant level of production.

Specific Styling Objectives

— *Specific External Styling Objective* should certainly include adaptability of the body design to the production of two models of different performance with only minor modifications and minimum cost difference. In the case of one model with a 1600-1800 c.c. engine and another of 1800-2000 c.c. for a different class of customer, it is essential to achieve substantial differentiation with the smallest possible number of variations.

— The design should be such as to allow of adapting most of its basic features to the production of models of the same family of alternative models of the same "family" (usually of the saloon type, which is the most widely sold). It should also lend itself to "face lifting" by modification in order to avoid any possible decline in sales, either by minor changes, or major force and aft alterations, retaining the main body structure between windscreen and rear window, which is the most complex and costly to produce.

In such a case, there may be two saloon models, one of 1600-1800 c.c. and another of 1800-2000 c.c., which must continue to be supplied with their own distinctive variations. Engine power may be increased to give the impression of a new model when aided by improvements in mechanical equipment to meet market variations.

Management will be the more certain of the succes of a "face-lifting" operation when there are large numbers of the basic model on the road. Second-hand cars will thus continue to fetch a good price, which is a positive indication of the merits of a particular model or make.

— Considering the characteristics of the previous model with those of a competitor's car of the same class, it may be desired to increase the speed by 10%

The stylist will then be required to meet this objective by appropriate modifications.

The curvature and inclination of the windscreen and the curvature of the side window sections are important for overcoming wind-resistance; small improvements inspired by wind-tunnel tests with 1 : 5 scale models can produce outstanding results, but such improvements must also take account of the economic aspect. For example, the window glass is sold by the makers in flat sheets in sizes of multiples of 30 mm, and this factor must be exploited to the limit. By bevelling and rounding off the upper part of the windscreen, which in the flat has the form of an isosceles trapezium with a curved base, it is possible to use smaller size glass and thereby save 10%.

— Visibility from inside the new model must be better than from its predecessor, to enable the driver in the evergrowing traffic volume, to judge accurately the position of his car in relation to other vehicles in order to drive safely, with a clear horizontal view of road signs and traffic signals at high speeds, and an unimpeded lateral and upper view when driving in cities.

Passengers, too, should be able to enjoy the scenic view, which is possible if a careful study is made of front and rear. Personally, I am strongly in favour of very high side windows, by substantial alteration to the traditional ratio of the total height of the side panel and that of the window. In addition, the windows should be generously curved to provide optimum internal and external dimensions.

— Accessories should be in line with body styling so far as possible, and in this connection I would draw attention to the need for moderation in the use of chromium trim. Italian body styles have been adopted in many cases in recent years; among other things, this is due to the absence or limitation of chromium plating. I always think that a body form should be pleasing for its crisp, clean-cut design and beauty derived from overall balance and its treatment. Every emphasis strikes a false note and should be avoided or treated with a light touch. While I have had the personal approval of leading manufacturers on this point, the same people have advised me to bear in mind the customers' prevalent desire for luxury. This creates problems for the pure stylist, who must provide the effect required without disturbing the general neatness of design.

— As regards *internal trim and accessories*, care must be taken to avoid projections which may cause injury to passengers. Unfortunately, no great progress has been made in this respect, but engineers and stylists are seriously working to resolve the problem, and initial results are satisfactory.

A recent solution of German origin has been generous padding of the interior and of the completely covered supporting members. Sun visors and fittings, rear view mirrors, roof lights and coat hooks were similarly treated. This could also be applied to windscreen and rear window posts, and now that provision of complete air conditioning is approaching, to ventilation channels too. Another advantage is complete sound-proofing of the roof, which, in my opinion, will continue to be of steel sheet.

It is evident that such internal treatment is very successful from the design and production points of view, and, with adequate equipment, the cost is reasonable. This shows that industrial design resolves functional, constructional and economic problems at the same time.

Technical and Economic Objectives

Although it cannot be considered a determinant factor, another objective which must be taken into account by the stylist is concerned with car body construction as regards material, line production and operation cycle.

At this point we must consider the use of steel, especially the thin sheet now used by most car manufacturers. A question arises as to the future use of plastic material, and it may be useful to review the situation. Many attempts made in the past and recently have produced excellent results in small or limited series production, especially from the point of view of cost, provided the chassis is of adequate strength, since the plastic body contributes nothing to structural stability, since it is "supported" and not in itself "supporting". The chassis of sport cars for example, often made of tubular steel, can stand up all bending and torsional stresses in service.

Technological studies have up to now dealt separately with frame and body, and in my opinion, this is the reason why not much progress has been made with plastics in car-body construction.

The champions of plastics point out that bodies made of this material are lighter. This is true, but consider all the items that make up the total weight of a car all other characteristics being equal and you will see that a lighter body makes little difference. My own view is that the unitary steel body structure which contributes to overall stability offers great advantages by way of strength and rigidity, ease of construction, better utilization of space, economic cost and simple maintenance. Let us first consider the steel roof which some manufacturers have replaced with plastic material on the assumption that the steel structure below ensures sufficient strength. This may be true, but a steel roof welded to the body structure offers better protection in the event of overturning than a bolted plastic body. For safety, I would recommend a robust transverse steel structure as in competition cars, for which it is obligatory. For panels of movable parts too, such as bonnet, boot cover, doors, etc., where weight saving is essential in high performance cars, I would prefer aluminium-alloy sheet.

There is no doubt: the future still belongs to steel. The fact that the American automobile industry is returning to a separate chassis and body as in the 1930's, is not to be taken as a step towards the use of plastics. The real reason for this is concerned with the production cycle. The big American companies produce components, including car bodies, in separate highly specialized plants at a speed requiring special organization. No less important is the need for ease and rapid changes, or "face-lifting", to meet ever-increasing demands for modernity without altering the mechanical features.

Plastics are nevertheless proving most valuable to the motorcar industry, in the form of epoxa resins for models and mouldings required in limited series, because of their resistance to deformation and easy processing. Many car controls are being successfully made of this material today, because they are easy to reproduce. For internal accessories too, such as instrument panel trim etc., plastics are widely used, since they can also be chromium-plated.

As I mentioned earlier, the stylist must always bear in mind the manufacturing process and the need for line assembly. Single items must be easily spot-welded and joints concealed on assembly. Items which may be considered ornamental should also serve as an aesthetic solution to a constructional problem. For these items, there is no better material than stainless steel which, because of its pleasing appearance and long life, has completed displaced copper and zinc alloys. An additional advantage is that a damaged item can be repaired and mirror-polished without dismantling.

Other details to be considered by the stylist are ease of painting by obviating recesses and projections to facilitate the various polishing operations which are carried out with mechanical tools. The same applies to sharp edges from which the paint is liable to be removed down to the bare metal in the polishing process.

Having assembled all the data and other factors concerning physical and aesthetic requirements, we can now start designing our model "ZX" car.

This is where styling begins. The styling centre where this work is done is a proper studio located in a single building detached from the works, with appropriate sections arranged for easy communication, where highly qualified teams work together in great secrecy. Only the "members of general management and their immediate staff" are admitted, but product planning managers can authorize entry of production staff for consultation.

The styling centre comprises product line studios, scale-model fabricating shops, a shop equipped with wood- and plastic-working machinery for making full-size models and a sheet-metal workshop to which an upholstery and paint shop is attached.

Work begins on the basis of a simple outline drawing prepared by the technical department, specifying wheel base, track width, position of steering wheel and foot pedals, size of wheels, and their corresponding movements, as well as an outline of the mechanical features (engine, suspensions, rear axle, etc.). From these details a drawing is made of an ideal body, indicating the overall dimensions and interior space requirements to be observed. There can be no doubt about these factors, since ample records are kept of the most successful cars produced by competitors and, of course, those by the stylists' own company, proved by practical tests, driver convenience, interior comfort, visibility, etc. Having established these points, a full-size mock-up in wood with some metal parts is produced without considering external lines, but provided with doors and seats. This represents the body interior, seating, entry and exit, steering wheel and driving seat positions, controls and instruments. This mock-up is examined and discussed with the management at a meeting until general agreement is reached.

The stylist is by then already at work on the basis of the data approved so far, with indications of the limits to be observed, regulations, prescribed dimensions, etc. He begins drawing the first basic lines of the new model, guided by his long experience, talent and inspiration. He has the style of model "ZX" in his head. He must, however, be allowed some measure of freedom, without which a new conception would be impossible to achieve. A stylist always has new shapes and forms in his mind, often ideas which are impracticable, but adaptable to development of new styles by careful dimensional changes. In general, I prefer to develop a model in progressive stages; this is why I ask my assistants to start out from traditional types representing the contemporary form and to work by degrees towards more advanced styles, whose more daring features would be discarded as they would most probably exceed the prescribed limits. The team is also inspired by more exacting requirements to create a new design within practicable limits.

The first rough sketches executed in this way, usually to a scale 1:10, show various views and silhouettes, and about a dozen are then further developed for selection. Selection is not easy and may cause embarrassment, since all of the drawings, representing variations of the styling theme, are most interesting; the boldest are the most attractive and are checked regarding dimensions. The first selection is limited to three or four of the designs submitted, and of these colour renderings are executed again to a scale of 1:10, with great fidelity as to finish, highlights, chromium plating, etc., to give an exact picture of the vehicle. At this juncture, the basic idea is further developed and improved upon. It is now easier to make a final selection, and everyone being satisfied, the model makers set to work with enthusiasm. A 1:5 scale model is quickly produced for wind-tunnel tests, and is at the same time provided with fittings such as, bumpers, trim, doorhandles, etc. As soon as the laboratory reports favourably on wind resistance, except perhaps suggesting some minor retouching, a full-size model is constructed. At the same time, other designers make sure that the doors, bonnet, and boot are easy to open, that their hinges can be suitably fitted, and that the windows can be lowered completely. The model makers construct the framework of thick plywood, coat it with epoxy resin and shape this down to the smallest design detail.

During this stage, the stylists follow the work closely, retouching and moulding with their own hands any parts considered to require modification of style. The model is then painted; for this it is important to select sober colours, since the use of bright colours may result in visual distortion. Window glass, door handles, bumpers, trim and wheels are then fitted to complete its realism. The model is thus ready for formal presentation to management, first in an enclosed shop, with the seating mock-up at hand for a final check of interior comfort dimensions in order to enable the finished car to be visualized. For judging appearance and visibility, it is most important to study effects from a sitting position.

In the meantime, the contours of the lights and the outlines of the front and rear ends are appropriately formed, after which the model is brought into the open for comparison with other models produced by the company and those of competitors. Further modifications may be necessary, and while these are being made, consideration is given to the important question of adaptability to mass-production. Provisional approval having already been given by the engineers, specialists, presswork and assembly method designers carefully study the model, breaking it down into sections most adaptable to pressing processes and assembly, to ascertain whether production can be achieved with existing plant or whether new plant is necessary. Further modifications of detail may be required, and sometimes these are quite important. The product planning section steps in cases of contesting requirements and any problems arising are dealt with promptly and efficiently. The modified model is then examined once more by all the departments concerned and finally accepted.

Subsequent stages include the taking of profile patterns, preparation of the form plan on plasticized paper, construction of a sectional master model in resin for the preparation of positive and negative moulds from which steel press moulds and assembly jigs are produced. Meanwhile, the design team prepare the detail and general drawings, in close co-operation with the production method specialists who work out operation cycles to the final stage. Now that the creative industrial design stage is complete, it is for the engineers and production process personnel to organize series production.

As we have seen, steel plays a predominant part in automobile production, and I am convinced that it will be used more and more in future for the car body framework, floors and external panels, while stainless steel is the best material for accessories. No doubt, car manufacturers will follow this course, and it is up to the steel-sheet producers to offer consistent quality.

Is the new model "ZX" going to be a success? The experience, skill and dedication of those who created it justify high expectations. It must not be forgotten, however, that the new car must be based on the sure foundations of first-class quality, a high degree of comfort, economy in use, prompt and low-cost servicing, and lastly, a reasonable price.

Louis L. LEPOIX

Industrial Design and the Future Development of Transport

(Translated from French)

Means of transport have always been of vital importance to mankind. Their progress and development are linked with improvements in the use of metals, the discovery of new alloys and the conquest of power. Their use, installation and structure are determining factors for civilization, prosperity, expansion and also national defence. It is extremely important to foresee their development, evolution and adaptation.

In 1965 we live in a transitional period; the traditional rhythms of the human race have quickened to keep pace with discoveries, civilizations and industries. The great inventions of the 19th and 20th centuries have speeded up these rhythms and their evolution may be compared with that of the speed of vehicles which was very gradual until a few years ago.

We are now living in an age where, amazed and sometimes uneasy, we see records suddenly shattered, techniques relentlessly outdated, fantastic achievements becoming an everyday occurrence and the improbable becoming fact; energy unbelievably more powerful than any previously known force is now available to man; speeds unthinkable even 10 years ago are now achieved by vehicles sent out to explore supposedly inaccessible space. The achievements are many and increasingly sensational: aircraft taking off vertically, vehicles travelling on both land and sea.

A transitional period since the future development of all these outstanding techniques holds enormous promise. A transitional period for man too: demography is also at a turning point; we all know that in the very near future populations will increase to such an extent that it is already essential to reconsider all the vital problems. This will also directly affect the development of transport since both existing and future economies are inconceivable without transport.

In this context, what part can and should be played by industrial design? Here I must give a definition of this comparatively recent discipline with which some people are still unfamiliar: "the aim of industrial design is to study the factors and attributes of a product or machine best suited to present and potential customers or users".

The designer has a complex role if this aim is to be achieved:

(a) together with the company, he must reconsider the product, analyse its possible evolution and think in terms of rationalization;

(b) he must be familiar with materials, methods of processing and utilizing them and their influence on cost prices;

(c) he must seek, select and make effective use of shapes and colour, depending on the intended purpose;

(d) he must be familiar with known and foreseeable market requirements;

(e) finally, he must be daring, think in terms of the future and follow the trends of vital social and practical requirements.

It is obvious, then, that he cannot work alone and must receive the support and enjoy the *confidence* of the technical and commercial departments of the company or organization. The designer's role is *conceptual* and his work will be more effective and profitable if the manufacturer realizes this, grants him the free hand he needs and provides the requisite technical and moral support.

In the design of means of transport over the ages, beauty has always been a major consideration: the vehicle is the external sign of power, riches and prosperity.

Opulent beauty has given us ceremonial chariots, royal galleys, carved and gilded carriages, ambassadorial ships, prestige automobiles.

Functional beauty moves us by the design of an Egyptian chariot wheel, the lines of a mast, the shafts of a gig, the curve of a hull, the power of a locomotive, the architecture of an engine, the outline of a wing.

Audacious beauty is manifest in the nervous line of a phaeton, the elegance of a sailing ship, the delicate lines of an aircraft, the daring of a bridge, the proportions of a car body, the majesty of a liner.

Its wide range of applications and its many alloys give steel a number of properties which ensure that it can always adapt itself to the increasing demands of modern technology and of the market.

It would be tedious to list all the past achievements in the field of transport which would have been impossible but for steel. Everyone is aware of its use and importance in the present age. It has enabled us to produce more functional, faster, more economic and more attractive vehicles.

Stainless steel has provided an answer to manufacturers' concern for perfection and economy. It allows safety to be coupled with a reduction in weight.

I should like briefly to stress its use in:

(a) the production of railway wagons, where valuable economies in maintenance work and power consumption have been obtained;

(b) cars and coaches, various parts of which thereby have a longer life than the vehicle itself;

(c) sea transport, where its increasing use in varied applications has provided an answer to corrosion, weight reduction and maintenance problems;

(d) the aircraft industry, where physical and thermal stresses do not permit the use of light metals.

Industrial design has contributed to the improved use of steel and its influence will become increasingly important.

The national and international market for industrial products has become a buyers' market; the problem now is not to produce but to sell. To do this:

(a) the company's products must be suited to the market: *conception*, improvement in function, quality and attractiveness of form and colour. The research into and the planning of the article or machine should enable it to outclass rival products by ensuring that it complies with known and foreseeable market demands;

(b) products must be on sale at the lowest possible price, which implies a technical *conception* of the product: design, choice of materials and economy in means of production will help to ensure manufacture at the lowest cost price if functional design allows, or at the most balanced price if justified by the element of novelty.

From this dual point of view various surveys have been carried out and the figures 1 to 6, p. 131 and 132, show the various achievements in recent years.

The industrial designer is constantly preoccupied with the analysis of future market problems: a long time elapses between the complex study of a land, sea or air vehicle and its coming into service.

No less long is the duration of a product, or rather the length of time for which it must be manufactured to ensure that the capital invested is amortized and then shows a profit.

The designer, who must look at things from the purchaser's or user's point of view, must therefore extrapolate the indices of human, psychological and social problems to cover the average production period, which somewhat modifies the perspective of the product.

Finally, the period spent on estimating, preparation, design and final development of vehicles suited to the demand of the world of tomorrow will necessarily be long, but this is unavoidable if the manufacturer and the country are not to run the risk of being outstripped by more dynamic rivals.

Viewed from these aspects, how can one foresee an extension in the use of steel and its adaptation to future objectives?

By analysing:

(a) the development of vehicles in future years;

(b) the necessary, probable and possible evolution of means of transport.

Let me say at once that future transport developments will be marked by an overlapping of techniques. The often rigid demarcation between industries will give way to continual consultation.

In the near future, steel production will obviously increase in consequence of the growing and more demanding population. Even more emphasis however will be laid on safety, reduction in weight, strength and profitability in the field of transport. Greater use will therefore be made of stainless steel:

(1) in motor cars, where stainless steel has not yet been used for parts operating under high stress;

(2) in railway vehicles; on the basis of the conclusive experience of the past 30 years when a reduction in weight of 8 % to 10 % has been achieved, the use of stainless steel will be extended to goods wagons,

and passenger vehicles will be improved. The underground railway, with its more frequent halts, will also utilize the advantages of that alloy;

(3) in inland waterway and sea-going vessels, where corrosion and reduction in weight are of great importance. This problem is particularly vital for the construction of the new hydrofoil boats, likely to expand enormously.

(4) in the aircraft industry, where safety and speed problems require a metal which is strong in thin section.

On the whole there is likely to be a considerable increase in the number of private and commercial road vehicles, and mention should be made of one "young" vehicle which has a large potential market in the near future: the caravan. There will be a smaller increase in railway stock and sea-going vessels, both of which are on the verge of a technical revolution.

The aircraft and space industry is outside normal commercial trends. This industry's research should be watched since it will undoubtedly affect the vehicle of tomorrow.

In the rather more distant future, some important trends can already be foreseen; they are of direct concern to the steel industry.

What are the various aspects as seen by a designer?

The bicycle was an important factor in the development of land vehicles. The cycle industry played a leading part at the start of the century. But this vehicle's design has stood still for 50 years, and it follows that the industry is foundering. The novelty of the scooter, a vehicle not designed by traditional cycle manufacturers, gave it new blood. But it is obvious that the cycle, with or without motor, can never regain its past position, although this does not necessarily mean that its market is small — far from it. However, to make progress, this industry would have to reconsider the wishes of the market, make innovations and acknowledge marketing requirements. Nothing is more certain than that the traditional bicycle is defunct.

The lines of *motor vehicles* will be modified to comply with the laws of aerodynamics, all the more essential since production models will become faster and faster. 100 m.p.h., a speed only reached by sports cars barely 10 years ago, is now common. The limit of 125 m.p.h. will be exceeded within five years. The body structure will therefore be reinforced.

Roadholding problems will call for efficient suspension system using electronics. Until a few years ago, the engine was the centre of interest (before the war it occupied up to two thirds of the vehicle), but tomorrow's car will be designed around the human body: more utilizable, reliable and practical passenger space.

The traditional piston engine will continue to predominate for many years to come; it has the benefit of long experience and in present production models does not provide anything like the power which might logically be expected of it. The space occupied by the engine in the vehicle however will be reduced and passenger space increased.

The turbine engine is in its infancy for ground vehicles. Although the turbine itself is small, the transmission is at present too bulky. When this engine is further developed, it will play a vital role in the transport industry.

Numerous research projects are in progress on the rotary engine and it will probably be developed to meet certain uses.

The present general purpose motor vehicle is likely to become more specialized: family car, business car, public service vehicle. For the latter uses, the vehicle will become more compact and quieter; possibly urban cars and taxis will be electrically driven, one answer to the problem of air pollution in cities.

Recent discoveries give cause for some speculation on electric traction, a field in which the greatest surprises may be expected.

The *commercial vehicle* will be more radically changed: its design will be modified very rapidly. The slow development observed so far will be speeded up and new ideas will be adopted. Useless wasted space will be greatly reduced. As in the car, the space occupied by the engine will become smaller and smaller.

The commercial vehicle will be the first to benefit from the rotary and turbine engines, and this will change its structure, its use and consequently its design. The general purpose lorry of today will become more specialized: public works, long distance haulage, short haul. Compactness, reduction in weight, power and safety will be this industry's key words.

In a report written five years ago to a firm I was advising, I suggested an idea for a delivery lorry, a special feature of which was the short cab with a floor little higher than that of a car. The driver would not have to hoist his own weight almost 5 feet above the ground and would be spared the fatigue caused by doing this many times a day. This lorry was exhibited for the first time at the 1965 International Motor Show in Frankfurt. This is obviously only a minor advance, but designers are already working on several ideas for the future.

Logically, the design of the *agricultural tractor* should not merely be modified but radically changed. Based on a short-chassis lorry, it has developed by meeting requirements as and when they arose. Mechanical, hydraulic and pneumatic jacks have been grafted on to the basic unit of engine and gear-box. The driver has been forgotten: the space reserved for him is cramped, obstructed by levers, difficult of access and unprotected from the weather. This conception will have to be reversed: new designs must be centred on the user and the vehicle must be civilized.

The railway suffers from its age and the fact that it was established more than 100 years ago. The constant fear of demolishing the existing infrastructure and discarding present techniques has been the major obstacle to its development. Outstanding opportunities have been lost because of this. Rapid connections are required today and will be needed even more in the future. Average speeds on the railway will of course increase, but its structure will prevent the achievement of speeds much beyond the limit of 125 m.p.h. even at the cost of expensive improvements. At this speed, the railway will be able to cope with the problems of goods traffic and with passenger connections on secondary routes, but not compete with the services offered by internal air lines.

Technically it would be feasible for trains of the future to attain speeds of between 250 and 375 m.p.h., with average speeds of about 220 m.p.h. This would make rail travel practically as fast as today's air travel, ensure greater safety, provide more regular services and have a vital influence on a country's economy. Naturally new ideas will have to be studied and a new infrastructure is required. It would seem that funds might reasonably be appropriated for this type of public transport. It should cost little more to plan and put into effect than is already spent on research for internal air lines, the purchase of aircraft and the construction and development of air-fields. It would be possible to co-ordinate the layout of such railway lines with the motorways.

In 1953 I prepared designs for a monorail train which are now 12 years old. My firm has continued these studies, taking technical developments into account, and we have found some solutions to this problem.

There will be a notable extension of the *underground railway*. Its advantages in urban transport are well known. It will also concentrate on speed with safety. It will be extended to cater for goods traffic in order to relieve the growing congestion of surface traffic. Its design will then have to be reconsidered since construction costs can be appreciably reduced while the work of construction is facilitated. These new developments will have some influence on passenger transport. There is likely to be an extension to the infrastructure of a dense industrial region.

Inland waterway transport will increase; its conception will develop slowly at first, but new techniques together with the greater power available will accelerate this development. An examination and analysis of the possibilities of inland waterway traffic, or even of the use of water, will lead to the increased use of such transport.

As regards *sea transport*, a distinction must be made between passenger traffic and freight traffic. For freight, the problem of speed will always be secondary to the question of tonnage and economic factors; development will be slow, and shallow submarine shipping may become of some importance.

Passenger travel by sea in a direct competition with air travel and ideas will have to be revised, the new engines utilized and use made of coming techniques such as the hydrofoil or cushioncraft if the demands of tomorrow's market are to be met. Speed, greatly increased, together with the traditional comfort and safety of this type of transport, will not only open up satisfactory horizons, but will disclose new possibilities to be exploited.

The aircraft industry will continue its rapid development. The increased speed of aircraft will continue to reduce the distances between nations and continents. It is the ideal answer for long distance routes. Linked with efficient land transport facilities, air lines will provide mankind with a remarkable tool. The problems of take-off and landing will be the dominant concern in the near future.

The helicopter, increasing in speed, appears to be taking on a private role: special journeys and missions, business trips. The experience gained with it is invaluable for the design of the new vertical take-off and landing aircraft. These will be able to provide ultra high speed transport over short distances.

New techniques based on experience gained in the interplanetary field are likely to bring surprises in this industry, which never ceases to astound us. Rocket travel will be possible. But the rocket will have many military duties to perform, and this type of travel will be reserved for the more distant future. Interplanetary flights will provide the technical and political "suspense" over the next few years. It is already clear that they will succeed.

Finally, I should like to mention *pipeline transport*. We are all familiar with the use of the pipeline, that simple technique for transporting liquid or gas products. I firmly believe that its use will be greatly extended. Steel will be the first to profit from this. The pipeline will reduce the amount of surface transport in cities, and will carry the most varied products to commercial centres and factories.

I have not mentioned military transport in this paper for the following reason: developments in vehicles have always been put to military use. Very often in recent years the Army has achieved great progress. For some time now they have taken the initiative in designing and experimenting with numerous vehicles. Their efforts will be of vital importance for progress in the field of transport. Let us hope that the military will continue this task. If only its activities were limited to that, we should all be satisfied.

George WILLIAMS

Industrial Design and Rail Transport

It is unnecessary, for obvious reasons, for me to dwell upon the connection between steel and the railways. From the advent of the "Iron Horse", steel has been the basis of their existence troughout the world and may well remain so for as long as railways serve as a means of transport.

The modernization of British Rail has altered the forms in which steel is required; in some, but not in all cases, there has been a corresponding alteration in the qualities required.

The willingness of our engineering and research departments to try out new steels and steel in new shapes is sufficient evidence that they are aware that modernization, whether it be an aspect of the current Modernization Plan or of the constant need to aim at efficiency at the lowest overall cost, demands the best long term solution which the steel industry can offer to any particular problem.

British Rail and the steel industry are, therefore, developing side by side, and just as the pattern of demand is changing, so is the pattern of supply.

But this paper is concerned with design; or, more properly, with that aspect of the many creative processes now known internationally as industrial design. It is more particularly concerned with the recent application of this relatively new science to an industry which, in England, is rapidly shedding itself of a grand but cumbersome Victorian mantle.

This transition from "ancient to modern" is interesting in that the changes are perhaps the more startling and effective; but the transition also brings its problems, both in terms of personalities and techniques, and for this reason the results so far achieved in England should perhaps be judged as a new basis for future design thinking, rather than an example of a permanent design standard likely to meet the demands of critical analysis.

In England, as elsewhere, there have been many attempts in industry to get away from the dominant influences of the past and, since the turn of the century, to achieve a modern idiom on its own merits — first, art nouveau, then modern, mainly derived from the Scandinavian.

Apart from the odd transgression into decorative adventure, such major influences tended to bye-pass the railways until the introduction, six or seven years ago, of the professional industrial designer, who, keeping in step with technical advances, is now bringing nearer the emergence of a new, purer strain in design in rail transport.

The facts of life for an exporting nation dictate that the aesthetics of its products are vital. The case is no different for a public service whose success will largely depend upon its attitude to its users. The railway engineer, with a fine nineteenth century design tradition behind him, but with new, more urgent, specialized problems, began to see the gap between his engineering achievements and public acceptance of design standards progessively increasing.

It has been said many times, and in many countries, that design is a top management responsibility, and that if someone — if possible at Board level — will take a close personal interest in good design and its obvious commercial value, then the fortunes of the Company or undertaking are likely to prosper. There are many examples in recent British industrial history that prove that "Good design is good business" and our own experience is beginning to show that the same maxim applies with equal force to a public undertaking.

Until the advent of the British Railways Modernization Plan there were few opportunities to introduce good industrial design. The Plan was the great opportunity and a few enthusiasts at the highest level of management were determined that the mass of new equipment for use or to be seen by the public should be developed to a good standard of design.

The development and implementation of an overall design policy can, of course, only be related to the requirements of the organization for which it is meant, and the policy must adapt itself to the structure of the organization and to its services or products.

The railways have never before had to consider, so closely or so deeply, the objectives which are essential to their commercial survival. Design is important in so far as it contributes to achievement of these ends. It is not a question of spending hard-earned revenue in the aimless pursuit of some generous ideal of beauty.

By 1963, four years after it had been set up, the influence of the Panel and the scope of its work had very considerably expanded. It was no longer always necessary to seek work, and today there is little possibility of any locomotive, passenger coach or ship being built without embodying the influence of the industrial designer and architect.

There is one most satisfying aspect of the Panel's influence. After a comparatively short time there are already indications that the industrial designer is becoming more and more involved in engineering problems, and that the engineer is becoming more and more appreciative of appearance and amenity. We are beginning to merge together all the extremes on a large scale in order to produce good design in its true sense, as co-ordination of all the interests involved, where *the product as a whole* is the only thing of importance, not the personalities involved.

It is not always easy, in the older industries, where two distinct kinds of designers are involved, for the engineer to accept the fact that engagement in the appearance and amenity aspects of any engineering product implies involvement in its engineering design or that because these particular aspects influence the degree of acceptance and the use of the product, they are therefore as much part of the functional design as the mechanical and material specifications.

The contribution of the industrial designer must be made in the language and to the conventions of engineering. He must comply with standard engineering drawing practice in order to interpret and reconstruct the engineer's drawings as a basis for evolving recommendations and checking these, and in order to make their proposals readily unterstood. No changes of shape or arrangement can be recommended until their implications in respect of mechanisms and structures have been examined. This would be impossible without an understanding of engineering by the industrial designer and without his being allowed to use that understanding to check his proposals.

This involvement in engineering design is inescapable, and only through it can the industrial designer's contribution be realistic and properly realized. Where appearance and amenity design is considered as something apart from engineering design, only unsatisfactory and uneconomic results can be expected.

As the work of the Design Panel expanded, it was necessary to strengthen its executive team. It is now called the Industrial Design Department and this has firmly become a part of the railway management structure. The initial research needed for each design problem is carried out by this department in order to prepare a satisfactory design brief. Where the project is a large and important one, such as a new train, or staff uniforms, a working party will be set up consisting of the appropriate senior railway officers in the engineering, operating and other divisions, members of my own staff and the consultant designers, to examine and develop the scope of the brief. Meetings of the working party are continued until the design work is well under way.

The normal stages of designing are used, in association with other interested departments specification, general planning, sketch designs, working drawings, scale models and, where necessary, as in the case of a new train, an actual full size model of a carriage complete in every detail.

The establishment of an industrial design management team within our organization, which is very large and diverse, has influenced thinking throughout the whole structure. Once its value was recognized, support and enthusiasm for what we were doing came from the most unexpected sources, and the demands for our services increase year by year.

It is not necessary to build up a large team to create this kind of impact. I have a comparatively small staff, and although we do some actual design work, our principal role is to know the "design market", that is, to know which consultant designer is best fitted for a particular need, to prepare the brief or instructions for the designer and to act as a link between him and the railway staff with whom he must work.

Consultant designers — furniture designers, architects, textile designers, graphic designers, typographical designers and industrial designers — are very carefully selected in relation to their qualifications and experience of similar work for other industries and they are thus often able to bring to the railways knowledge and experience not available before.

The executive team is entrusted not only to give advice on methods of designing but has assumed responsibility for design policy, far deeper than had been envisaged when it was first set up. It has become, in effect, a design department in the true sense, and we have established standards for the design (in the industrial design sense) of new locomotives, trains, ships and station equipment and the basic elements of a new "corporate image" for the railways. We have also designed a complete new range of staff uniforms. The encounter is, in fact, already less one-sided.

It is perhaps of interest to examine one or two facets of the department's work in some detail.

One of the first tasks entrusted to it was to work with the engineers on the body form of the first series of new diesel and electric locomotives to be built under the Modernization Plan. Two major factors materially affected this collaboration. Firstly, the engineering work, in terms of structure and the distribution of major components was well under way to completion. Secondly, the overall dimensions (and therefore the basic visual characteristics) of the body forms were severely restricted by British Rail's loading gauge and operating requirements which had their origin in the days when the railways were invented by Britain.

There was little opportunity for the expression of new and existing ideas. The introduction, for instance, of the "wrap-round" front such as is now becoming common elsewhere in the world, was incompatible with the severe dimensional restrictions. The results, although tidy and workmanlike, gave rise to criticism: — Why are we so far behind the continent? Where is the drama of the steam locomotive?

In retrospect, it can be claimed that the industrial designer, avoiding the dangers of superficial styling and even though he was working against the clock, at his best made a major advance, creating that thoroughbred look in the appearance of a new generation of locomotives which had seemed to be the prerogative of the steam locomotive. He was able, also, to introduce successfully the often maligned science of ergonomics in the design of driving controls.

As we gained experience of the design problem and in working with the engineers, the situation gradually improved and a consistent style in locomotive body form emerged. The latest thoughts on the frontal design of locomotives in England are now concerned with improving the aerodynamic treatment of the more powerful types. Speeds in excess of 100 mph are going to become more frequent in England, and although the frontal resistance is only a small proportion of the total air and rolling resistance of a complete train, wind tunnel tests have shown that a saving of as much as 150 hp is possible. This has, of course, already been realized on the continent where there are reduced dimensional restrictions, and in Japan.

The design and layout of passenger carriages is, in England, similarly restricted by the limitations of a transport system planned before the turn of the century. Overall length and width of a carriage are controlled to a fraction of an inch and this presents a severe challenge to the designer who, in the face of competition from road and air transport, must create a high standard of amenity design.

Our first attempts in carriage design were restricted to the detailed improvement of standard types already in series production, through minor amendments to seating comfort, lighting and decorative treatment. These were only a first step towards a more fundamental study of aesthetic and user requirements.

The first opportunity to carry out major design studies arose when it was decided to produce high speed multiple unit trains for the Pullman services, and an up-to-date commuter service in Scotland. The work of the industrial designer in these fields proved greatly successful and paved the way for their introduction at a much earlier stage in studies for the passenger trains of the future. Whilst the Industrial Design department is still committed to normal work priorities, we are also at liberty to undertake important experimental projects.

One was a series of new standard carriages intended for future standard locomotive-hauled trains. After 18 months of critical analysis of every feature of existing carriage design, both in England and on the Continent, an assessment of the design and commercial needs were assembled in order to create the basic design brief.

We did not limit the extent of our research, calling in lighting, anthropometric and medical experts, as well as the consultant designer selected. When the design brief was completed, sketch designs, detailed working drawings, models and a series of full size realistic models, complete in every detail, were made.

However experienced a designer, the element of doubt about his intentions when presented only in drawing form must frequently exist. There is also the difficulty of conveying ideas to others in a convincing way. These problems are, of course, vitally important if tooling is involved or if a long period of standardization and use is required, as with railway equipment.

In the case of the experimental train, given the project number XP64, therefore, the industrial designers themselves made full size mock-ups of first and second-class compartments, first and second-class open saloons, toilet and entrance vestibule. They were familiar with the motor industry and had been in the habit of making full detailed mock-ups of their own designs for many years and thus the techniques were understood and the facilities available.

When the mock-ups had been completed, they were presented to the Railways Board and the senior officers of those departments concerned. The designs were approved and the drawings and mock-ups were sent to the works who engineered and constructed the actual train.

Authority was given for eight experimental carriages to be built in order to test public reaction. These carriages have now been in service for a year and a very careful analysis has been made in order that the main successful features can be incorporated in future stock.

The British Railways Board have employed consultants to evaluate the new design features of XP64. Although this study was commissioned as a market research exercise, it has developed into a study of human behaviour in relation to design.

When the consultants completed their work, we had a study of a kind that has not been carried out in England to date. It represents an advance in the use of scientific disciplines in major passenger reaction in defining the degree of comfort and in describing the total effect of a new environment on a passenger. The scientific disciplines used included psychology, ergonomics, operational research, etc., and in using these academic disciplines, new methods were devised by the consultants towards an economical, practical application of techniques which are usually employed in a laboratory situation only.

We found a great advance was to be made in the evaluation of seating of passengers. The success of this experiment was possible only by the consultants and the designers working in very close collaboration. There was an immediate feed-back of information from the consultants to the designers and discussions on the practicability of modifications that the consultants suggested. It has convinced us that we must evaluate our designs in depth and extend and test our new designs through an independent evaluation. They were pleased, as we were, to find that, given the care that a designer likes to exercise if he is given a free hand, the response from the passenger is overwhelmingly in favour of his new environment.

British Rail's new ships have proved to be one of the outstanding examples of the commercial success to be found from the engagement of professional architects and designers. The economic use of available space coupled with a high standard of amenity design has proved immensely popular with the traveller, and therefore profitable; and yet through a rational approach to design and to standardization in furniture and associated equipment, it has been found possible to reduce the cost of furnishing the more recent ships by, in some cases, something like 30%.

One of the more important tasks recently entrusted to the department was the creation of an entirely new corporate identity for the Railways. Our present visual image, in terms of symbols, lettering, colour and uniforms is negative, almost Victorian and certainly out of step with our technical advance. The case for a unifying and visual scheme of the kind we have now designed is unanswerable. Far too much of the front which shows to the public — train liveries, uniforms, ill-assorted symbols, signposting and publicity material — is still an ill-thought out perpetuation of steam age railway fashion.

It has been decided that British Railways will have one modern unifying symbol, a new name-style for publicity and buildings, a new standard alphabet for station signposting and other purposes, and new standard house colours to replace the present regional liveries. It seems certain that this brand-new, all-embracing visual identity will do a powerful amount to make the psychological point of a thoroughly transformed transport system. It is an essential move towards the recreation of national pride in the railways.

The following list and the figures 7 to 9, p. 133, indicate the scope of design work currently being undertaken by the Industrial Design Department.

— Locomotive body forms and the ergonomic design of driving cabs

— New carriage design including ergonomic and anthropometric studies

— Public areas and crew quarters of all new and reconditioned British Rail ships

— Catering vehicles and station buffets and restaurants

— Road and rail freight vehicles

— Lineside equipment — crossing barriers, signal gantries, overhead electrical equipment

— Station equipment — porters' trolleys, seating, little bins, signposting

— Uniforms for station staff, train crews and road vehicle drivers, hotel and catering services, BR travel centre staff

— Graphic and typographical design, including stationery and forms

— Tableware for trains, hotel and cafeterias

— Development of the new Corporate Identity

— Exhibitions and conferences.

René POUGET

The Use of Stainless Steel for Car Body Parts

(Translated from French)

M. Lepoix' interesting paper emphasizes how important stainless steel is to the transport industries. I should like to give you some first-hand evidence of teamwork between designers and engineers in the use of stainless steel for car body parts.

Although the bright parts usually termed "chromium" are primarily intended to give cars a sleeker appearance, they are also a practical necessity. The real-life atmosphere of heated discussion so vividly evoked by Sig. Bertone shows that mass producers do not give designers a free hand. Streamlining is not always immaculate and the bright parts are useful for concealing joints or pinpointing certain areas.

No other chromium-plating can match stainless steel for corrosion-resistance combined with outstanding mechanical characteristics. French car manufacturers are therefore using it to an increasing extent despite its comparatively high price per kilo, as owing to these good characteristics lighter-weight stainless steel parts can be used than is the case with mild steel or chrome zinc alloys. The methods used must minimize scrap production, and polishing work must also be cut down as the material is rather hard to polish. 18/8 stainless steel is sometimes used, but steel with a 17 % chromium content is usually preferred.

The front of a certain car (fig. 10, p. 134) is an interesting example of the use of stainless steel. The radiator grill is made of welded sections polished prior to assembly and finished by electolytic polishing. Hardly any material is wasted with the use of steel sections, and for the same reason the bumpers are made by forming. The wheel hub-plates are pressed (apparently no good alternative can be found), the result being a hub-plate with better shock-resistance than aluminium and better corrosion-proof qualities than chromium plating.

The door-handle (fig. 11, p. 134) was originally made of zinc alloy, but it was found that stainless steel reduced the price and weight and also gave better resistance to corrosion. It took a long time to perfect, but we succeeded in producing a part of exactly the same shape as the earlier zinc handle.

We would emphasize that except for a few minor details all these parts correspond to the designer's blueprint. Let us hope that steel manufacturers will continue to improve the quality of stainless steels and that steel processing specialists will make further progress in the new forming methods. The result will be shapes approved of by the designers, while the material used will meet the most exacting engineering specifications.

List of illustrations

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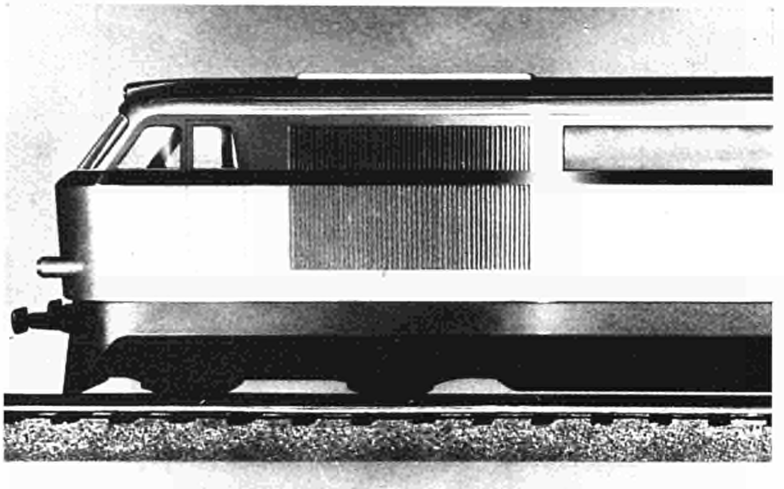

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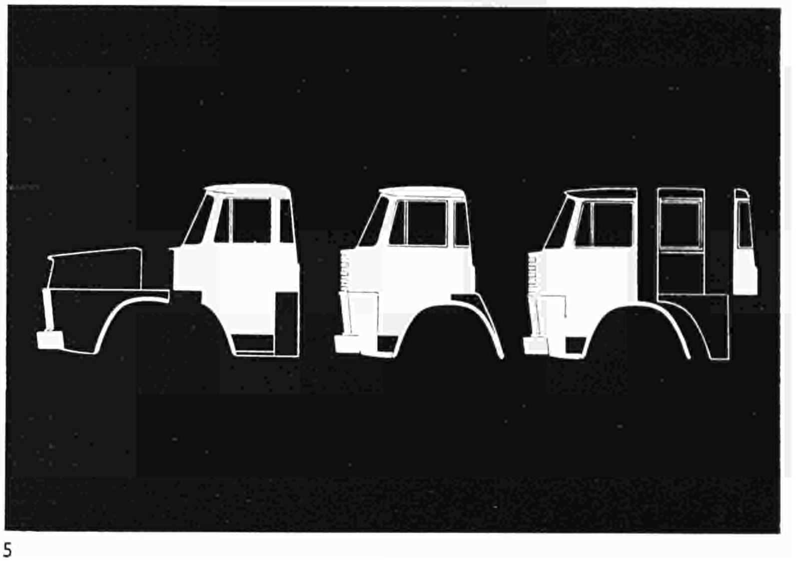

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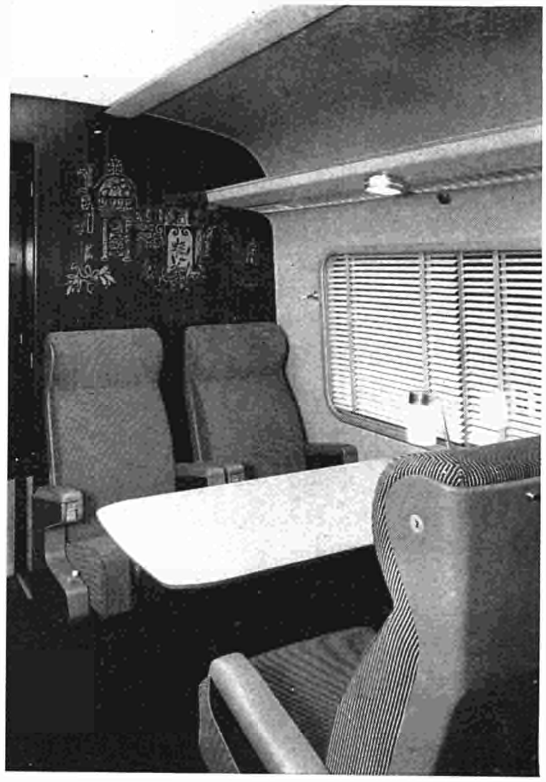

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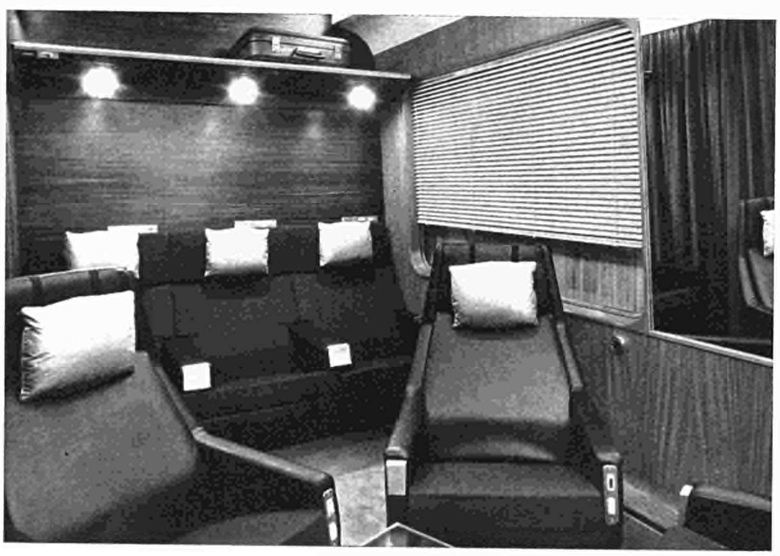

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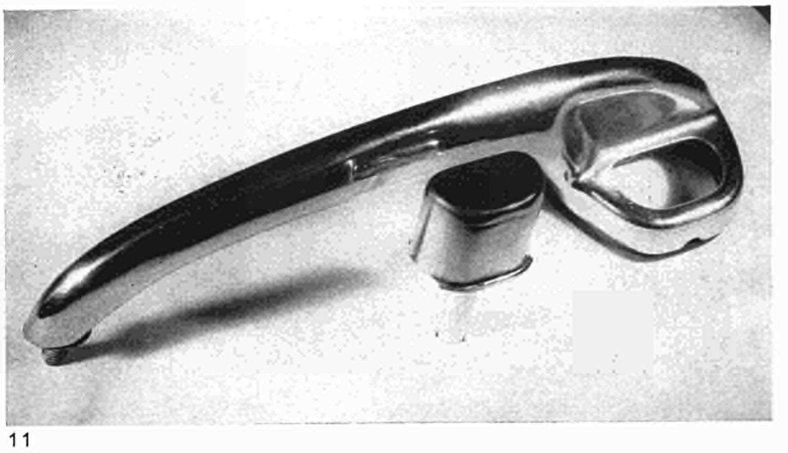

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Alan MEIKLE

Industrial Design in Prefabricated Constructional Steelwork

This paper tells the story of the use of prefabricated structural steelwork in Britains' post war schools. It covers the building programmes of local authorities and their achievements in providing schools, and other public buildings, of high quality, rapidly constructed, and in great number throughout considerable parts of Great Britain (fig. 1 to 7, p. 163 and 164).

A typical example of this type of building was the prize winning United Kingdom Primary School erected at the Twelfth Milan Triennale in 1960 in the C.L.A.S.P. System of Construction. This school was not an isolated showpiece specially designed for the purpose of winning awards, but was typical of the high standards now being achieved under Britain's school building programme. It marked the culmination of 13 years development in the application of new methods of building to urgent social problems. It also served to illustrate in a tangible way the advantages of component prefabrication in a situation far removed from its conception, and helped to spread ideas amongst other western European countries. Since then C.L.A.S.P. has been used in Western Germany, Italy and France. At home there has been continued application of the system to schools, old people's homes, fire stations, health centres and a whole range of public buildings including universities.

Much of the impetus for this development has stemmed from the work of the Nottinghamshire County Architect's Department. As a member of that Department for the last 10 years, I have been closely associated with this work.

Many other systems of prefabricated construction have been used for public building, but it is significant that the majority of all schools built since the war have had steel frames and a sizeable proportion of these have been built in complete systems using prefabricated steelwork.

To describe only the way in which steel has been used in these systems would underrate the importance this material has played in liberating a completely new way of architectural thinking, in which the use of highly flexible lightweight frames has provided an adaptable skeleton supporting a wide range of building components, most of them factory made, specifically designed for the function of the buildings in which they will be used.

A brief review of the development of prefabricated steel frame systems will show that the design process can only be considered in its social and architectural context. The last 20 years has been a time of steady and continuous development and each evolutionary step forward by one team of designers has been on the experience gained from previous group working on similar problems. The systems in general use today are the summation of much experience and the skill of the architect combined with the manufacturer's know-how.

Like most European countries after the war, England had an enormous building backlog which could not be overcome by conventional building methods alone.

in 1945 such developments in prefabrication, as there were, had been conditioned by the needs of war time bnilding and subsequently housing. Most of the work had been done by engineers who, being closely allied to factory production during the last years of the war, were in a better position to apply themselves to the problem than architects, whose normal activities had virtually ceased.

The engineers tended to regard the house and school as prefabricated units in themselves and conceived prefabrication in terms of putting together a number of basic units for entire houses or classrooms to produce multiple assemblies which were identical and inflexible. Manufacturers faced with the problem of material shortages concentrated on those with which they were familiar and had the means to fabricate. A number of houses and classroom units were produced predominantly of one material, for example — the steel house, the aluminium house, the concrete house, and the asbestos cement house. The appropriate usage for each material had not been recognized and disregard of a basic tenet of industrial design often brought the products into disrepute because of structural failure or uneconomic production.

Hertfordshire 8 ft. 3 in. System (251 cm.)

It was against this unpromising background that the Hertfordshire school building miracle occured. The story is too well known to need full repetition. A team of brilliant innovators decided that it was necessary to design a set of components — structural elements, windows, roof deck units etc. — which could be handled and assembled easily with the minimum of site labour and which would still produce a wide range of different buildings for different requirements. This was the first great achievement of prefabrication — the giving to the architect and the building owner the opportunity for real flexibility in planning, so that environmental and user requirements could be met, maintaining that freedom of choice which is lost when only large scale building units are available. Thus began prefabricated building from a kit of parts, just like the Meccano Set so beloved by English schoolboys. The idea was not original, having been foreseen as long ago as 1909 by Walter Gropius when he observed that only the standardization of *component* parts could "satisfy the public desire for a home with an individual appearance", but it was the first time that this ideal was to be translated into quantitative reality.

Whilst the other local authorities in England were using huts as temporary expedients, Hertfordshire in 1946 began the first of a whole series of schools whose basic structure was a lightweight welded steel frame. Initially it was designed in an orthodox way, e.g. stanchion sections varied for different load conditions, and each component was designed with a specific job in mind. After the first prototype it immediately became apparent that simplification and standardization of components would be essential if quantity production techniques were to be used.

Accordingly an architect was despatched to work in the factory of the steelwork manufacturer side by side with a gifted engineer, Ernest Hinchcliffe. Together architect and engineer moved forward on empirical lines, believing more in practical testing than too rigid adherence to code-of-practice methods of design. This close collaboration became a hallmark of all subsequent developments.

Very rapidly all components were standardized and only detailed once for a whole series of buildings. The number of stanchion types was reduced from sixty to three (low, medium and high). Stanchion shafts were drilled on all four faces to deal with any combination of parts, and all possible combinations of beam connections, windows, wind bracings and cladding rails were catered for.

The degree of standardization enabled the manufacturer to produce components at a time most convenient in the organization of the factory and to stockpile them against site requirements. On site the steel frame for a whole school could be eretecd in three days. The original system, designed for primary schools, was limited to single-storey construction but was developed in 1949/50 to deal with the more complex requirements of secondary schools. The various Marks of the system were in use for 17 years and in Hertfordshire alone some 180 8 ft. 3 in. (251 cm.) schools were built, representing a capital investment of $16 million.

Even by "Volkswagen" standards this was a long and worth-while production run, fully justifying the investment of architects' time and industrial resources. The use of this system terminated in 1962 when the manufacturers went out of business.

Hertfordshire 3 ft. 4 in. (10M).

Ministry of Education 3 ft. 4 in. (10M) Multi-storey

From the early fifties the more complicated planning problems associated with secondary schools led to the investigation of the possibilities of systems based on the 40 in. (10M) planning grid. The dimension "M" is the internationally accepted basis of modular co-ordination and means 4 in. in the ft. in. system and 10 cm. in the metric system. 9M thus means 36 in. or 90 cms.

Between 1949-1952 work took place in parallel on the development of a 40 in. (10M) multi-storey frame both in the Hertfordshire Office and by the Development Team at the Ministry of Education which had been recently established under the leadership of Johnson-Marshall.

The team in Hertfordshire were especially interested in modular co-ordination and the conception of an all dry lightweight system of construction with as much factory production as possible. Bruce Martin, who was prominent in this development, was anxious to experiment with thin plastic panels of constant modular width which could be used for external and internal walls. But these could not be used if columns were to remain in their normal position on the centre lines of the planning grid. Discussions took place with Lord Llewelyn Davies and John Weeks who had been working on a similar problem, and a steel frame was devised in which the structural grid was disassociated from the planning grid, having free standing columns at fairly wide centres up to 20 ft. (60M) apart. The columns were cruciform shaped, composite stanchions made from 4 in. × 4 in. angles braced by steel plates.

The prominent feature of the frame was the constant beam depth, irrespective of span, to give a level ceiling. Some variation in beam design to meet variations in loading could be accommodated by varying the flange thickness, but it was accepted that true economy in beam design could not be completely reconciled with the enormous advantages to be gained by having a constant depth.

The team working at the Ministry of Education, inspired by somewhat different ideals, were concerned to carry forward the same principles which had served well for single storey building into multi-storey construction, and to devise a new system based on as thorough an understanding of educational needs as possible.

In structural terms this meant designing a steel frame which was capable of meeting all the conditions of planning within the limitations of 3 ft. 4 in. (10M) horizontal and 2 ft. (6M) vertical heights up to a maximum of four storeys. Unlike the Hertfordshire development the structural grid remained coincident with the planning grid and the problem of accepting the column within the thickness of walls was solved by making a virtue out of necessity, for in multi-storey construction the steel frame must be protected from fire and this was comparatively easy to achieve if columns could be contained within the thickness of partitions and walls. The uniform beam depth common to both the Hertfordshire and the Ministry's developments enabled fire resisting ceilings to be attached directly to the bottom chord of the buildings.

Only the perimeter stanchions were galvanized, the interior ones being pre-treated and painted with one coat of calcium plumbate.

At Wokingham (the first school in the new system) subsidiary pieces of steel were welded to the stanchion shaft to accept the cladding components. This method of welding cleats and connections to the stanchion shaft was radically different from that used in early systems where each shaft was holed so that every connection that could possibly occur might be made. The use of universally drilled shafts increases the standardization of stanchions for production purposes but the welding of cleats in pre-determined positions permits a wider choice of material for the stanchion shaft to meet different loading conditions with a resulting economy in steel. Furthermore, there is no need to encase the stanchion except where this is required for fire protection. (Subsequent experience with C.L.A.S.P. has shown that a compromise solution is best in which the primary fixings for wind bracing and beams are welded to the shaft and subsidiary fixings for other components are made through universal drillings. Using this procedure economy in shaft production can still be obtained).

Droppers were also used for the support of cladding for windows where there were no perimeter stanchions.

Ministry of Education 3 ft. 4 in. (10M) Mark I Cold Rolled Steel Frame, Multi-Storey

The Ministry of Education Development Group, in collaboration with the Derbyshire County Architect, designed a frame of cold rolled steel sections which was used in a school at Belper in 1954. The frame was conceived as a series of independent "table tops" supported by stanchion "legs" at selected points. The stanchions did not have to line up across the building but could be offset on the perimeter, and secondary beams were connected either to stanchions or main beams. Like Wokingham they were contained within the wall thickness for fire protection. The beams could span from 90M in 8 ft. and 12 ft. high rooms to 120M and 150M in rooms 18 ft. high. Cold formed steel was widely used for window reveals, external corners, window sills etc. which proved to be rather uneconomic.

C.L.A.S.P. 40 inch (10M) Mark II Frame, Multi-Storey

In the following year the Belper school was to be of particular interest to the neighbouring county of Nottinghamshire where a new County Architect was in the process of reorganizing his Department. Having imported some new staff, three from Hertfordshire, the Architect's Department began an intensive programme of investigation and development. The story of C.L.A.S.P. has been well documented in the Ministry of Education Building Bulletin No. 19, but some of the significant facts should be recalled. Schools at that time were taking too long to build, were too expensive and were being damaged by coal mining subsidence which was not entirely prevented by extensive structural precautions. Confronted with this problem, a survey was made of existing systems of prefabrication and it was apparent that none were entirely suitable but the school at Belper suggested some possibilities. It was suitable for three storey construction; a high degree of prefabrication of the component parts allowed rapid assembly on site with the minimum of skilled labour; and although the steel frame had rigid connections, it was essentially a pinjointed frame which depended on diagonal steel wind bracing for its stability and the construction generally was light by normal standards. These last two characteristics were of particular importance because of the problems of damage to buildings which can occur with mining subsidence. Heavy traditional building is liable to crack when ground movement takes place and from discussions with specialist advisers, it became clear that if a system could be developed lighter than traditional building which could sit on the surface of the ground without deep foundations, being flexible enough to take up ground movement, then it had every chance of being a cheaper, safer answer to the problem of building on land liable to subsidence.

The firm selected to manufacture this frame did not only supply the frame to the Belper School but they had in their Technical Director a designer of proven skill whose experience in chassis design for heavy motor vehicles was to be invaluable. From the outset he appreciated that only a comprehensively designed structure would be acceptable and throughout the subsequent years of development he has remained a full member of the Development Team.

The two main problems were to reduce the cost of the Belper frame and to make it completely pin-jointed and flexible. Each range of components was critically examined and simplified wherever possible. The stanchion shaft was made 4 1/2″ × 4 1/2″ in every case. The span of secondary beams was reduced to a maximum of 80M and main beams to two types — 20M and 30M. The perimeter stanchions, being so small in section, were used to fix the horizontal cladding and thereby eliminated the special cladding steel. The horizontal wind bracing was omitted and in designing roofs and floors to produce a rigid diaphram, the same effect was achieved. Learning from the experience at Hertfordshire, it was decided to connect the roof beams direct to the stanchions at 20M and 30M centres. The same design of beam was used for floor and roofs which, although it did not produce a completely economic roof beam, brought the cost of the standard component down. Whereas the Belper frame had been almost entirely made of cold rolled sections, the first Nottinghamshire frame (as it was then called) used hot rolled sections where these were appropriate. On concluding this exercise it was apparent that the steel frame bore no relation to the Belper frame which had inspired its conception and was different in almost every important aspect. At that time it was one of the lightest steel frames ever produced and even when a three-storey building was completed it still weighed less than the average two-storey house. By saving weight it was possible to re-design the foundations in accordance with the conditions determined by ground movement. The time had now come to put the theory to test and a full size mock-up of the frame was erected for testing. The frame was distorted up to 8 in. (20 cm.) in 10 ft. (3 metres) and the helical spring wind braces returned it to normal as planned. This was greatly in excess of what could be expected in the field and was a highly satisfactory result. The Engineer, on seeing this prototype, remarked, "This is the biggest chassis I have ever worked on."

C.L.A.S.P. and Other Consortia

Meanwhile the architects had been working on the first few projects which were to use this new steel frame. It soon became apparent that the 400 tons of steel required for these Nottinghamshire projects would not be enough to obtain the full economic benefit from the manufacturing capacity available. It was not sensible to make expensive jigs and tools for a few buildings and the high skill of the development architects and engineers ought to be invested in a number of projects. There was clearly scope for further economies if the potential of the manufacturer's factory could be employed more fully. Nottinghamshire had already approached Derbyshire and Coventry with a view to possible co-operation and both had helped with the development work. All three authorities were faced with the problem of mining subsidence and thus were united in a common interest. These three authorities agreed to pool their school building programme in order to create sufficient demand. Systems of prefabricated construction had of course been used before by more than one authority but the task of co-ordinating their requirements had been left to the manufacturers. The poor manufacturer had been unable to reconcile the divergent requirements of his customers and had been unable to organize his production efficiently when they all required something that was basically the same but different in detail. These minor discrepancies in individual requirements were enough to nullify the economic advantages to be derived from quantity production. There was only one alternative — the customers themselves must co-ordinate and reconcile their varying needs by associating in a consortium, organizing their programmes and speaking with one voice to the manufacturers and suppliers. Thus began the "Consortium of Local Authorities Special Programme" now known by the word "C.L.A.S.P." from the initial letters of this title. The full development of this revolutionary approach to co-ordinated demand is a story in itself and has been well told in the Ministry of Education Building Bulletin No 19.

Before long the success of this first building consortium brought enquiries from other local authorities and within three years the Second Consortium of Local Authorities (S.C.O.L.A.) was established with similar aims. They too used a prefabricated steel frame for their system which is similar in many respects to the frames described previously.

Meanwhile the Hertfordshire County Council, where this story began, had continued with the development of their 8 ft. 3 in. (251 cm.) system and a new frame which was to replace it based on a 2 ft. 8 in. (80 cm.) structural grid. Recognizing the advantages to be gained by co-operation on the lines of C.L.A.S.P. and S.C.O.L.A., Hertfordshire have combined with Kent, Essex and the Ministry of Public Building & Works to form S.E.A.C. which is "South East Authorities Consortium." The last few years have seen the growth and establishment of these consortia and others like them, and the spreading of system prefabrication to include many other types of public buildings besides schools, which continue to form the bulk of their programmes.

Development of C.L.A.S.P. Mark IV

C.L.A.S.P. is now using a new mark of its original steel frame (Mark IV). The main factors which have conditioned this revision are as follows:

(a) C.L.A.S.P. should conform to a Government recommendation that structural grids should be based on a 3M increment.

(b) An annual programme of work in excess of 10 million pounds requiring 4,000 tons of fabricated steel components can permit a wider range of components without increasing tool costs.

(c) A need for greater planning flexibility to suit a wider range of building types.

The Mark IV frame is based on a 3 ft. (9M) grid with columns at 6 ft., 9 ft. or 12 ft. centres, roof beams at 12 ft. and floor beams at 6 ft. 6 ft. column spacing used in association with floor construction permits the use of simple post and beam construction and main beams are only necessary for planning convenience.

Floor and roof beams are now separate components. This has enabled the roof beams to incorporate a shallow pitch in the top chord to assist roof drainage. The pitch also helps to increase the structural depth at the centre of span without increasing the depth of cladding at the perimeter and is shallow enough to avoid complicating planning.

The greater planning freedom in the external wall which is necessary for some types of building has been obtained by making all cladding span vertically between horizontal cladding steel at ceiling and floor levels. The cladding steel has been provided as economically as possible and is used to perform structural functions wherever this can be done; it is however likely to increase the cost and weight of the steel frame slightly although this is offset by simpler cladding assembly and fixing. The steel frame is very efficient in terms of site erection time and this being exploited to simplify other work.

Design Trends in Steel Frames

There appear to be two main concepts emerging from the development of light steel frames. The first assumes that a large number of small columns give an inherently cheap structure and small columns can be absorbed into the walls of the building without affecting planning. Experience with C.L.A.S.P. has shown that it is comparatively easy to incorporate the vertical wind bracing, with the possible exception of four storey buildings where there are some special limitations. This arrangement does mean that if the building should need extensive internal re-planning the high incidence of columns in certain internal partitions will severely restrict alternative arrangements. However, extensive re-modelling of this nature is not common in many of the building types for which the system is used. Pin-jointed structures are proving to be very economic for simple frames and other manufacturers are now using the same principles even when subsidence movement is not a criterion of design.

The second concept is that columns and wind bracing are an unacceptable complication in the construction of walls and partitions and seeks therefore to reduce their incidence to the lowest possible level. The simplest means of achieving this is to separate the structural and planning grids so that the two never coincide, and to use fixed end beam connections. The free columns then become an embarrassment in planning and the desirability of spacing the columns as widely apart as possible makes them larger because of the increased loading. A further development along these lines is the use of a space frame which gives more freedom in the disposition of columns and this idea has been incorporated in the Nenk System of Prefabrication developed by the Ministry of Public Building & Works.

This appears to be an attractive solution and is architecturally very desirable, but the assembly of space frames is a complicated exercise if overstressing of certain components is to be avoided. The space frame is more suited to mass production techniques, and if full advantage of these can be taken, it may provide a very economical structural solution.

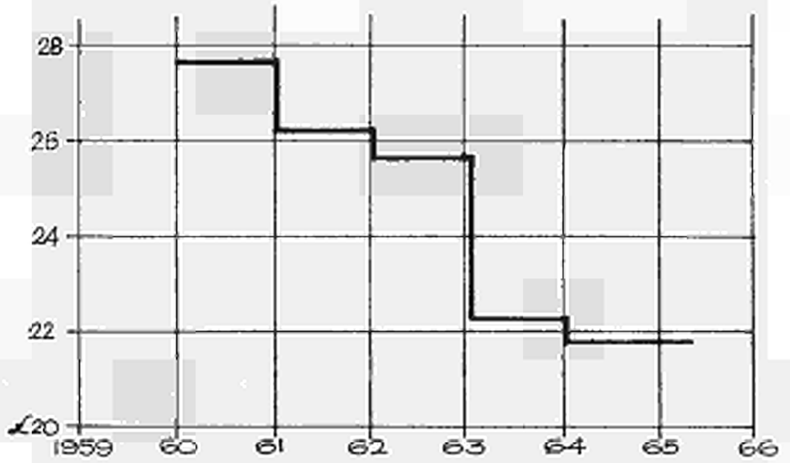
Conclusions

Need for Co-ordinated Programmes

It is essential, if the advantages of quantity production are to be enjoyed, that the building client should arrange his programmes so that continuity of manufacture is maintained. The creation of stable conditions starts with the Government or other body which provides the finance and controls its distribution year by year. The client must be prepared to think ahead for a minimum of three years and provide the architect with his projected requirements. He must also be prepared to combine with clients having similar problems to ensure the establishment of worthwhile quantities. In providing the right circumstances for success the the client has the right to see that the system of prefabrication used meets his specific requirements. Commercially sponsored systems are at a disadvantage in this respect and cannot, by their speculative nature, be completely successful in providing comprehensive systems of prefabrication capable of satisfying many different clients. Mention should be made of the Thermagard System, which has for 16 years provided a partial system of prefabrication to many local authorities who were outside the main-stream of development. A more recent system is the Anderson A.75 which occupies a similar position in the market. These two are the only steel frame based systems to have made a significant contribution outside the client sponsored systems described in this paper.

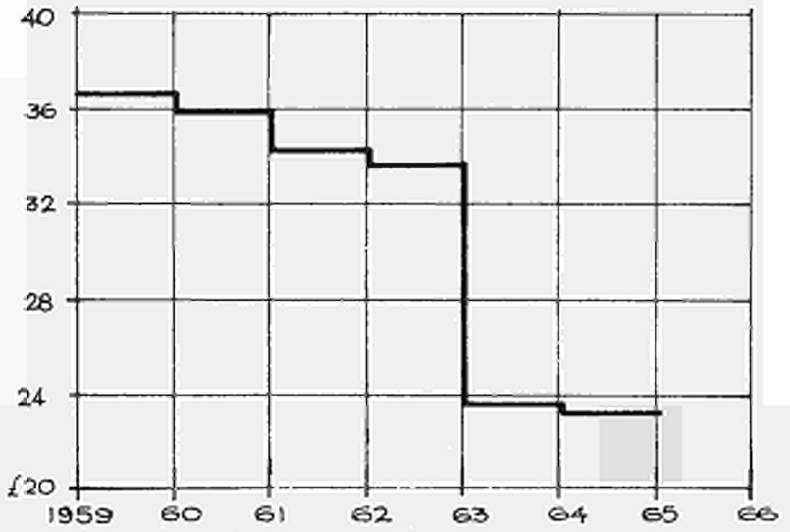
Cost

The constant process of evolutionary design and gradual development has stabilized the manufacturing cost of steel components and show how the cost of steel components for the C.L.A.S.P. system has been slowly reduced during the last eight years. The following three Graphs show the costs of stanchion and beams and the fourth Graph (on p. 143) shows the gradual reduction in steel per sq. ft. for single storey construction. The weights per sq. ft. are currently 3.3 lbs. per sq. ft. for single storey and 5 lbs. per sq. ft. for multi-storey construction. Although regard must be taken of the whole system of construction, these are very low weights by any standard.



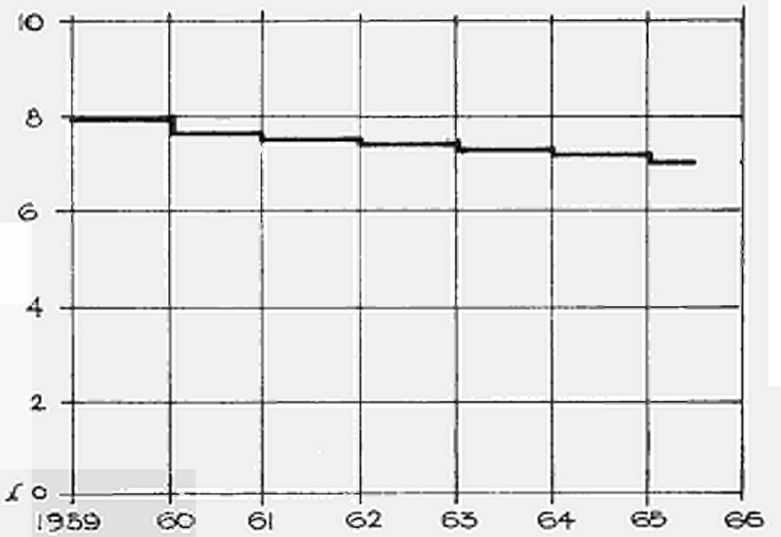
Cost per stanchion

Cost of 20' AA(T) stanchion



Cost per beam

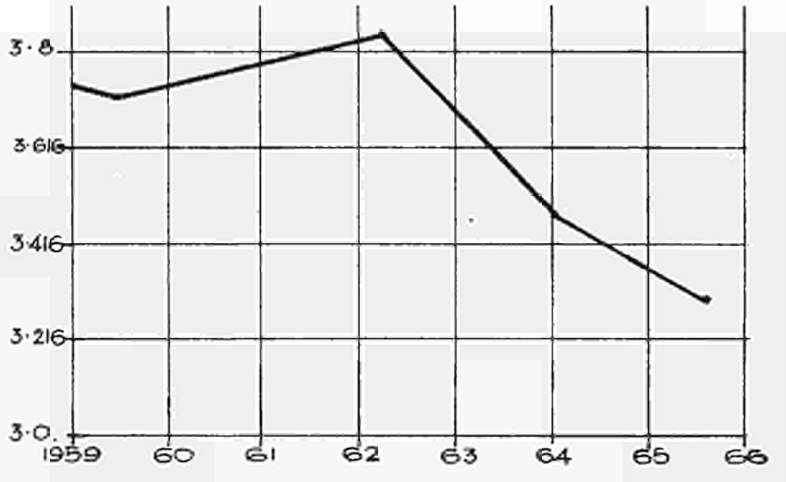
Cost of 80 M secondary beam



Cost per stanchion

Cost of 10' perimeter stanchion

The large annual C.L.A.S.P. Programme of approximately £10 million (about 80 large buildings) has provided the continuity essential to the amortisation of factory work space, jigs and tools etc. Furthermore, it has been possible to invest money in long term development and allow for the full size testing of components in the laboratory before manufacture.



Weight of steel frame (single storey) lbs. per sq./ft. of floor area

Number of New Schools

In terms of quantity the provision of new school places in Great Britain is impressive. Since the war nearly 4 million new school places have been provided of which about 1 1/2 million are in prefabricated buildings.

One quarter of all Education Authorities in England and Wales are now members of consortia, i.e. they have combined to sponsor one or another of the prefabricated systems in current usage, and these Authorities are responsible for nearly one half of the total number of new schools built annually. This proportion is rising rapidly and it will not be long before a majority of all the new schools in England are constructed by industrialised building methods.

International Use of Prefabricated Systems

During the last five years prefabricated systems have crossed the frontiers of the countries that originally sponsored them. In England continental systems for building houses are popular because we have long neglected this building type. In Western Germany, Italy and France, buildings are now being erected in the C.L.A.S.P. system. This interchange of national skill and experience is in keeping with the best traditions of European co-operation. They emphasise the advantages of modular co-ordination, for example the 40 inch (10M) English C.L.A.S.P. system is easily converted to the 1 metre (10M) German and Italian C.L.A.S.P. without structural re-design. Nevertheless it will be many years before a system of dimensional co-ordination which is universally accepted can be developed, as many other problems besides dimensions prevent complete interchangeability. For the time being it would seem more profitable to concentrate on the co-ordination of building demand so that the benefits of mass production can be given to the people who need them most urgently. It is hoped that the habit of co-ordination so invoked may ultimately lead to dimensional standardization at an international level.

Economy

Many of you will be familiar with Professor Buckminster Fuller's philosophy of doing more with less, this being an international problem which affects the whole world. We in the industrialized countries of the western world are fortunate in our possession of the raw materials and the means to make steel and fabricate it. This should not be an excuse for squandering a material limited in supply and ultimately irreplacable. The pattern of modern life is changing at an ever increasing pace and what we built today will certainly be out of date before another generation has passed. One of the good things about light steel frame structures is the ease with which they can be dismantled permitting the re-use of the basic components if necessary and the scrapping of redundant members. Some of the present impetus in prefabricated building has sprung from the experience of the airaraft and ship building industries who are accustomed to a life span for their products of between 15-30 years. Emotional attachments to outworn human shelter must be resisted and a readiness to design and construct disposable building accepted as the norm.

Speed of Erection

Systems of prefabrication based on steel frames have the potential for extremely rapid erection and are a long way short of full achievement. At the moment it takes about 5 days to erect the frame for a 320 pupil primary school and about 21 days to erect the frame for a 500 pupil secondary school, and total building periods are approximately 8 months and 15 months respectively. These times are about two thirds of those for conventional buildings. It seems likely that the optimum building period will level off at about half the time previously taken. Since this represents a 100% increase in productivity this should meet anticipated building programmes which are more likely to be limited by finance than by the resources of the construction industries.

Quality of Architecture

It has been the concern of all the architects that the quality of the architecture in C.L.A.S.P. should never fall below that which can be obtained by other methods. The continued acceptance by the community of system-building is dependent upon the buildings produced being delightful as well as commodious and structurally firm. In this context the steel framework must be seen as not just another piece of structural engineering providing the means of support for the walls, floors and roofs, but as part of the design of a total building in which all the elements are inter-related and conditioned by the need to make a pleasing environment for intricate human needs.

To the designers this means that the normal commercial relationship between architect and engineer is no longer adequate and that only by complete collaboration and mutual understanding of the ultimate objective can the correct balance of often conflicting requirements be obtained.

The structural engineer ceases to see the design of the steelwork as merely providing stanchions and beams in accordance with a code of practice but appreciates that his contribution must include an understanding of the use to which the building will be put, the amount of money available for the frame and the relationship this bears to other elemental costs, the way in which the steel will be transported to the site, the method of erecting it and the attachment of adjacent elements. The architect must be prepared to discuss with the engineer the design of all the elements even if they do not involve structural steel, so that both have a common objective. In return for this confidence and collaboration the engineer will ensure that the weight of steel used is the minimum for the job in hand, will be irritated by uneconomic design and may feel a sense of aesthetic failure if, for example, his beam designs do not reflect the same "fitness for purpose" which characterises the rest of the system. Above all collaboration will produce a comprehensive and integrated system of construction.

The Future

In the prefabricated systems discussed, the steel frame is generally the most highly developed element. This has not happened by chance. The production of iron and later steel components for building stems from the earliest days of the Industrial Revolution and has behind it 150 years of continuous development, both in the means of production and in the application of these materials to the construction industries. Prefabricated building makes its most significant impact at the point where factory production is most highly developed, as is the case not only with steel manufacture but also in the joinery factories which have for so long pioneered industrialization in what has hitherto been a craft industry.

I have only described prefabricated school buildings, for this has been the post-war success story in which steel frames have predominated more than any other single frame material. Although reinforced concrete has been intensively used, it is interesting to note a current trend towards the use of bolted steel connections to join together pre-cast concrete components. In other words, to make pre-cast concrete frames more like steel ones. So great is the reputation for flexibility and speed of erection that the all dry construction steel frame has earned.

Future development in steel frames may not produce great returns until methods of steel manufacture and processing are further advanced. As architects we look forward to the day when high yield steel capable of resisting fire is available and needing no protection. If this can be combined with an inherent decorative finish, as obtained with stainless steels, then the opportunity will exist for radical improvements in our present techniques.

Should a technical break-through of this nature occur and be economically viable, there is no doubt that light steel frames would become the dominant structural system for many classes of building. These are the challenges then — protected from fire and self-finished. If the metallurgists and manufacturers can rise to the occasion, we — the building designers — would ensure an almost limitless market for their products.

Herbert OHL

Design of Industrialized Building in Steel

(Translated from German)

This wording of the subject has been adopted in place of that originally proposed "Industrial Design in Prefabricated Constructional Steelwork," the object of the change being to bring out more clearly the coming trend development towards industrialized architecture in steel.

Creative design, which is a comprehensive and penetrating process of co-ordination and integration for bringing into harmony all aspects of a given problem, includes technical design proper, which is a peripheral and final product.

Industrialized building, the full reorganization on an industrial basis of the entire building process from demand to supply, culminating in the completed construction, is replacing "prefabrication" a mere intermediary stage governed by time and circumstances, amounting only to partial rationalization of the building process by variation in construction.

Steel, a necessary element in the range of choice, in combination with other materials, processes and construction methods, contributes towards resolving the whole business of building and replaces the "steel building" as a final and independent conception for the structure only.

Alteration of Fundamentals

The change in the fundamentals of building in steel is evident in the emergence of an aesthetic of steel building, followed now by a change into an aesthetic of industrialized building in steel.

The use of steel as a material for building components and for steel structures has, since the beginning of the industrialization of our society, led to the first significant interpretations of steelwork and to the discovery of its characteristic, new, aesthetic values.

Construction of suspension bridges, open gridwork, skeleton frames in cast iron or rolled steel sections had already indicated clearly new possibilities, conceptions and forms, and introduced a trend towards a new aesthetic of steelwork. Already these contributions were partly more progressive than many apparently modern-inspired solutions of our contemporary technical age.

In the succeeding phase of pre-industrialization building, which includes modern building and prefabrication as one of its intermediate forms, increased its use of steel in erection work, brought about an unmistakable aesthetic in constructional steelwork, which is however restricted in scope by the industrially available semi-manufactured products, linear profiles and space grid skeletons derived therefrom.

"Material suitability" and "constructional requirements" excuse and clarify the creative motivations of this pre-industrial phase, the decisive design criteria of which had to be the consideration of narrow boundaries and limitations of materials and processes.

Today, this simplified and isolated aesthetic appraisal has become more or less established, and has led to a stylistic expansion of steelwork aesthetics, although the original puristic conditions no longer apply. Steel skeletons are faced with concrete, concrete skeletons are partly covered with steel and fitted with steel joints, façades are steel panelled *à la mode*, and designs in other materials are being tried out in these styles.

The limitations, and therefore also the applicability, of materials and processes have now been greatly changed and tend towards even greater design flexibility. Thus the end phase of the reformed, modern construction with the right materials is being superseded by a new age of design with greater freedom of selecting and utilizing special materials, processes and construction methods, according to suitability for their primary functional and environmental purpose, using combinations and compositions. These changes are already affecting industrial design of consumer goods, but in the field of the new industrialized building with steel, this insight is a pre-condition of any major future contribution by steel.

Three Working Parties of this Congress in Steel Processing, Surface Treatment, Cold Forming and Jointing Techniques, deal with the actual basic problems and elements and comprise a wide range of innovations and possibilities in design and application of steel in constructional work. The degree of creative freedom has thus been greatly extended. Correlation and dovetailing of technical possibilities with further relevant influence factors of design based on actual functional and environmental requirements, enables us to have a positive choice and a characteristic application of material, production methods and construction.

The basic problem of building — to facilitate working and living conditions in suitable environmental conditions, can be solved only simultaneously, if not preferentially, by combination of the most efficient materials, construction and industrial processes.

Steel can contribute here more than ever, in combination with various other materials, when its new potentials for the building and building process as a whole are fully appreciated.

Form is no longer determined by steel, but creative design, the embodiment of many interacting technological and human factors is circumscribed and optimized, if indeed not made possible in the first place, through steel.

The new aesthetics of design in industrialized building with steel succeeds the concept expressed by "dictated by environment" and "related to material".

New premises

New premises are necessary for the structure of the steel building industry, just as they already apply to the designer of industrialized building with steel.

The constructional steelwork industry must be transformed from a part-product industry which produces only structural framework, into an end-product industry. The existence of a steel-building-industry in a comprehensive sense, and not a constructional steelwork industry narrowed in scope through rationalization caused by a variety of builders and contractors, in any case the premise for industrialized building with steel. This should be a new complex industrial organization, which embraces, co-ordinates and is fully responsible for planning, construction, production and distribution. Only then can the design of industrialized building become effective, with the object of obtaining improved solutions by means of a complete industrial end product.

The constructional steelwork industry of today should be the starting point for such a change of structure, since, with few exceptions, it has so far been unable to introduce new industrial processes and construction methods which constituted for a long time the successful basis of the consumer-goods industry.

Vehicle construction and ship building are branches of industry which give preference to steel as a structural material. They use it and simultaneously co-ordinate and progress subsequent manufacture, inclusive of machining their products from smallest to largest dimensions and complexity. These industries are examples of the industrial organization which is required to produce complete and complex industrial products. Their inclusion in the realization of industrialized building with steel would further this process.

Utilization of steel was the first major contributory factor in the industrialization of many products of our society. It facilitated the development of raw-material, semi-fabricated product, and finished-product industries. Similar comprehensive and conclusive achievements of industrialization, with the object of making building a finished product, are yet to come. The development of industrialized building is a decisive prerequisite for new and effective utilization of steel in building. Only mass-production permits the economic utilization of highly developed and refined processes and construction methods which, in conjunction and co-ordination with other materials, can lead to specific and characteristic solutions of new problems, with an optimum of efficiency and utilization.

The comprehensive nature of the industrial organization, capacity and potential, of the constructional steelwork industry, must be supplemented by the adoption of a common language, definitions and rules, and the resultant standardization and typification in building. Typification of structural elements and types of building by means of building systems with multi-purpose applicability for producing manifold variations, is a pre-condition for effective communication, order and the taming of our technical world. The solution of typical cases by means of system-building should be the aim of an unbiased product development and research of the constructional steelwork industry.

The successful co-operation of the designer of industrialized building and consequently the promotion of steel application is sure, as a result of the designer's objective and expensive purpose, to attune the true requirements of consumer groups with the industrial potential by means of systematic overall design.

According to the trust placed in him, and also because his inherent sense of responsability, he will analyze critically all relevant conditions and relationships and be inspired to develop new ideas. By collating experience and ideas of all members of the building team, and by systematic investigation, comparison and reference, he will be able to produce a number of fundamental and progressive alternatives. Being relatively independent of individual interests, his responsability for the design task as the industry's product response to the society's consumer demand, ensures his elevation from middleman to a designer in charge of entire projects.

Objectives

What new objectives and unexplored possibilities are being opened to further development in industrialized building with steel?

An analysis of a comprehensive constructional steelwork undertaking may help to highlight and appraise development criteria of the future. A study of American multi-storey buildings, administration buildings up to 60 storeys high, may permit certain symptomatic conclusions. The subjects of investigation were not studied for their aesthetic value; this has long been recognized, but for their utility values and properties. The choice of this extreme example has the advantage of enabling us to recognize in potential form critical values in the steel erection of contemporary tall buildings, values which may be neglected in less extreme types of building, although they also apply equally here.

Steel's share in the construction was compared by volume with the building's pay-volume relative to floor structure (up to 33 % share of total ceiling structure, including installations and fittings), and related to support structure (up to 20 % for fabricated structural elements in lower floors).

The share of steel in lower constructions by weight, was compared with the structurally neutral self-weight and the pay-weight of the building (large expenditure, small efficiency).

Steel as a design component was evaluated according to its contribution to the total stability (due to material, but not arrangement or shape), according to structural efficiency of the shape of its structural elements (low utilization of light weight construction methods), according to material quality (tendency towards higher quality material), according to methods of jointing of the structural and auxiliary elements (conventional production and high material expenditure methods), by consideration of the installation systems (space and labour division), according to interaction with supplementary materials and - elements (no interaction), according to the utilization of the entire building process (independent prefabrication of bearing structure and supplementary structural elements only), according to the specific efficiency of special organization, working and environmental conditions (none, apart from sufficient degree of freedom of arrangement) and according to utilization of modular co-ordination, typification and standardization within an open building system (employment of preferential mass and forms in closed part-systems).

Certain critical values deserve more detailed explanation. The space-consuming total ceiling construction, trusses and installations which are either independent or lack penetrating integration principles, are technically extravagant, and lack practical advantage. In spite of a certain architecturally pleasing design, the main and secondary structures, installation systems and fittings have not been conceived as integral problems or at least as co-ordinated units, but, due to their shape and independent location, they perform often the same function. In an integral design, unnecessary expenditure of self-stability for each unit is avoided, since this is provided simultaneously by the construction. Reduction in construction height of the entire floor space and a possible reduction in weight of the structure may be achieved by fuller use of the principles of integration and weight-saving techniques and will result not only in savings in material and labour costs for construction and production. It would also mean considerable advantages through full utilization of the buildings, erection sites and, preferentially, town centres, resulting in a greater number of storeys for the same total height, reduction in vertical circulations and service passages and the relative reduction of the building's outer surface. An appraisal of the building's whole construction and stability, nearly always shows an even distribution of the statically effective materials over the building's total cross section, when they should really be concentrated where a high degree of rigidity is required — in the outer zones of the building, which are functionally unimportant and environmentally difficult to control. This more modern approach will not only result in an overall stability of the building at a lesser cost, and a greater adaptability of floor and space arrangement achieved by shorter horizontal throughfares, but will also facilitate simplification to the stage of industrialization of the building and assembly processes on site. In the investigated examples, the building and production process which defines the fundamental principles of design, was directed by an organization of building contractors, who manufacture a large quantity of independent products and fabrications and fit the final production and final assembly to suit the numerous time intervals, locations (storeys) and responsibilities (trades). Prefabrication of steelwork is limited to linear structural elements, which are joined by a variety of conventional assembly methods and processes to form an unchangeable building structure.

An important question to complete this examination is whether any new specific and characteristic potentials were discovered in steel due to its particular suitability for multi-storey building. This cannot yet be answered with certainty, since the investigated solutions were for conventional structures and did not provide for the optimum use of steel that would be envisaged in the case of industrialized building with steel.

This analysis may initiate new ideas and criteria of objectives in the field of planned development and research.

The discovery and development of new ideas for building in steel, will be initiated by utilizing comprehensive and fundamental design principles. New fundamental solutions have been arranged in the continuing pages with a view to interpreting these principles and illustrating new perspectives. The potential of "extreme and optimal lightweight building principles" is demonstrated by the "relief membrane system (fig. 8, p. 165)."

The "profiled membrane system" derives its shape and effect from the joining of two thin membranes, pre-stressed and indented with depressions of various sizes, rigid and interstabilizing. Simple industrial production methods result in a hollow membrane, which is self-supporting in all directions and which, in addition to its low building height, small weight and high loading capacity, includes an integrated freedirectional installation zone as an additional factor. At the same time, the joints of the hollow membrane are formed into strengtheners for load transfer to support or suspension points within the building height of the plates. Exclusive use of relief membranes as trusses for self supporting long-span structures is also possible. The applicability of this structure as a semi-manufactured product and the variety of resultant building systems, is most extensive and promising, since it represents a complete merging of construction and installation interests.

Consequent, integral design principles lead to a "structural and mechanical grid." (fig. 9 and 10, p. 165)

It combines by integration two major fields of activity — supporting structure and service passages — into one unified system. A space frame of steel tube-construction is arranged and joined in such manner, that the continuity of tube connections whether in straight line or at changes of direction is maintained. At right-angled and diagonal points of contact, the tubes run into each other tangentially and interpenetrate semi-diametrically. They are joined by ringwelding in the workshop to form large grid areas, the final assembly on site being done by means of pin- and screw joints, with two tangential contacts per tube section. Adaptation to a large variety of arrangements, to suit structural and mechanical requirements, is possible through changing the grid spacing and the position of grid levels. With the exception of watermains, which utilize the hollow space between the grid structures, all other services, high current, low current, air conditioning supply and return lines, vacuum and light, are accommodated by the mechanical grid. Inlets and outlets of the various services are fitted in a convenient network between the tangential contact points. Supplementary panels serve as heat-, sound-, and moisture-insulation, accommodate the distribution of connections and power points, and enclose the gridwork internally and externally. The structural and mechanical grid system is continued vertically in a similar manner.

Environmental effects through specific and characteristic application of steel lead to an unusual concept — "breathing-optical-steel-skin." (fig. 11, p. 166)

As an external skin of a building, it was conceived following a fundamental inquiry into the job-planning of tall buildings, and a critical comprehensive re-appraisal, resulting in the discovery of a new specific characteristic principle of steel application. A porous steel skin, with approximately 8 % perforation, with tapered holes of some 0.8 mm diameter, and of approximately 1 mm -thick stainless steel, assumes the functions of optical, ventilation, heat and air conditioning control, cover and external protection of the building. Slight internal over-pressure causes 20 % of exhaust air of the air conditioning to escape through the pores of the outer skin, which in a conventional design has to be exhausted through the roof. The tapering shape of the holes has the effect of a non-return valve, and effects of wind turbulence are thus avoided. According to elevational and directional floor location, suitable automatic gauges cater for simultaneous pressure and temperature control within the building. Thermal insulation of the outer skin of the building can be left out, similarly, extra expenditure on moisture and air sealing is saved. The net-like perforation of the outer skin remains optically transparent and clear, whilst at the same time some 90 % of shading and sunray protection is obtained. The principle of the "breathing, optical skin" was developed for a particular case of a multi-storey administration building, which was subjected to extreme weather conditions and proved practicable. It is evident how decisively and simply this concept solves the technical and functional problems of curtain walling. But primarily, this indicates that an overall examination of all issues of a given problem, and an unprejudiced re-appraisal of all its parts, is a main condition for the development of new characteristic conceptions.

True homogeneous compositions with other materials are embodied in the principle of "fibre-concrete." (figs. 12 and 13, p. 166)

"Fibre-concrete" is a new true composition of steel and concrete developed as a result of a consequent analysis and the realization of the behaviour of two classic incompletely homogeneous materials. Very thin, short steel fibres are introduced into the concrete during mixing, and are distributed homogeneously throughout the mix. The length, diameter and spacing of the fibres in conjunction with the concrete mix, represent certain optimum conditions, which are enhanced in inversed proportion to size. The fibre-content in concrete prevents crack-formation in tension and hence increases the tentional strength of concrete decisively. Thus, the concrete in true composition with steel is capable of taking all forces, in contrast with the classic separation of composite materials due to tension or compression. Fibre-concrete makes possible the production for the first time of thinnest concrete shells and complex, manifold transition shapes, which suit its flow production process. Among its other advantages is the very simple production and, what is completely new, it is very effectively heat-, explosion shock- and moisture proof. The formability of this new composition is now determined by the design freedom of the membrane technique alone.

Modular, typified building and space units applied within the building structure and special organization by the "Ring-Space-Unit System."

This system (figs. 14 and 15, p. 167) demonstrates the principle of typification and standardization of large space modules for special organization and building structure on an example of a building scheme for garage and service stations, where a large degree of prefabrication and industrialization at the workshop stage can be reached. Various types of buildings and building variants can be designed, without loss of their functional values, by joining and superimposing standard space units. The structure consists of a ringshaped light-weight steel sandwich panel, integrally joined and sealed by simple ring-shaped elastic connectors and provided with pointed elastic bearers to ground level. It is feasible that similar modified schemes may be developed for steel erections.

Continuous and complete industrial production processes are applicable also for highest buildings in steel by the "groundlevel-building-process."

This process (fig. 16, p. 167) is eminently suited for tall buildings, multi-storey buildings in town centres. The principle of locational unity, through the choice of the erection site where only final assembly is being done of large building units, which were industrially produced and pre-assembled in a workshop, was developed in conjunction with the principle of space frame construction, for uniform spans over the floor, are supported entirely by a tubular structure at the periphery of the building line. The erection work is effected by hydraulic power acting at the peripheral tubular columns, after a storey-unit has been fitted and assembled from prefabricated and pre-assembled trusses and tubular columns, and is incorporated into the building structure. The final phase of contact fitting and arranging of spacers for the inner and outer walls, takes place at this ground-level in a rational and controlled sequence, thus as each storey is raised, it becomes a completed part of the building. The whole industrial production process becomes a closed system, most rationally simplified and mechanized with due regard to the ever valid requirement of site erection.

It is evident that simple and emphasized objectives have not led directly to resolving of the illustrated principles and examples. It was necessary to establish and over-emphazize the decisive characteristics of the objective in order to initiate the right train of thought. But only repeated interlocking with further aims and influencing factors brings about the necessary narrowing-down and precision, required in the search for special and characteristic solutions.

Design of industrialized building with steel has exemplary prospects of characteristic contribution. The introduction and adoption of highly developed industrialized production methods ought not to result in just a rational multiplication of classic product-types, nor need the new discovered freedom of a planned and flexible adaptation according to requirement and demand, become a willing interpretation of contemporary and abstract ideas and a period symbolism, as is evident in the design sphere of consumer goods production. There, impositions of restricting demands for an optimal structure and a consequent flow process, have been by-passed, since the greater freedom of industrial processes and potentials facilitated adaptation to suit the

sublime and changing consumer demand. The transfer of this new, many-sided technical and functional capability into building with steel will be completed by a pronounced awareness of steel in structural work, flow processes and modular order, and can become the basis for a new phase of building, an industrialized architecture with steel.

Bernard LASSUS

The Visual Element in Industrialized Construction

(Translated from French)

For several years I have been engaged in two types of research which were parallel although they were conducted independently, *viz.*

(*a*) A study of the colouring of industrialized construction and research into the visual impression created by various types of building.

(*b*) Workshop research into the relationship between natural and artificial lighting, colour and surface state and also into the extent to which a volume creates in us an impression of material presence and the sensation of form and dimension which we receive (figs. 17 to 19, p. 168).

Experience thus gained leads me to make these few remarks: Colour may modify the appearances of buildings to an extent which is often underestimated or even unrecognised. This is probably a factor which, while involving only a very small proportion of total building costs, enables the greatest change to be made in the appearance of the building. Most important of all, it enables connexions to be established between neighbouring buildings and passages which are not mere repetitive copies.

Prefabrication, industrialization and their corollary mass production involve the multiplication of the same elements in a building or building complex.

Here I would only remind you of the difference between *building* and *architecture*, since architecture is the direct result of choice of appearance. (Biblio. 1)

It is moreover, a wellknown fact that the appearance of over-simple and over-familiar elements repeated in identical form, gives the observer an impression of monotony or a sensation of mass which does not seem to meet the wishes of the inhabitants who prefer a certain visual complexity. This problem is at its most obvious when we consider a dwelling complex or an estate which is to be entirely composed of industrialized buildings.

At the present stage of our study of the subject, it does not seem that appearance should be the product of functional construction which is improved to a greater or lesser extent for aesthetic reasons. Neither does it seem to us that inhabitants or visitors should be subjected to a visual description of the principle of construction since, though this is of interest to the constructional engineer, it does not necessarily convey they most desirable urban impression. On the contrary, in our opinion the appearance of a building should be studied from the point of view of producing complexes which are attractive to the eye, that is to say, from the point of view of establishing some connexion or communication between the various elements which constitute our surroundings. This may be attained in particular by the integration of the buildings with the site, its accessories, the accentuation of its character or the design of a new overall landscape.

It will first be necessary to see to what extent visual form may differ from constructional form, *i.e.* to assess the maximum divergence possible between visual sense and reality, as this will enable us to determine which are the constructional elements — which we shall call resulting elements — which may be repeated over and over again and yet convey the most widely differing visual impressions, depending upon their surface-finish, colour and constructional possibilities.

These considerations are working hypotheses which serve as a basis for workshop research and which might be defined as the study of the relationship between theoretical form and real form. This research should — and to a certain extent already does — permit us to work out the relationship of proportions which is most desirable from the different viewing angles.

We hope that this will provide us with means more in keeping with technical possibilities.

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Günther HEBBEL

Stainless Steel Members from the Viewpoint of Industrial Design

(Translated from German)

The great master Mies van der Rohe, preceptor and model to many generations of architects, who in his buildings and plans anticipated so much what is the aim and object of this congress, once said in the journal "G" which he edited:

> "As long as we use essentially the same materials, the nature of construction will not change and in the final analysis this nature determines forms. The industrialization of building is a question of materials. Therefore the first essential is a new building material. We must and shall succeed in finding a building material which can be produced technically and processed industrially and which is strong, weatherproof, soundproof and heat resistant. It will have to be a light material which not only can but must be processed by industrial techniques. The industrial production of all parts can only be truly rationalized in the fabrication process, and work on site will then be limited to assembly and will be completed in an unbelievably short time.'

This was said in 1924.

Soundproof and heat resistant = modern insulating materials. Technical production, industrial processing, strength = steel. Weatherproof and light in weight, *i.e.* can be used as very thin sheet without additional coating by enamelling, lacquering or anodic oxydation: that means stainless steel. The special steel industry gives us the material in minimum thicknesses unobtainable in any other metal building materials without risk of corrosion. Alloys to enable any demands to be met, workability as desired, as if made to measure, and finally great strength.

What can we architects and designers do with it?

In the "Socony Mobile House" we see members which are successful from the technical and structural aspects but complete failures from the point of view of design. Inferior design, but stainless steel only 1 mm. thick, with dimensional stability despite the large format and, at the time the photograph was taken, after 11 years without attention in a harmful industrial atmosphere.

We can do better today:

An exhibition pavilion, not perfect from the point of view of industrialized building, but very successful designwise. The elements were adjudged to be "good industrial form" in 1964 (fig. 20, p. 169).

The alternating key-shaped components of 18/8 chromium-nickel steel, 1,25 m. thick, were produced by a German firm which has for many years been successfully striving for pleasing form (fig. 21, p. 169).

From the same firm is a small component for ceilings and walls, light and strong, only 0,8 m. thick, which may be varied by changing its orientation in the assembly and which is very easily erected (fig. 22, p. 169).

The examples I am showing here are not targets; do not represent maturity and perfection, but are merely small landmarks along the way.

Now in preparation is an octagonal roof structure of broad thin sheet panels formed into a fanfold assembly, which is being developed as a flat or domed self-supporting roof structure to cover spans for the 10 M grid and later for the 25 M module, a further step towards the goal evoked so expressively by the rapporteurs. Mies van der Rohe has so often been right and will be so again in the words I have quoted here. There is one material must not and will not be omitted from the ranks of building materials: stainless steel·

Marcel LODS

The Fundamental Problem of Industrialized Building

(Translated from French)

In thirty-five years of all-steel buildings, progress on the problem of industrialization has been less rapid than might have been hoped. It is a temptation to think that because industrial goods are machine-made buildings can be too.

But to think that is to ignore the inherent difference between the two. Industrial goods — motor cars, washing-machines, refrigerators, electric razors — are always manufactured from a small range of models each of which is turned out in tens of thousands, indeed hundreds of thousands of identical copies. In the case of buildings this is not so at all. A building is a dwelling, a school, an office block, a public building. Moreover, the industrial product is in its finished state when it leaves the works, whereas the building has to be tailored with regard to the site, aspect and weather conditions, and what is more has to be erected in the open air. In other words, with goods, once the thing is produced and packed for dispatch the job is done: with buildings this is not the case.

Then again, the expenditure involved by the amount of research and the number of prototypes required can be recouped on a long production run. In building, much larger funds ought to be available than can at present be drawn on by researchers, who seem usually to be simply instructed to work out a problem without having the money to do it with. Yet after all, building is humanity's Number One requirement the world over. Everywhere, though in differing degrees, we find the same abundance of extra adjuncts and shortage of essentials. Everywhere there is extravagant advertising to boast the sales of the television or radio manufacturer, while at the same time we are short of homes, shools and hospitals.

Really, it is high time we made up our minds to put an end to this preposterous state of affairs. Three things will be needed.

Firstly, the problem must be properly defined and Governments induced to give it its rightful importance.

Secondly, research specialists must be given time: it will take more than just a few months for the building trade to make up the leeway it has lost to industry.
And thirdly, the necessary funds and facilities must be provided: there should be teams comprising architects, engineers and manufacturers, with budget allocations proportionate to the size of the problem involved.

When we have these, it will be possible — and what a great thing that will be — to help people out of the present nightmare resulting from the totally unsuitable conditions prevailing for building. Order is needed: a building fulfils its function only if it fits appropriately into the setting formed by the other buildings around it. What is required is not just the planning of the individual building, but the planning of the town in which it is to stand.

All this, of course, means a tremendous amount of work. All the same, to our mind the human happiness afforded by decent living conditions is an objective for which no effort is too great. There is no graver problem today for the administrators, for the specialists, indeed for us all.

Jean-Baptiste ACHE

Industrial Design and Function

(Translated from French)

The highly interesting papers which have been submitted for our attention, most certainly call for comment.

1. Mr. Ohl's detailed study clearly shows that a number of misunderstandings are liable to arise from the fact that "industrial design" has been translated into French as "*esthétique industrielle.*" As M. Viénot points out, industrial design is most usefully employed in the capital-goods and consumer-goods sectors: in building it seems to me to play a smaller, and in any case a quite different role. This being so, Mr. Ohl's paper on industrialized building in steel deals primarily with matters of production and site organization, and with the tremendously interesting research being done by various centres in Germany and the United States — the preparatory stage, he has told us, for the further development of the iron and steel industry.

2. However, of the building systems he mentions, the one devised by the Columbia Graduate School of Architecture does not represent a particularly new basic principle, and is curiously reminiscent of the rammed concrete system, which, as used, did have the advantage of saving on shuttering: in the example, he has given, it only makes for extra work on site — which according to the economists is not exactly the object of industrialization.
   Mr. Ohl has also referred to a technological improvement in reinforced concrete which is being studied by the Carnegie Institute's Romualdi School of Engineering. This would be taking us a long way from industrial design if he had not several times mentioned that he envisaged new ways of using steel in conjunction with "all kinds of other materials."

3. On this point I should like to make certain reservations. The main underlying idea of the E.C.S.C. Congresses seems — to me personally at any rate — to be to assist the promotion of steel in all fields. It is on this aspect, therefore, that we should now concentrate especially if, as Mr.Maldonado suggests, the designer is to become the motive element in applied research. I myself am firmly convinced, like Mr. Ohl, that steel, with its past of a hundred years and more, is at the same time the material of the future, because it allows of a high degree of industrialization, and through *préfabrication ouverte* leaves a wide margin of freedom, as Mr. Meikle has so cogently pointed out. Mr. Ohl, if I have correctly understood him, shares this view; I am very glad he does, as I have not changed my mind since last year.

4. Now there is one thing I am worried about: all this is pretty remote, as we have seen, from aesthetics in the usual sense of the word, and I am horribly afraid somebody is going to remember that aesthetics is a branch of philosophy and get us on to those awful concepts of the "eternal beautiful" which have caused so much pandering to passing fashions, as we can see from nineteenth-century metal-founders' catalogues. Listening to two of our speakers, I found myself becoming even more worried. M. Viénot quoted the maxim "buying comes with eyeing," which is not too far distant from the equally celebrated maxim "what looks well sells well." Now if these principles were to be applied to building, we should inevitably, for the reasons I have mentioned, find ourselves progressively landed with the most utterly sham, pastiche architecture. M. Viénot also disputed the claim that "function creates form," but what Louis Sullivan said was, "Form follows function": there is quite a difference.

   The other speaker, Mr. Maldonado, emphasized the "line" aspect of the products, with references to "combinatory theory" and "line systematics." And there lies the danger. Mr. Lassus went so far as to say that architecture originated in the choice of appearances, which is tantamount to denying that it has a real existence of its own at all.

   The solution appears to me to be offered by steel itself. Steel has specific properties, notably that of small-section lift, and as we know it is supplied in varying types and after varying treatments according to the function it is to perform (which is in itself quite a stride in the direction of industrialization). In short, it is a question of using steel in accordance with its properties, and the different kinds of steel according to requirements, and being prepared to evolve new kinds to meet new requirements.

5. I was struck by Mr. Meikle's account of a co-operative venture in 1946 by an architect and an engineer who believed more in practical experience than in rigid adherence to a code of design.

   I agree with him that experimental empiricism is the principle on which one should work. I wonder also where the designer comes in in building, for while according to M. Viénot engineers have no artistic qualifications, architects do, and here we have architect and engineer acting together in building, that is to say, in using materials to make a structure to create volume to fit attractively into a space.

   I should like in conclusion to look back into the past. We have had large steel buildings for many years, but it was their knowledge of the potentialities of steel that those who built them produced works of unstudied beauty, which were beautiful simply because they expressed clearly and cleanly the potentialities of a material.

In effect, those builders were applying the thesis stated by Viollet-le-Duc in his *Entretiens* in 1863: "*Il faut être vrai selon le programme, vrai selon les procédés de construction.*"

The same writer, in applying to building the third principle of Descartes' *Discours de la Méthode*, the principle of "growing complexity," gives us a definition of some relevance to industrial design in building: "*Donner aux matériaux la fonction et la puissance relatives à l'objet, les formes exprimant le plus exactement et cette fonction et cette puissance.*" Thus it is in the making of the prototype, in *préfabrication fermée*, or in the making of the component, in *préfabrication ouverte*, that industrial design can play an effective part, irrespective of the individual who employs it, but provided it is functional and functional only. We must be grateful to Viollet-le-Duc for setting our minds at rest when he wrote: "*On peut donner à la structure la plus simple un style ... si l'on sait exactement employer les matériaux en raison de leur destination.*"

Stéphane du CHÂTEAU

How to Combine Aesthetics and Science

(Translated from French)

Now that we are debating the advantages of industrialized production in steel, and the respective rights, claims and virtues of those responsible for technical and plastic design who concentrate on seeking "design that will sell," *vis-à-vis* the industrial designer, I seem it wise to draw your attention to the dangers and difficulties of defining design criteria in the field of architecture. Architectural design is in itself a complex of problems peculiar to our time which are unmistakably made up of scientific considerations. To quote Mr. Siegel, "Science, the indispensable precondition to any understanding of the world of architectural form, requires us to know about design... Economy thus becomes a kind of moral and spiritual Common Law in the designing of forms intended to reach the height of perfection."

Mr. Makowski's beloved science includes the space-frame structures which are giving rise to a whole new world of geometrical and plastic forms with a design of their own based on the flexibilities of mechanics and governed by the inexorabilities of mathematics. They range and order matter within their spaces in accordance with the natural laws of "organic stability" emphasized by Le Ricolais. Those structures with their special capacity for "organicizing" large architectural spaces are made for industrialization, and so are a proper subject for the Congress's attention.

You will be hearing an account of some research projects which can suitably be classed under the head of architectural structures.

Giacomo SPOTTI

Steel and Industrial Design: Technical, Economic, Artistic and Social Considerations

(Translated from Italian)

In this age of dynamic technical progress, architecture is called upon to play its part in expressing the spirit of industrial, economic, political and social change.

Many and varied are the means by which this may be achieved and what a tragedy it would be were "unbalance" between the technical and aesthetic standpoints or, worse still, lack of understanding and realism to be allowed to jeopardize this unprecedented opportunity for steel to establish itself decisively in the sphere of architecture.

This presence of steel in the architectural ethos is obviously desirable and necessary, but it has to be spontaneous and inherent to human creative endeavour and must, as a corollary, permeate all stages of a project from conception to realization.

Particularly in the design of structural and finishing units, service installations and furnishings, in other words, in industrial design, is presence of steel nowadays essential. This need reflects and is reflected by our way of life and should most properly be channelled into the design and production of works of peace.

Only if this be so, can the benefits that steel has to offer be used to further the well-being and cultural progress of humanity, rather than be perverted to nourish armed threats against the rights of men and peoples.

The growth of the economic application of steel in the field of building industrialization and innumerable constructional sectors is, however, still conditioned by the dissemination and acquisition of new building methods and of the latest and continuously developing technologies.

Knowledge of these however must not be confined to the few; it must be extended to the many, until the point is reached where it can no longer be said that the use of steel for structural members, units, fixtures and fittings involves a lowering of quality or functional efficiency and an increase in building costs or overheads. It is this general misconception which so often seems to hold up the advance of steel as an architectural medium.

Industrial design signifies in practice an architectural choice that is not divorced from, but rather springs from a proper technological, technical and economic understanding.

The proper development and general acceptance of industrial design represent a process that is in fact intimately conditioned by technological and industrial considerations, of which the most important are:

(*a*) knowledge of materials, their choice, correct processing and use,

(*b*) knowledge of the technical, economic and production problems involved in ensuring sound project planning.

Against this background every endeavour must obviously be made to remedy the shortcomings of which we are well aware:

(1) in the training of designers and architects to a proper understanding of materials.

(2) in implementing the requirement, long overdue, for collaboration between engineers and architects.

(3) in co-operation between designers and the metalworking industry and between the latter and the building trade.

The training of architects and designers must henceforth embrace study of the nature of materials and their technology in order:

(1) to avoid the mistake of attributing to materials intrinsic and extrinsic properties which they do not possess and conversely of vitiating those that they do. The true nature of a material must be recognized and fostered to the maximum advantage.

(2) to avoid the risk of producing absurd and impractical designs.

(3) to brush away the cobwebs of prejudice and create a new outlook which accepts that architecture, to be beautiful, need not be based on ideas of the past but that modern compositions in steel may be equally harmonious and aesthetically satisfying.

Continuous exchange of knowledge and experience between architects and engineers will afford to industrial design the essential precondition for a studied and rational creation of structural parts and finishings whose marriage will produce an architectural synthesis artistically pure, functionally sound and economically viable.

It is therefore essential that all designers, particularly the more conservative among them, should become fully apprised of the new technical and artistic possibilities offered by steel and, casting aside the blinkers of traditionalism, should seek to express their creative ideas in an idiom attuned to the needs of an age whose onwards surge they can ignore at their peril.

The understandable efforts of vested interests and press, biased and unsupported by technical evidence, as they often are, to prolong the reign of traditional building methods and materials, must on no account be given fresh ammunition in the form of errors or imperfections in steel construction.

In pursuing the ideals of industrial design, any concession to misplaced intellectual arrogance, professional jealousy, "go it alone" production policies, lack of liaison between interested parties, failure to heed the social demands of this age of dynamic advance, any such crime of commission or ommission, is a betrayal of the credo of progress whose postulates include the acceptance of steel as a natural medium of the architect's art.

Conflicting self-interests and equivocal aims stand condemned whenever they stand in the way of modern structural design, since every delay is a denial of humanity's right to progress.

Realization of steel's potentialities proceeds with laggardly steps in all fields of building construction, a tardiness made all the more evident by the alacrity with which this material has been assimilated in other scientific and technical fields.

Let us hope that this snailpaced advance of metal constructional practice may soon be hastened, especially in concert with industrial design, but hastened with a solid scientific backing. The conceptual role of steel in architecture must be nnate and uninfluenced, however unconsciously, by outmoded traditional techniques resuscitated and dressed up in new garb by the use of this vital material. The use of steel must reflect contemporary thought in its noblest form, that of peaceful endeavour to promote the progress of man and his works.

Richard LYCKEBERG

Development of Design in Swedish Bridge Construction (especially with regard to the competition between steel and concrete)

In Sweden practically all bridge construction is planned and handled by the highway and railroad authorities, the highway authorities being responsible for the major part.

The structures are mainly executed by a number of allround contractors and some workshops and shipyards. Only a small part is executed by the maintenance departments of the various highway authorities — for instance some short span concrete bridges.

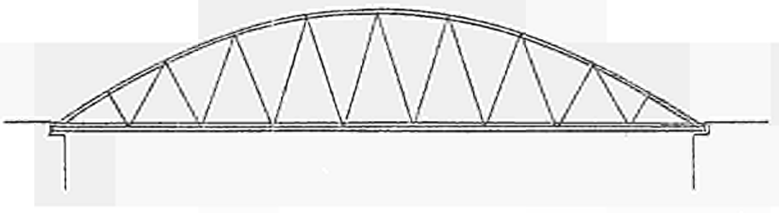
Bridges with spans exceeding 40-50 m. are practically always made subject to open licitation, whereby the main layout determining span, width, depth etc. is specified by the authorities, and in most cases the bidders are at liberty to propose alternatives within the specifications.

More seldom, and in such case due to special circumstances, detailed drawings will be prepared in advance. The general idea is that tenderers should be given the opportunity to suggest introduction of new construction methods and even new structures.

The authorities are organized with suitable departments for preparing preliminary proposals as well as detailed drawings, but may if necessary get assistance from consulting engineers. The contractors and workshops are mainly organized in the same way but are more often working in co-operation with consultants.

This system has been in use in Sweden for the last 50 years and it seems that both employers and contractors are quite satisfied with it. The result has been that the responsibility for promotion of new and advanced construction methods as well as design is shared between employers, consultants and contractors.

During the early thirties labour cost and wages were low in comparison with cost of materials and machinery. This was reflected in bridge design and construction where the aim was to save material. Even design cost had little influence on the total construction cost. This could be seen in concrete as well as in steel structures.



Design for a 30-40 m. span bridge
Steel or concrete span
Steel girder

In those days there would often appear a proposal for a 30 — 40 m. span bridge designed for instance as shown in the above figure. It is obvious that such a structure in comparison with a modern girder bridge of the same span entailed rather high labour costs, to say nothing of the more complicated design work. However, the low labour wages justified the proposal, especially if the arch was made of reinforced concrete.

Today the advantage of less material would be overruled by the greatly increased labour costs and even the cost for design would be an integral part of the total cost for the structure.

Spans of this size had earlier been made by using steel trusses, but the growing competition from the main contractors successively almost excluded such steel structures from the bridge market, and it was not until the introduction of modern welding methods that steel regained some of its status on the market.

During the war bridge construction for obvious reasons decreased. At the same time Sweden perexienced the immense change in labour cost as against material costs and after the war this trend continued and even the great demand for technicians had its consequences due to the increasing cost of engineering.

At the end of the forties prestressed concrete was introduced in Sweden and gave the contractors specializing in concrete a new weapon in the competition with structural steel. At the same time the shipyards were fully occupied by shipbuilding and were not particularly interested in other types of steelwork, which left the market for bridge structures in steel in the hands of a few specialized workshops. At the same time the prestressed concrete technique rapidly improved. Many new methods were introduced such as for instance the free cantilever system and even prefabricated elements were introduced in bridge construction. The result was that in the fifties a great number of reinforced concrete bridges and prestressed bridges was built, as competition from the steel side was rather small.

During the whole period between 1930-60 it was often proposed to introduce combined structures, i.e. steel girders connected to reinforced concrete slabs, which serve as upper flange of the combined girder. Considerable time passed, however, before any such structures were realized in Sweden possibly due to lack of research on the question of connection between steel and concrete.

In the beginning of the sixties road construction in Sweden began to expand more than ever before. This had great consequences for bridge building, in the first place due to the increased length of the roads, but also due to the fact that the number of bridges became proportionally greater, and moreover because bridges now had to be built with greater spans than before and at sites where the conditions were much more difficult. In other words — in places which earlier were avoided by the roadplanners. Compared with the thirties the actual volume of bridge construction increased to about five times the previous volume.

What is said above should give a general idea of the development of factors of significant influence on design for bridge structures in Sweden during the past 30 - 40 years.

It should also give the background for the development in Sweden of competition between steel and concrete.

At the beginning of this period concrete structures started to give steel structures real competition and the concrete structures took an increasing share of the bridge market.

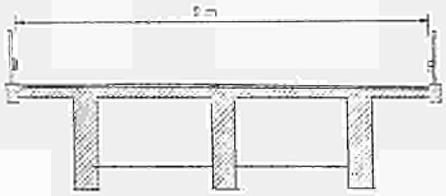
Welding gave new aspects to steel structures because it became possible to make more suitable and economical structures, which gave better competition to concrete. Also the improved qualities of steel and later on high tension bolts had a similar effect. However, the progress in development of steel structures was rather slow compared with that for concrete.

In this connection it may be mentioned that in comparison between proposals for steel and concrete structures the steel structure was earlier considered more expensive with regard to maintenance, i.e. painting etc. However, the general experience in Sweden is that even concrete structures will often be subject to expensive maintenance.

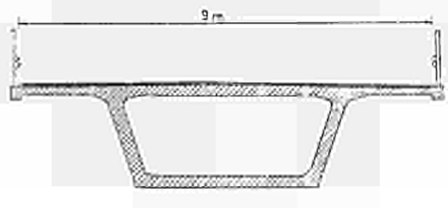
The increasing cost of labour was especially marked for formwork in the concrete structures. The first approach to better economics was the introduction of movable forms and later prefabricated elements in bridge construction. This was also a consequence of the increasing use of heavy equipment such as cranes on the bridge sites.

The movable form entailed several other advantages such as for instance the possibility to design a cross section which would better utilize the concrete materials.

Girder bridge: Conventional cross-section

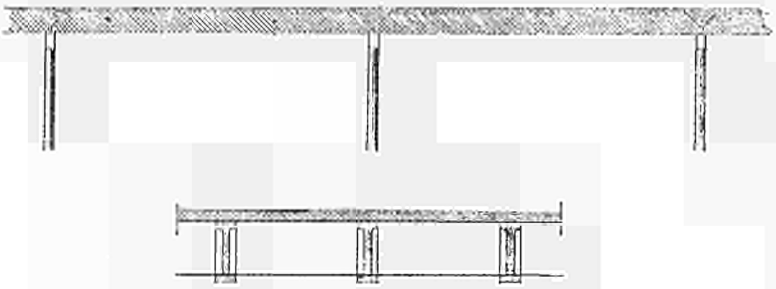


Modern cross-section



An illustration of this is to be seen in the above figure. It shows one conventional cross section of a girder bridge where the forms are practically vertical or horizontal depending on the designers' aim to facilitate the formwork. It further shows another cross section which is taken from a more modern structure. It is evident that the formwork in the latter case is more complicated and expensive — the sides are inclined instead of vertical and the corners are curved instead of rectangular. However, this will be more than compensated by the fact that the form is used several times, and further that the cross section with regard to reinforced concrete material is more economical.

The method with prefabricated concrete elements may be regarded as an idea borrowed from the steel side. Actually structures containing such elements are handled very much in the same way as the steel structure. The elements, i.e. beams, slabs, columns etc., are fabricated in a factory transported to the site and erected by means of cranes.



Prefabricated components
Cast. in situ
Prefab. beams

Cross-section

An example involving prefabricated elements is shown in the above figure. It is a concrete girder bridge for which the girders are prefabricated in prestressed concrete. The beams were erected on the supports and after this the slab was grouted on top of the beams. Provisions were made to secure a combined funtion of the slab and the beams. For dead load the beams will thus function as simply supported girders, but for live load the beams including the slab constitute a continuous beam.

From a main engineering point of view a bridge of this kind might without much consideration be designed with steel beams. Therefore it will be very interesting to see whether the still growing labour costs will change the picture in favour of steel later on.

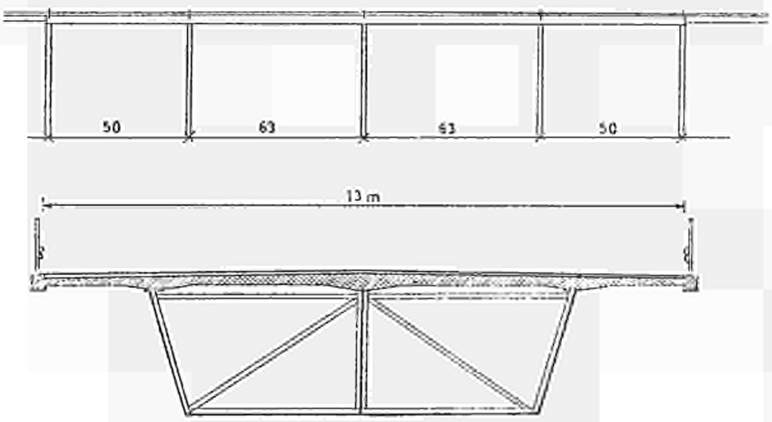
The two examples mentioned should give an indication as to how the changed conditions with regard to labour cost etc. have influenced the design.

This influence is obviously remarkable, not only in the details such as cross sections etc., but also in the main structural design.

During the latest years the interest in bridge construction has increased among workshops in Sweden, probably because the market has grown considerably and maybe also because other markets have ceased to expand.

Due to the continuously forthgoing increase in labour cost the possibilities for successful competition from the steel side are growing. The steel designers take advantage of this, and the possibilities for new design established by the welding methods are used more and more. At the same time it is interesting to see how the steel designers in certain cases seem to borrow ideas from modern concrete design.

An example is seen in the above figure showing a girder bridge in the range of 50 - 65 m. spans. The main girder has an open box-shape with a wide bottom flange and three webs each with separate top flanges. The concrete slab is connected to the top flanges so as to constitute a combined girder for live load etc. whilst the dead load mainly will be carried by the steel section alone.



Elevation

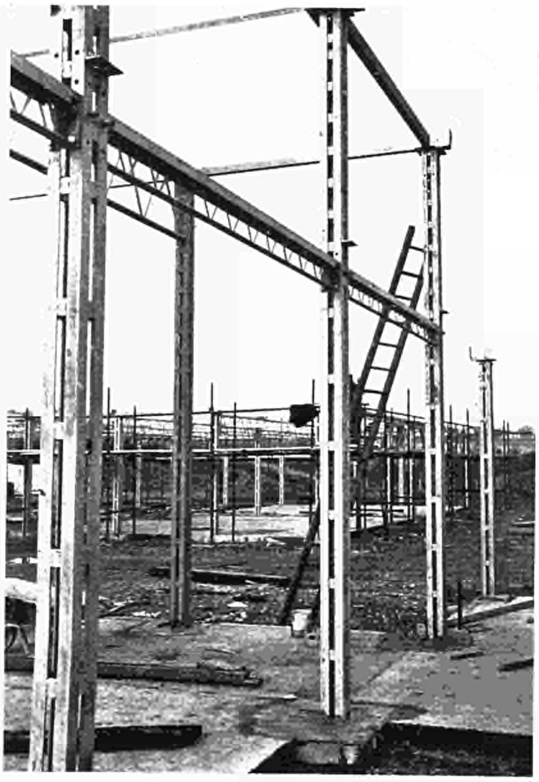
Cross-section

Girder bridge with spans of 50 - 65 m.

The outer webs are inclined. This is designed in order to obtain suitable spans for the slab without giving too much width to the bottom flange for which a minimum thickness however is necessary. This width is also suitable for design of the supports. The combined girder is to be prestressed in the longitudinal direction of the bridge, which will be done by adjustment of the supports after grouting of the slab. The slab will be prestressed in transverse direction in accordance with conventional methods presently used.

As a summary it may be said that concrete bridge structures in Sweden have been subject to a continuous and significant development during the last 30 years. At the same time the corresponding development for steel bridge structures was not remarkable to a similar degree. However, the trend in market conditions for bridge construction seems to have arrived at a point where steel structures will have better possibilities in the competition.

List of illustrations



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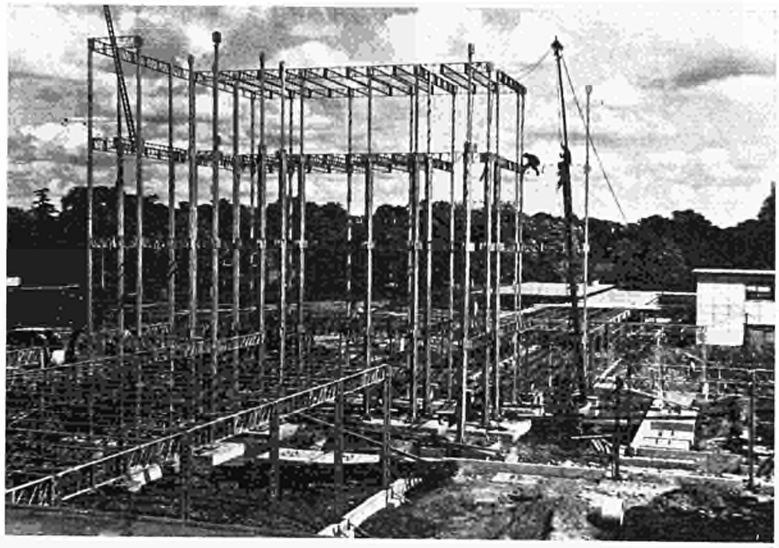

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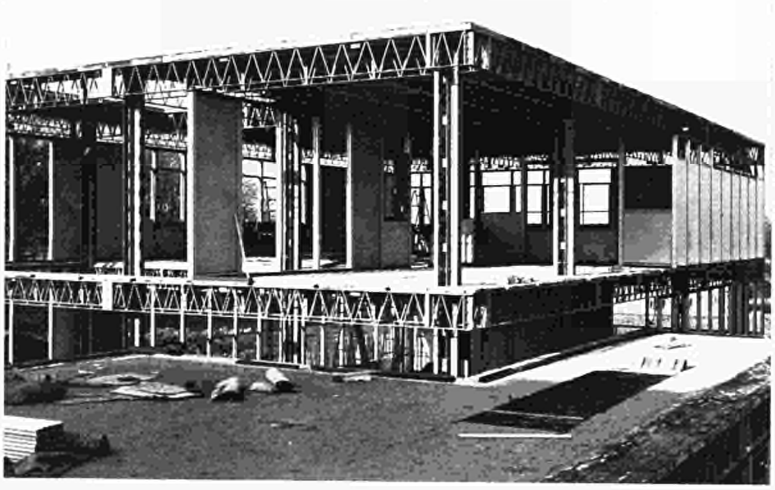

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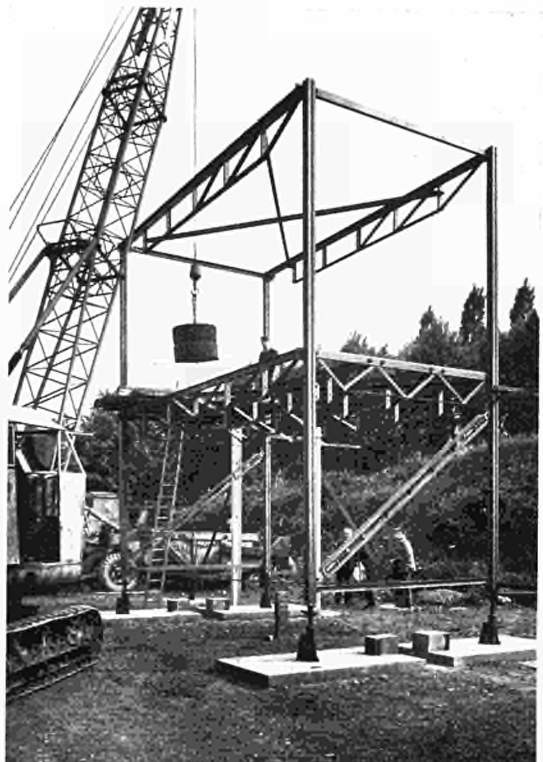

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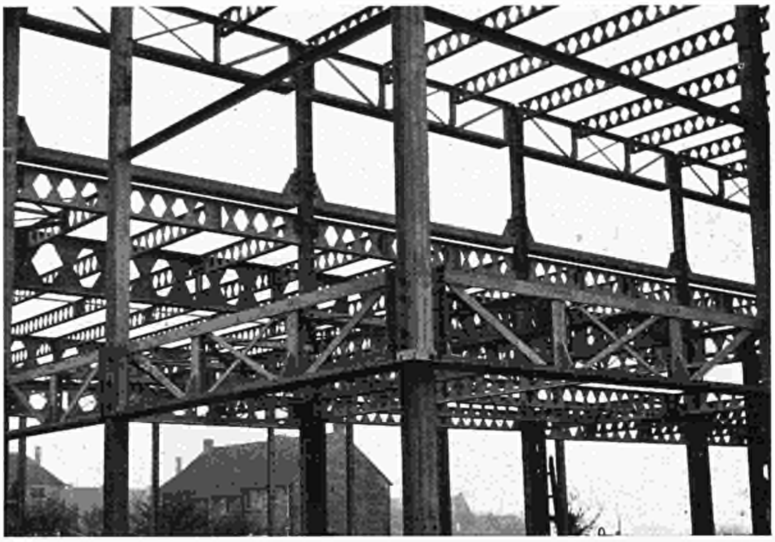
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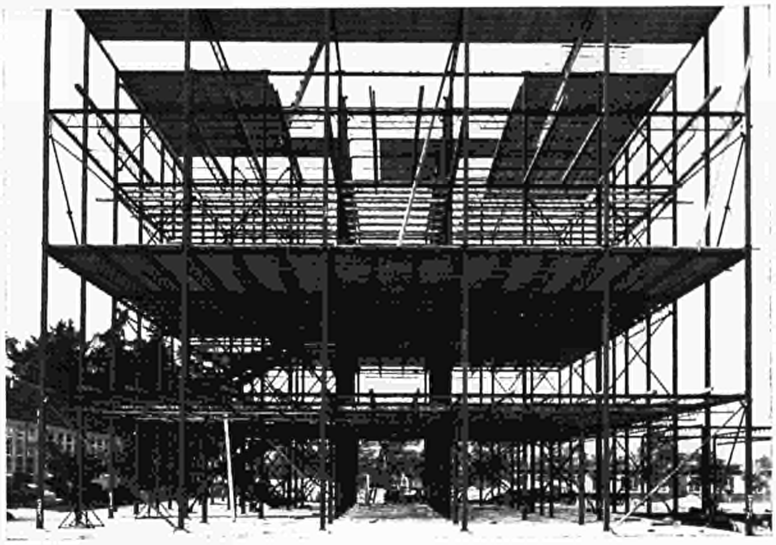
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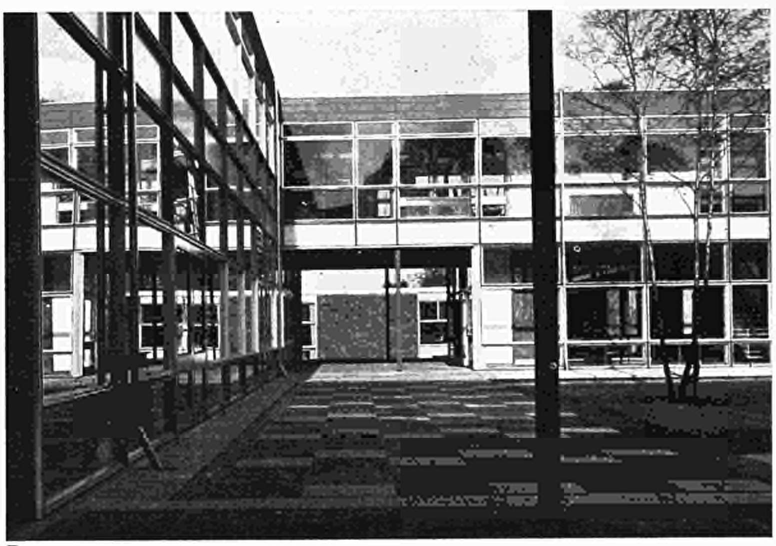
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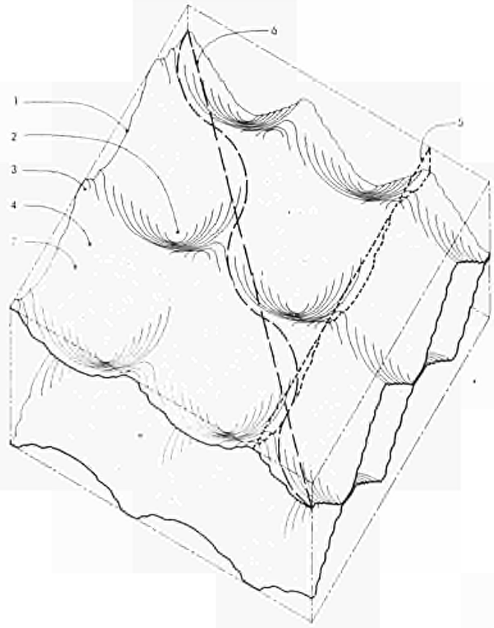

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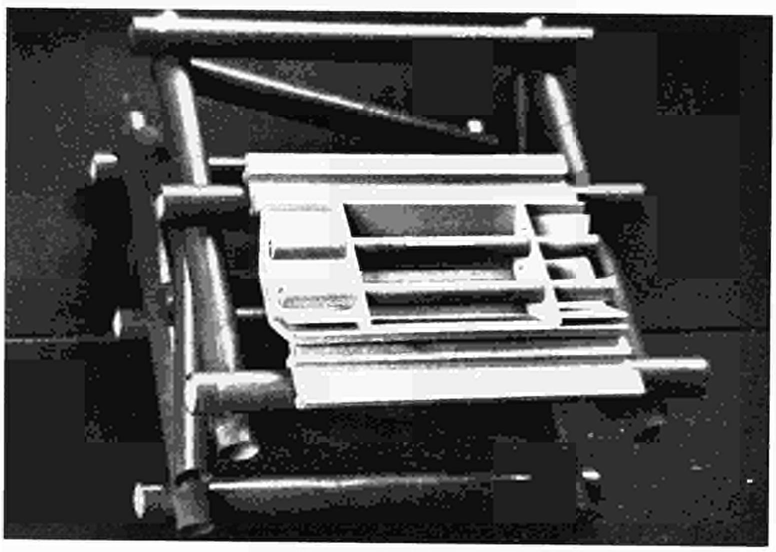

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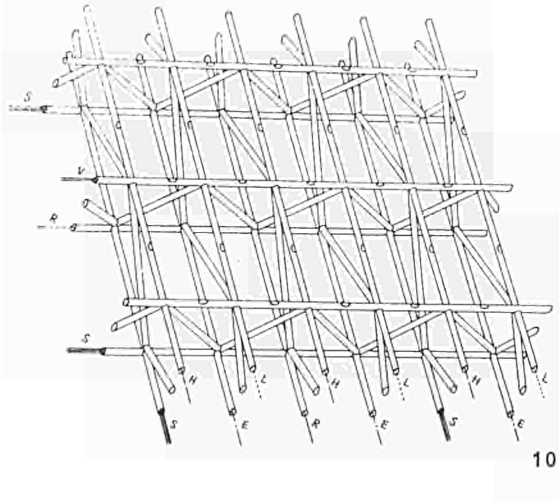

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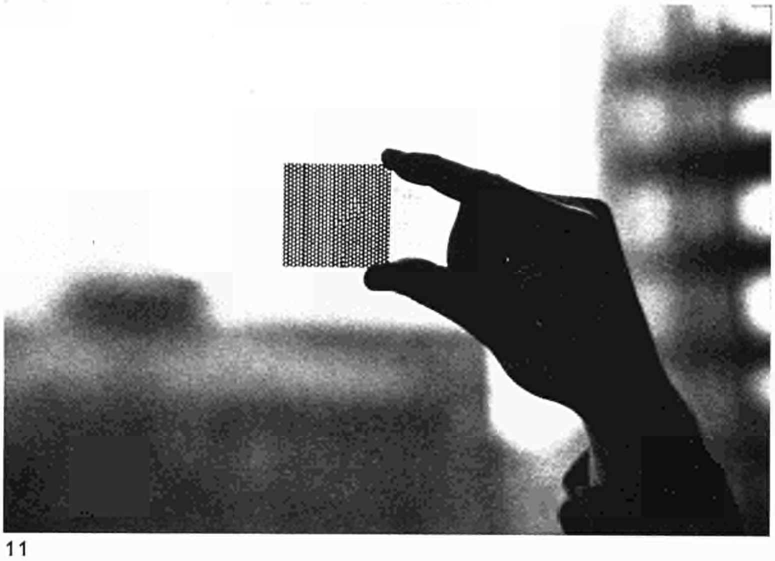

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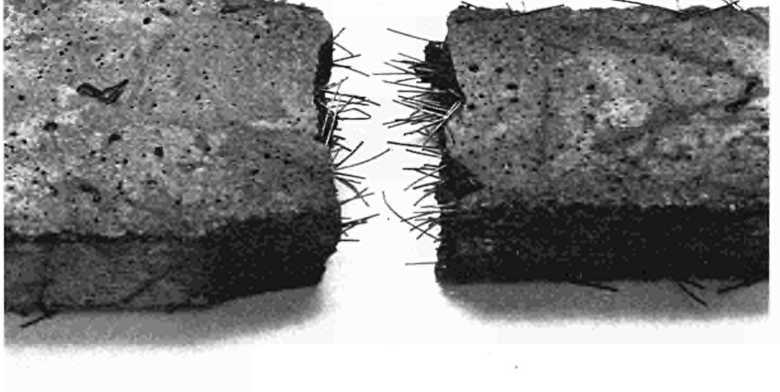

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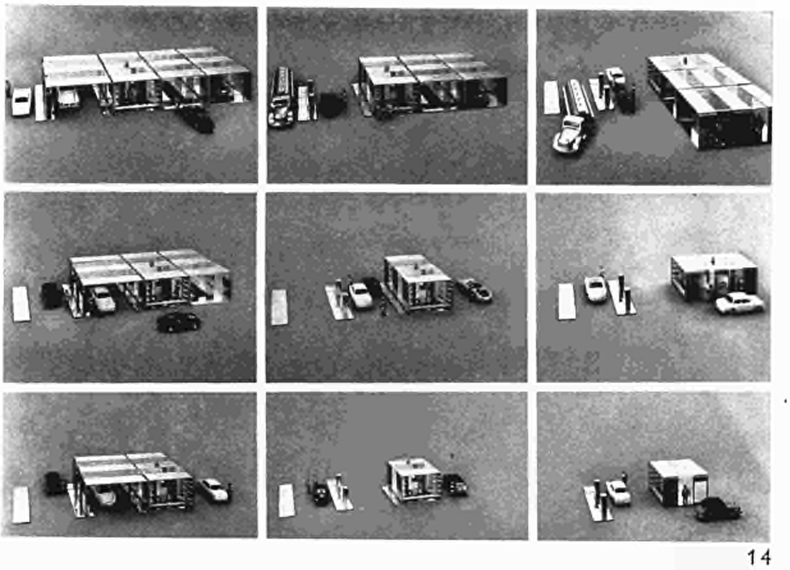

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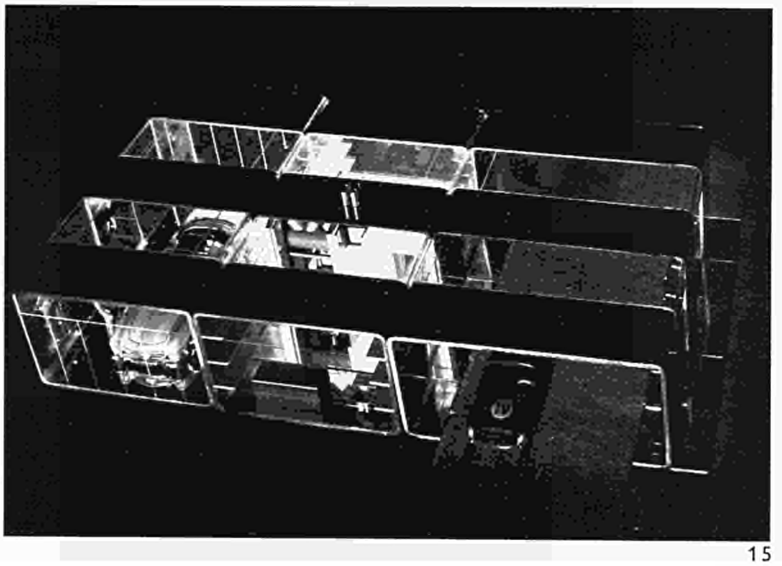

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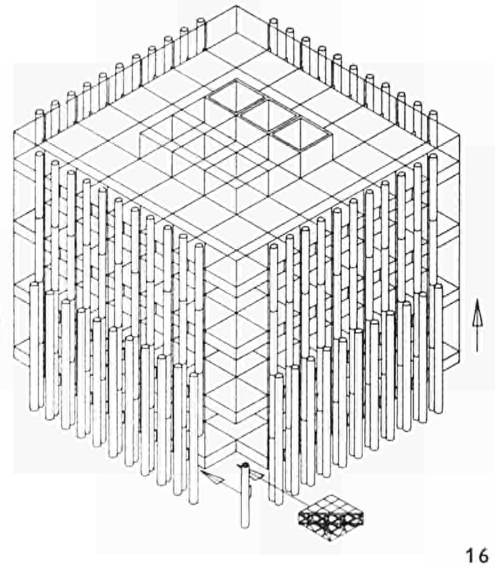

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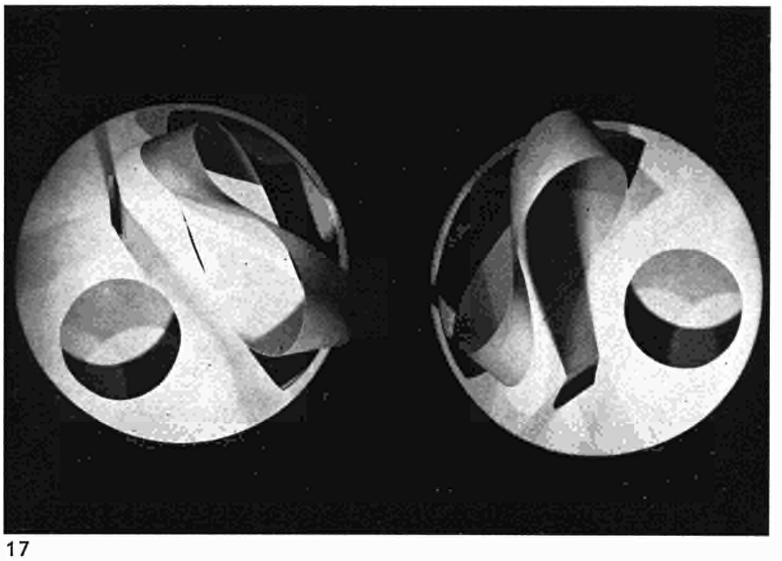

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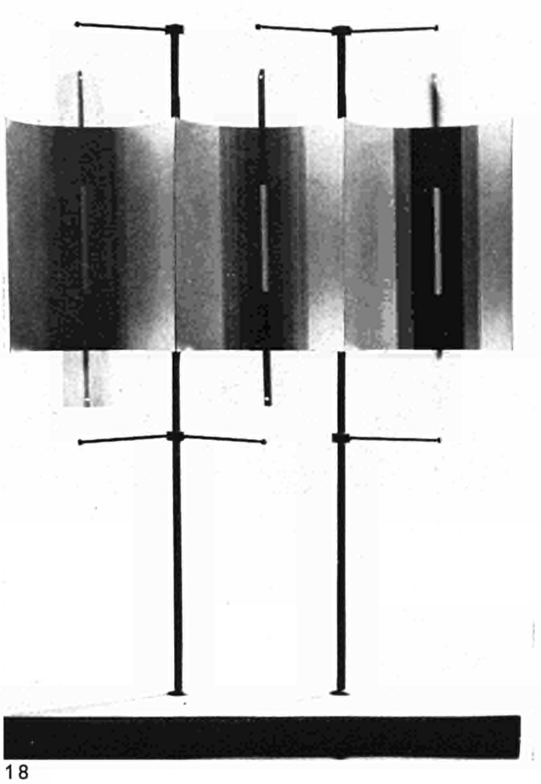

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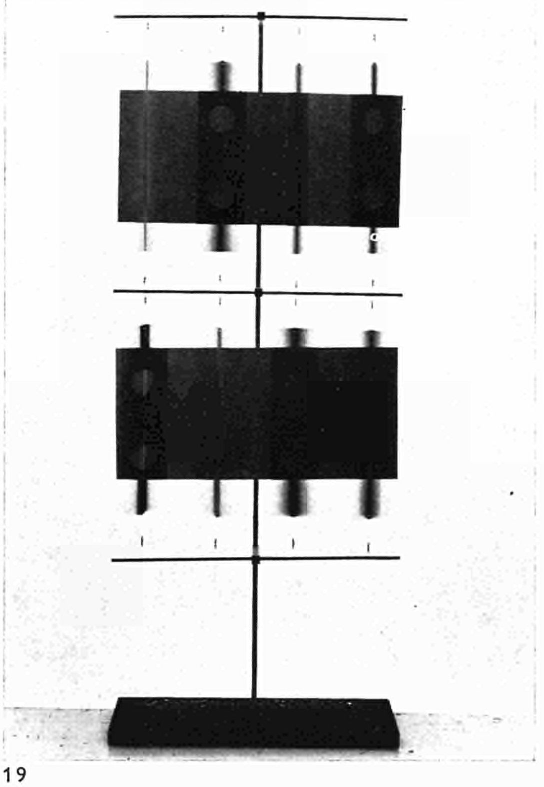

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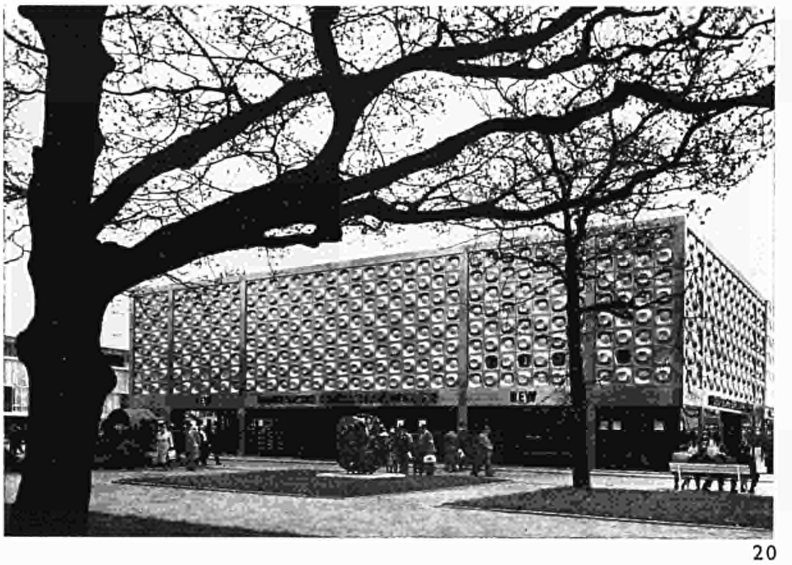

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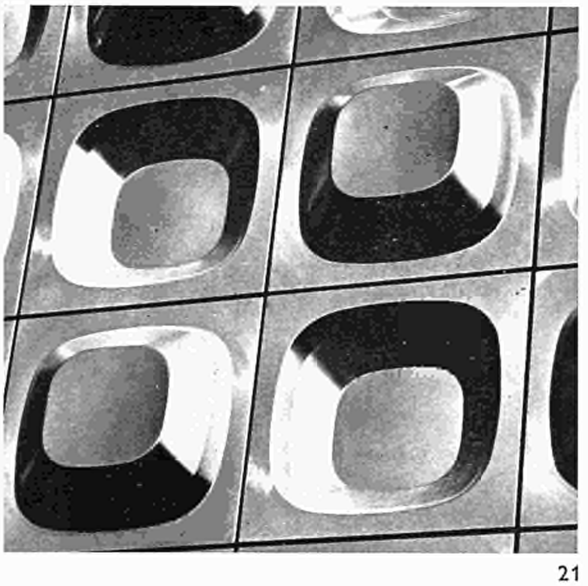

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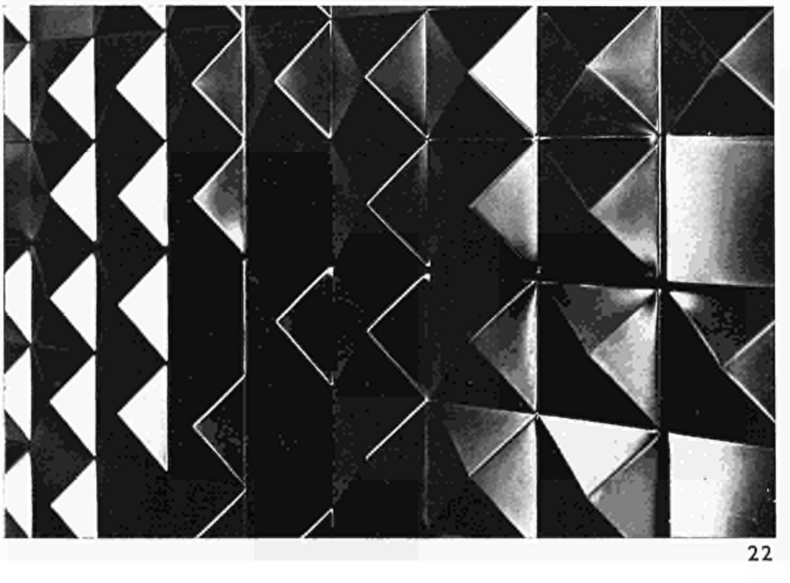


22

WORKING PARTY II

Surface Treatment of Steel

Chairman:

Albert Denis

Rapporteurs:

Marcel Pourbaix

Giovanni Odone

Pierre Bazille

Maurice Genot

H.O. Mulfinger

John Dinkeloo

Mario Signora

Walter G. von Baeckmann

Gilbert Andrieu

François Blanchard

Fabrizio Arnaldi

P. Morisset

Marcel Nepper

Introduction

The function of Working Party II was to consider how the surface of steel, exposed as it is to attacks of all kinds, should be treated to enable it to stand up to these, to prevent rust and scale from forming, in a word, to enable steel products to have a better performance in use and hence an increased utilization potential.

We have heard a number of scientific papers on the onset and progress of corrosion in its various forms; the electrochemical theory of corrosion would appear to explain most of the effects observed. The speakers have at the same time described the appropriate corrosion-proofing methods, which vary according to the nature and form of the steel products concerned, and especially to the use which is made of them.

As has been shown, in most cases one element gives insufficient protection, and it is necessary to use several to achieve the desired aim.

The corrosion experts, it has been emphasized, are making it their constant concern to select the right kind of pre-treatment for the surface to be protected, to improve the quality of the protective products themselves, and to introduce more efficient methods for their application.

We have heard also how the actual nature of the steel affects its corrosion resistance before and after treatment.

Reference has been made to possible research possibilities for all concerned — producers, processers and consumers — and also to the need for them to maintain regular consultation in order to evolve the best-protected steel product for the particular purpose.

Albert DENIS

Introductory Remarks

(Translated from French)

It is the surface of solids, and especially opaque solids, that we see, and it is also this surface which reacts to the surrounding media — the atmosphere with its varying humidity content and corroding agents, liquids, gases, and sometimes other solids with which they are in contact. With solids, therefore, the surface is an important factor as regards appearance, corrosion-resistance and wear and tear by friction. Some solids like steel possess physical properties such as tensile strength and modulus of elasticity which have caused them to be used a great deal in forming structures required to withstand repeated stresses. The state of their surface can be a very important point, since any appreciable defect can be magnified by nicking into initiating fracture.

In the case of ordinary steels, which at the surrounding temperature in the commonly rather damp climate usual in these latitudes is liable to rust, the preservation of steel fabrics depends on their being corrosion-proofed. Questions of outward appearance are thus directly bound up with this, and so consequently is the use of steel for constructional purposes generally.

Oxidation of iron, which takes place only slowly in the normal surrounding atmosphere, proceeds very much faster at rolling temperatures. The scale on rolled products as delivered from the mills can sometimes aid protection, but has no part in the steel's properties of mechanical strength.

Stainless steels of course are as a rule immune to corrosion by atmospheric oxygen. They can therefore be used as they stand or after only ordinary surface treatment, without special processing. Some alloy steels, particularly those containing an admixture of copper, undergo a degree of oxidation from the atmosphere which produces a layer giving protection against subsequent corrosion.

To enable corrosion-exposed steel to last, some form of protection is essential, whether afforded by surface treatment, in the case of ordinary steels, or by the addition of alloying elements.

There are a great many methods of protection, each with its advantages and disadvantages. In recent years there has been much research and some striking technical progress on longer-lasting and cheaper protection, as a result of which it is now possible to make increased use of steel for a wide variety of new purposes, especially in building.

Where the steel has to provide special properties, such as surface hardness, resistance to friction or refractibility, there are treatments, particularly in gaseous media, whereby these can be obtained at costs competitive with those of other materials.

The subject we are here to discuss is the main advances achieved in the surface protection of steel against corrosion and wear, having regard to the conditions in which it is used.

All surface treatments and alloying elements send up the cost of steel. It is essential that consumers should let producers know exactly what properties they require, while not insisting on pointless, and invariably expensive, refinements; producers for their part must do their utmost to supply steels that do possess, as uniformly as possible, the properties asked for.

Another of the objects of this Congress is to enable the requirements and possibilities of both sides to be stated and discussed, a process which I hope will prove instructive to us all.

Marcel POURBAIX

and

Antoine POURBAIX

New Surface Protection Processes and their Application in Structural Steelwork, in Particular in Prefabrication

(Translated from French)

In the last 25 years much progress has been made in protection techniques for construction steel. Although not so long ago we would have been quite content to "add a little colour" to a surface that had been only slightly prepared, if at all, for the protection of steel, the scientific struggle against corrosion has now provided technicians with reliable means, which, empiricism apart, will enable the problem to be fully mastered in most cases. The conception of a process of protection, its execution and continual control of efficiency, with the remedy of any possible defects, can all be achieved nowadays with he maximum of satisfaction, and often perfection.

This progress is reflected in the two basic stages of the protection process: the preparation of the surface, and the application of the eventual protective coating. On the one hand of course, the use of alloying elements can produce steels that are sufficiently resistant for a protective coating to be unnecessary, and on the other, the proper use of cathodic treatment can sometimes render a surface preparation unnecessary.

In the first part of this paper, we shall give a brief scientific survey, of the circumstances of corrosion and the protection of metals, with special regard to ordinary steels and the efficiency of relatively recent techniques, based on the use of wash primers, zinc coating and aluminium cladding.

In the second part, we shall assess a number of the technical aspects relative to the use of these processes. We shall mention briefly several other techniques, which will be examined in greater detail by other participants in the course of this conference.

Corrosion and the protection of metals

General Aspects of Corrosion and Protection

Thanks largely to the pioneer work of U.R. Evans (Biblio. 1) the electro-chemical nature of corrosion phenomena of metals and alloys in the presence of water and aqueous substances is now universally understood. The thermo-dynamic and kinetic principles of electro-chemistry, however, provide a basis for the study of these phenomena.

The figure below, taken from the "Atlas d'Equilibres Electrochimiques" (Biblio. 2), represents, in terms of the pH of an aqueous solution or a humid environment (measuring the acid or alkaline characteristics),

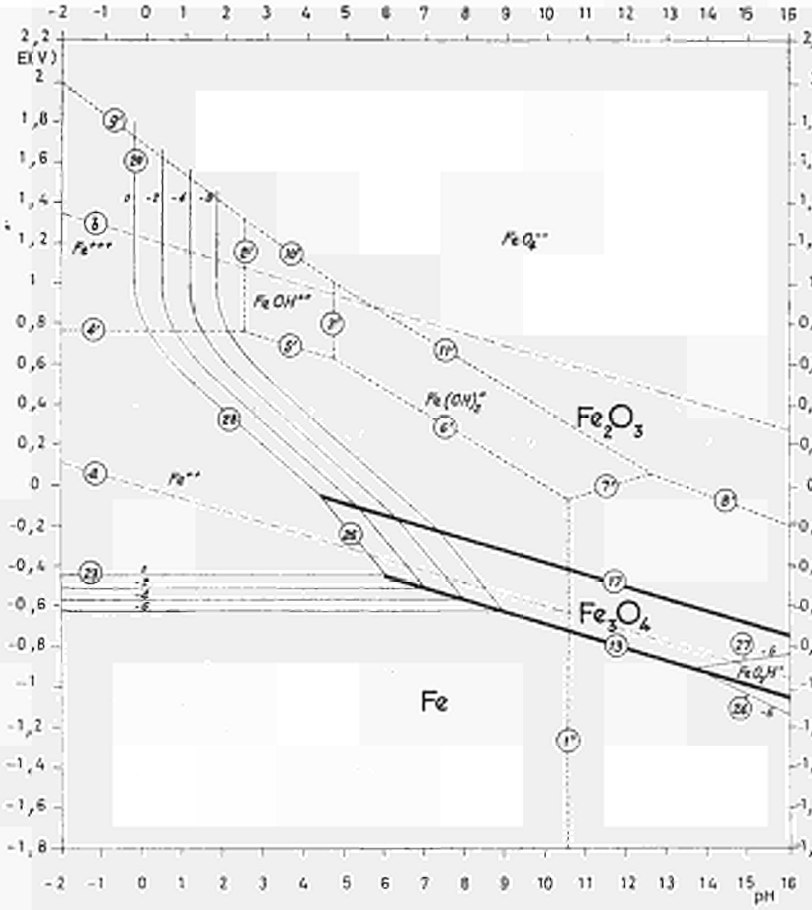
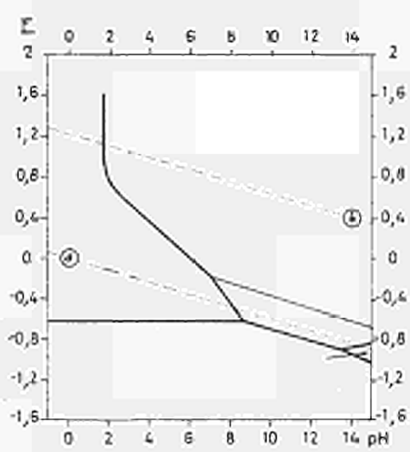
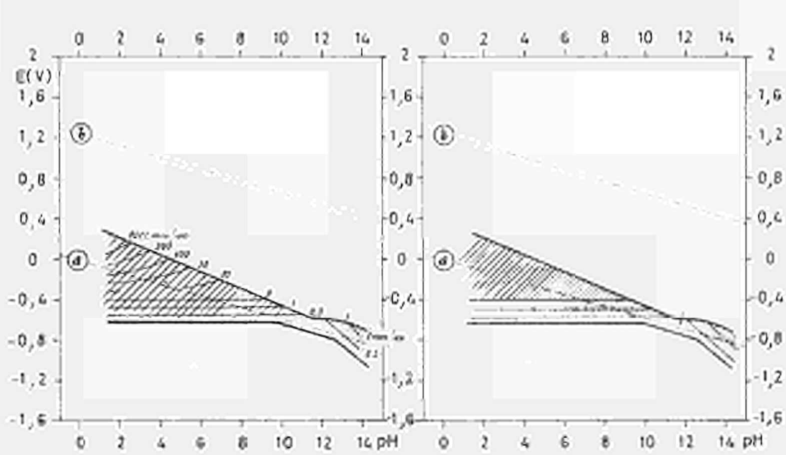


Diagram of the electrochemical equilibria of the system iron/water at 25° C.

and also of the electrode potential of the metal (measuring the oxidizing or reducing characteristics of the intervening surface between the metal and the water, the stability aspects of iron, its oxides and its dissolution products in water, at a temperature of 25°C. Through certain hypotheses, the following figure on the left, expressing the general aspects of corrosion(a), immunity and the "passivity" of iron (b), are deducible. In the zone of immunity, the iron remains perfectly stable, and corrosion is impossible. In the zone of passivity, the iron may attract a layer of oxide, which, depending on its protective ability, will either protect, or fail to protect the metol from corrosion. The two diagrams on the right represent these aspects, not only on





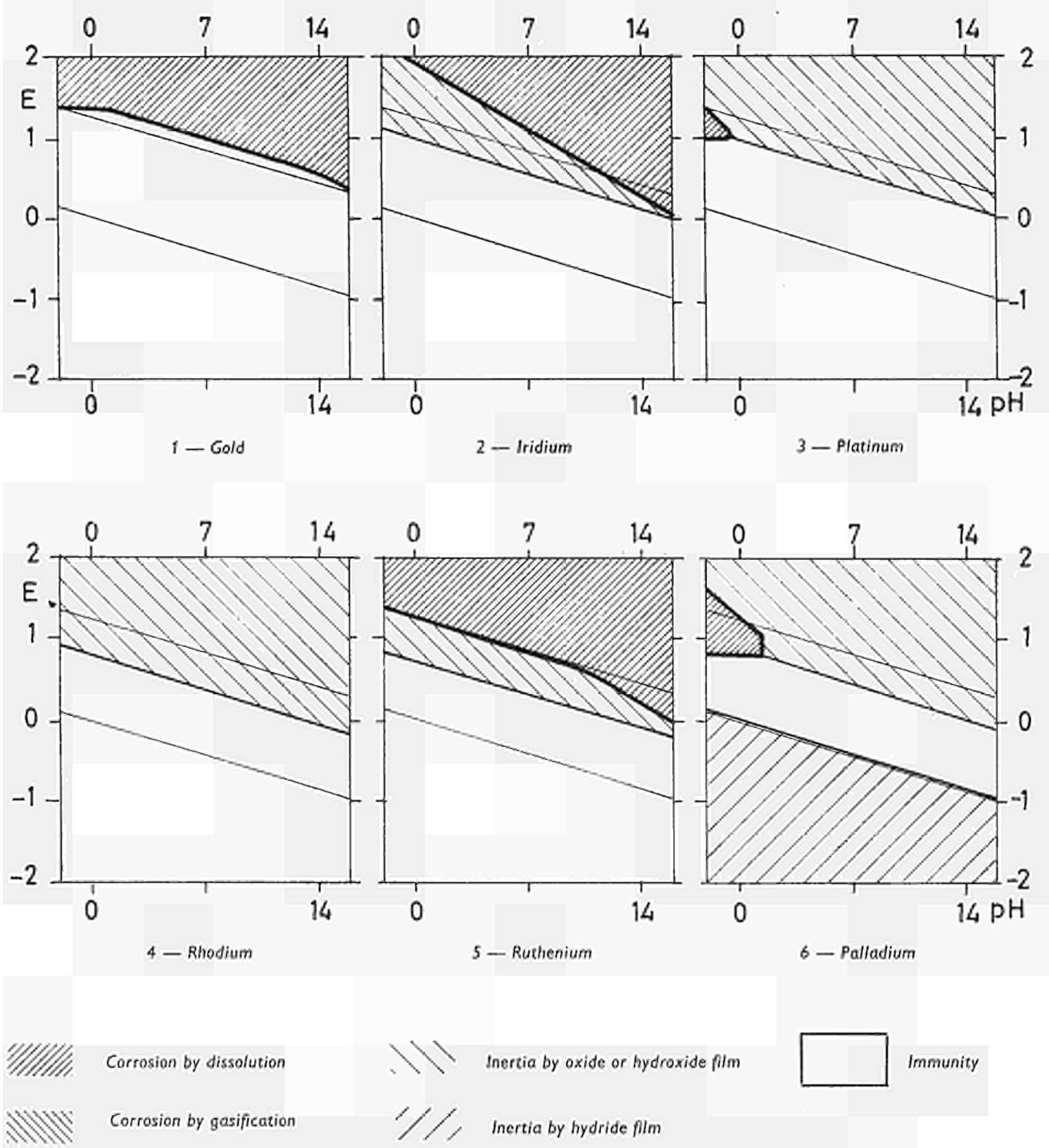
Speeds of corrosion *Intensities of corrosion*

Theoretical factors of corrosion, immunity and of iron inertia, at 25° C.

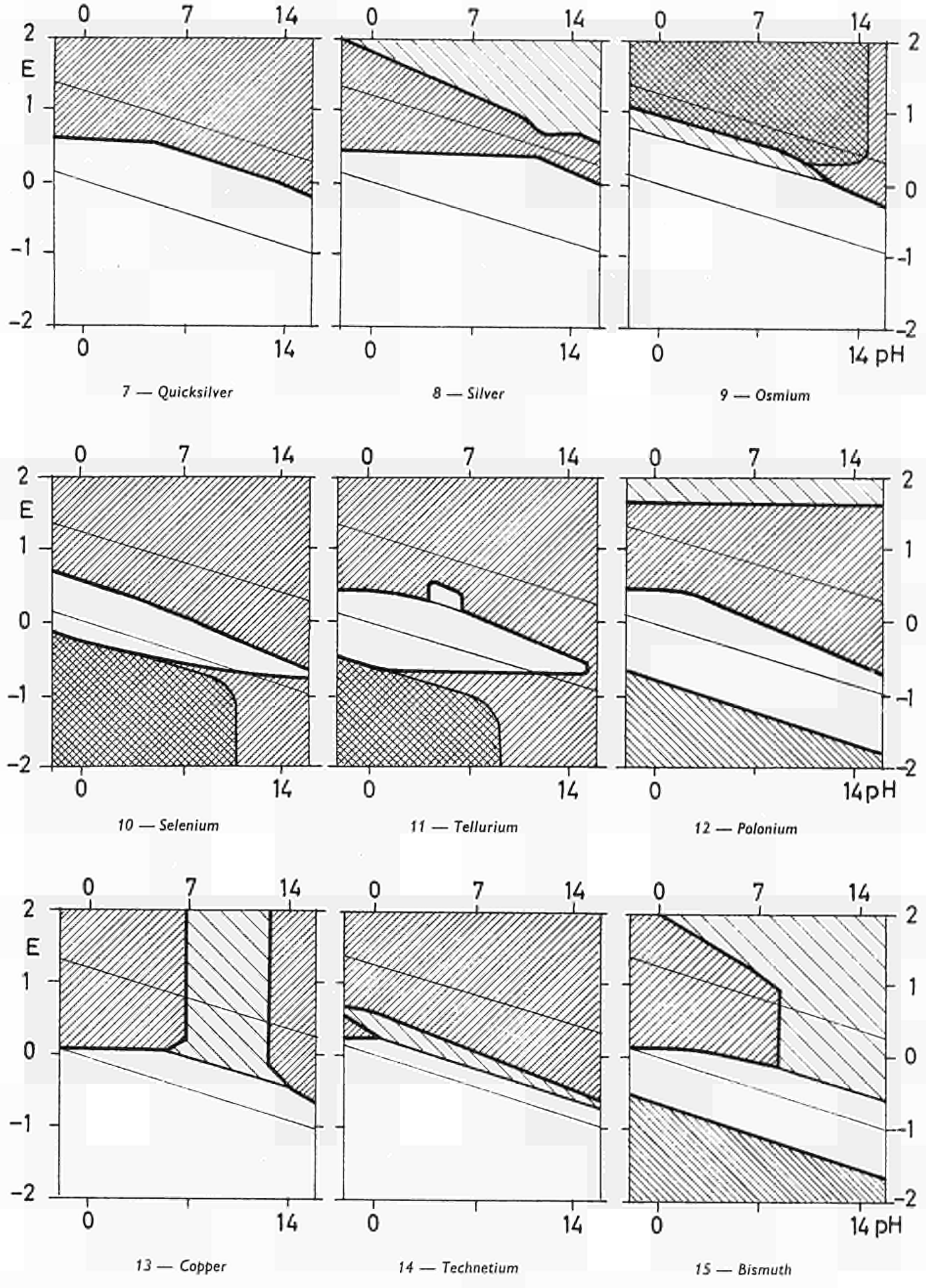
Experimental factors of corrosion, immunity and iron inertia in the presence of agitated aqueous solutions.

the basis of theoretic considerations, but also on the basis of results of experiments conducted in agitated solutions.

A detailed discussion on electro-chemical equilibria would emerge from the body of this paper. We shall content ourselves, however, with giving such diagrams as in the following figures for 43 metals and metalloids (Biblio. 2), of which No. 25 will be seen to be iron. The figures will also be found for: cadmium (No. 24), tin (No. 26), zinc (No. 32), chromium (No. 35) and aluminium (No. 39), all metals that are commonly used for the protection of steel. Elsewhere, (Biblio. 2,3,4,5), details may be found concerning the practical utilization of these diagrams, and also on experimental methods of the study of corrosion that are related to them. Later on, we shall indicate a few applications of these figures in the study of the protection of ordinary steels against corrosion, with particular regard to the preparation of the metal surface and the application of protective coatings.

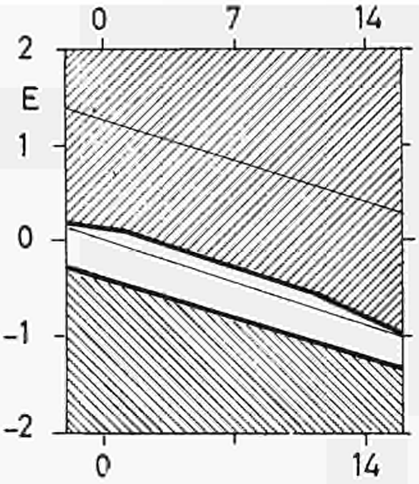


Corrosion zones, immunity and inertia zones of metals and metalloids classed in order of thermodynamic superiority.

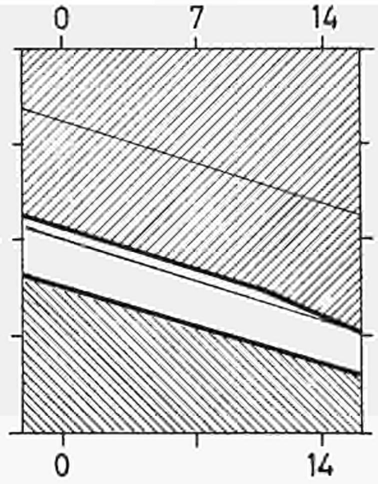


Corrosion zones, immunity and inertia zones of metals and metalloids classed in order of thermodynamic superiority.

(See explanation of symbols on p. 177.)



16 — Antimony



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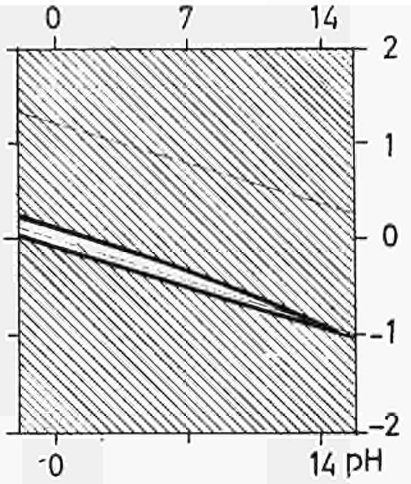

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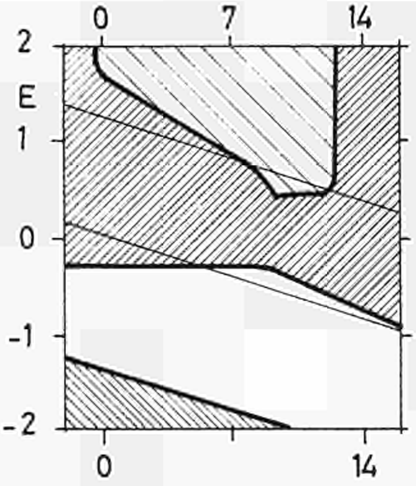

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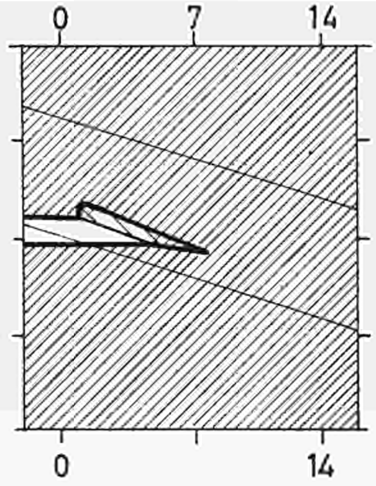
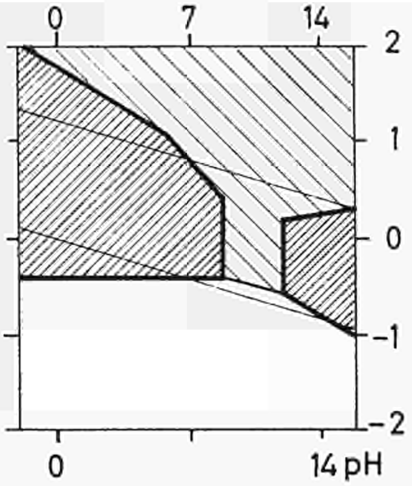
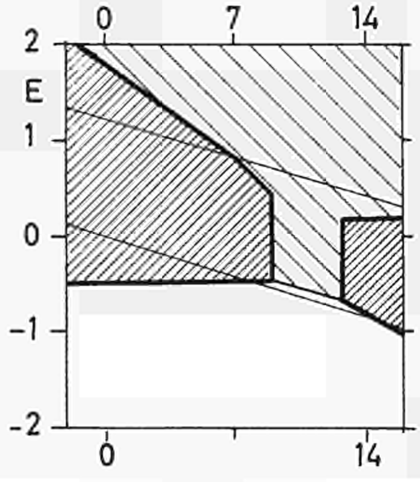


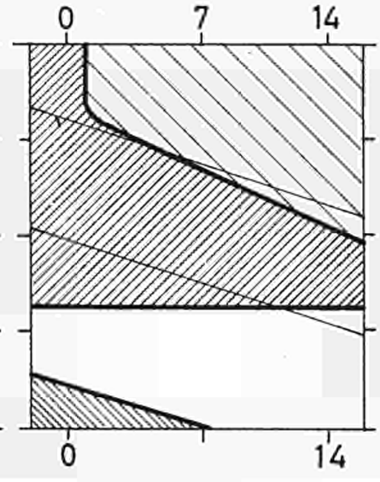
20 — Rhenium



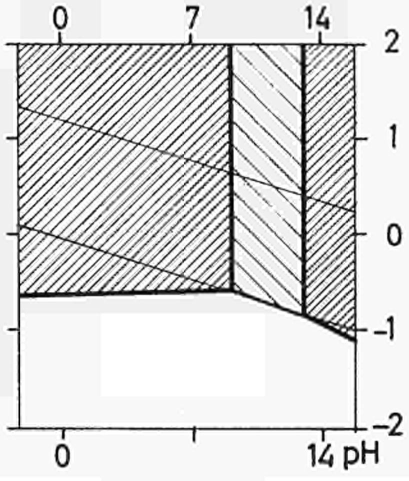
21 — Nickel



22 — Cobalt



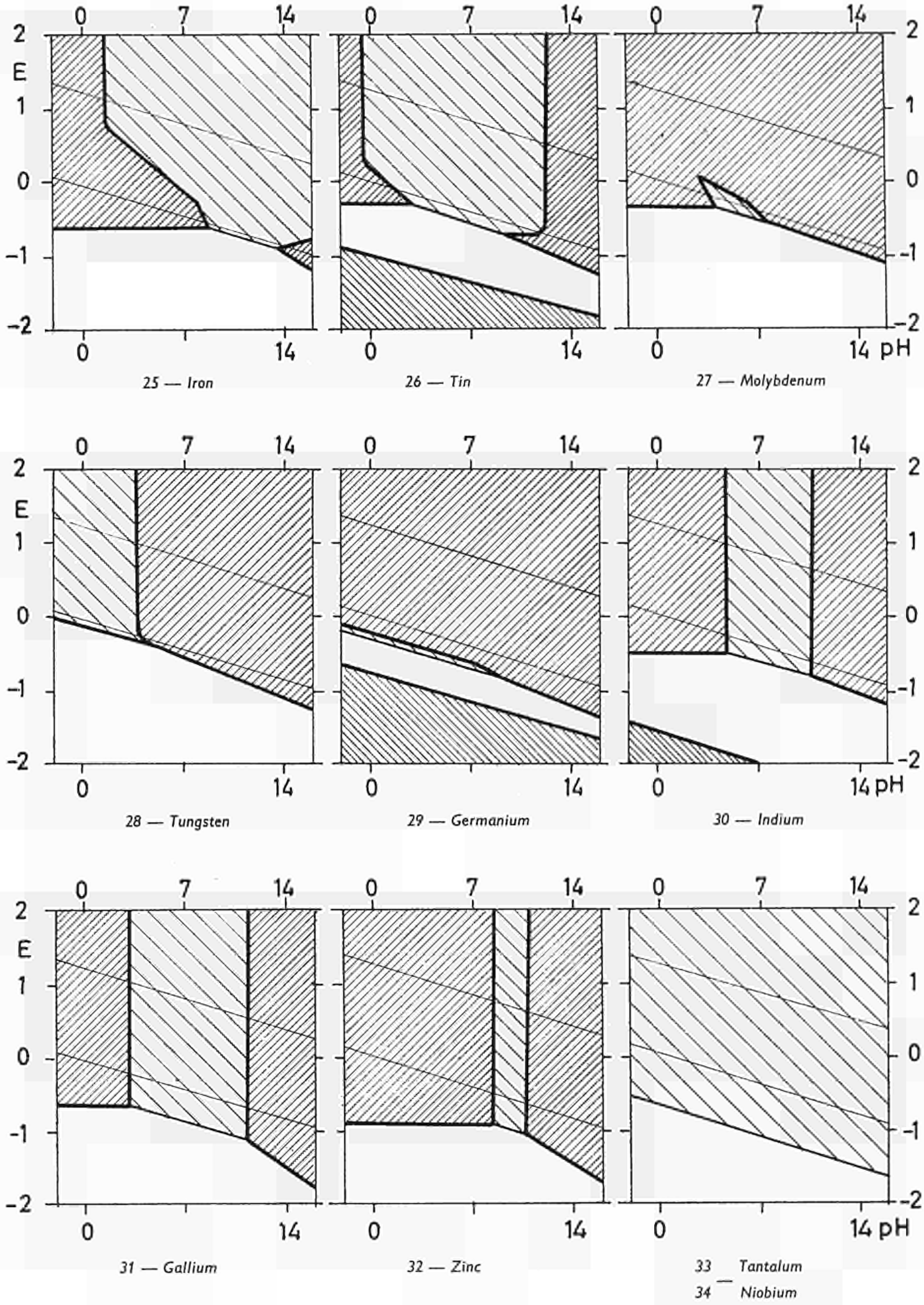
23 — Thallium



24 — Cadmium

Corrosion zones, immunity and inertia zones of metals and metalloids classed in order of thermodynamic superiority.

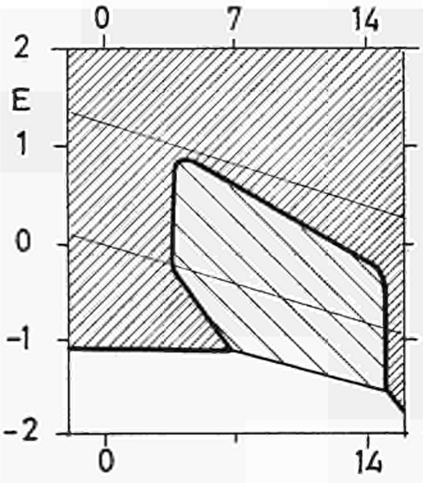
(See explanation of symbols on p. 177.)



25 — Iron
26 — Tin
27 — Molybdenum
28 — Tungsten
29 — Germanium
30 — Indium
31 — Gallium
32 — Zinc
33 — Tantalum
34 — Niobium

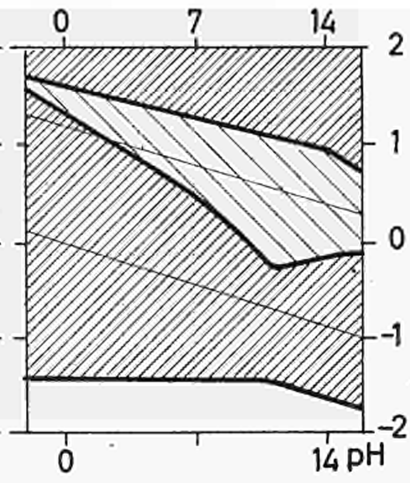
Corrosion zones, immunity and inertia zones of metals and metalloids classed in order of thermodynamic superiority.

(See explanation of symbols on p. 177.)

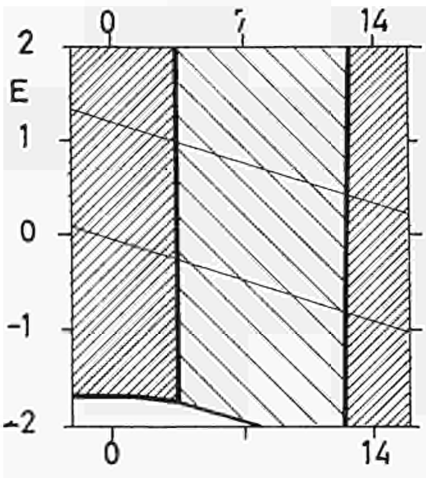


35 — Chromium

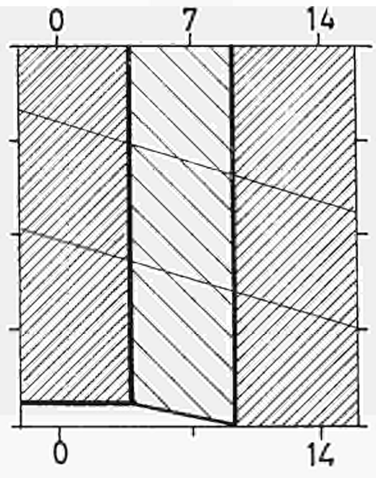
36 — Vanadium



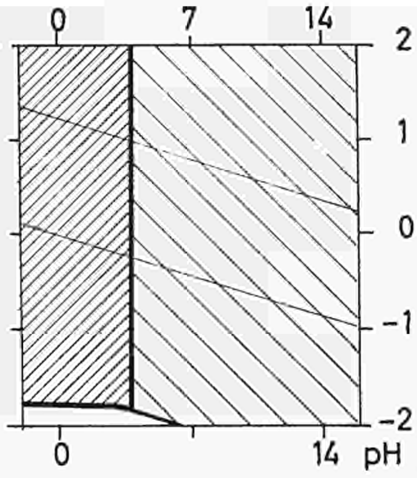
37 — Manganese



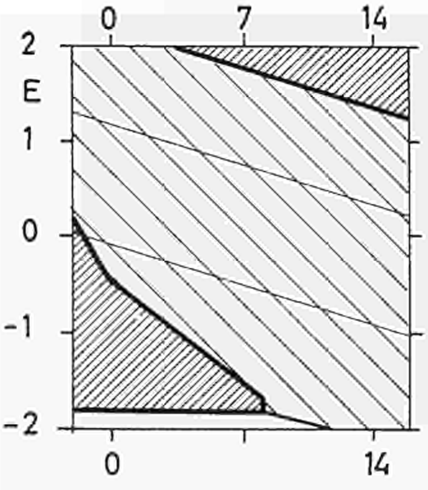
38 — Zirconium



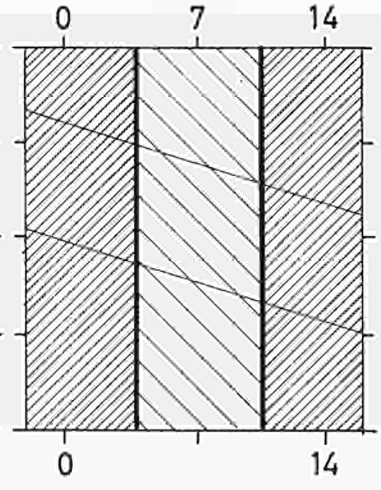
39 — Aluminium



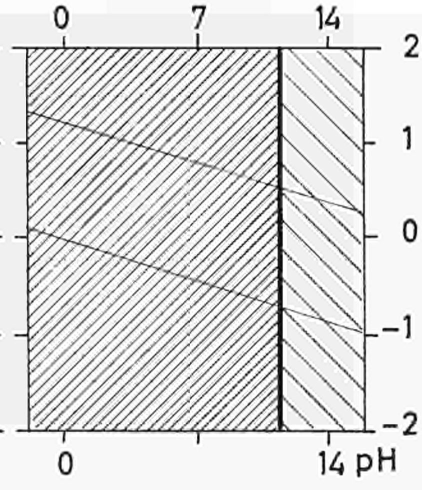
40 — Hafnium



41 — Titanium



42 — Beryllium



43 — Magnesium

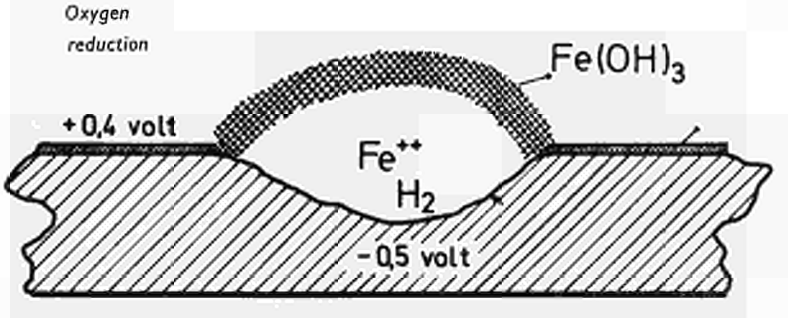
Corrosion zones, immunity and inertia zones of metals and metalloids classed in order of thermodynamic superiority.

(See explanation of symbols on p. 177.)

The zone of stability of the iron and the zone of stability of the water have no common points in the diagram of the electro-chemical equilibria. This means that the iron and the water cannot be stable simultaneously in the conditions for which the figures have been drawn up, and the electrode potential of the metal will normally be situated between these two zones, that is to say, in the case of slightly neutral water, in the zone of corrosion that comprises the central part of the figure.

Unless special precautions are taken however, iron and non-alloy steels will inevitably corrode on the formation, at places where the air has no access, of a ferrous solution, creating hydrated ferric oxide on contact with air, which is the main component part of rust. The triangular nature of the large corrosion area in the figure on theoretical factors of corrosion, due to the fact that ferrous oxide is much more soluble than ferric oxide, is therefore responsible for the fact that the corrosion of iron in water leads to the formation of craters covered with mushroom growths of rust, underneath which there is a continual, gradual destruction of the metal by differential aeration. The following figure, based on a design by U.R. Evans (Biblio. 1), indicates such a corrosion crater and its mushroom growth of rust, with an approximate indication of the values of the electrode potential existing in the interior and exterior of the crater, where the difference of the potentials induces the differential circulation of currents of aeration, causing corrosion.

Air O_2 aerated water

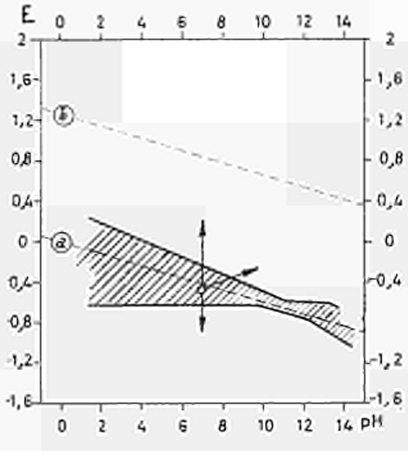


Fe_2O_3 film

Corrosion crater

From the practical point of view, if we disregard the protection processes of the application of water-resistant coatings, the struggle against corrosion in iron and non-alloy steels will lead to the metal potential being prevented from establishing itself in this corrosion zone. This leads us to consider two groups of protection processes, the principles of which are shown in schematic form in the following figure, deduced from the diagrams on page 176:

— The electrode potential will be lowered in the zone of immunity, which is chiefly possible through contact with the zinc, by galvanization, for example, or by painting with zinc powder. The cathodic protection obtained in this manner will be completely effective, if the electrode potential is maintained at less than — 0.62 volts.



Anodic protection

Protection by alkalization

Cathodic protection

Protection of iron against corrosion

In this connexion, we should like to point out that an insufficient cathodic protection is less harmful than a complete lack of protection, since it causes no risk of increasing the speed of corrosion. Moreover, cathodic protection, which implies that the water is reduced to a state of instability, and then further reduced with the formation of hydrogen, involves a permanent intervention of energy, as for example, in the permanent consumption of zinc.

— Furthermore, the potential in the zone of passivity may be increased by the introduction of oxidizing inhibitors, such as chromates, or possibly by alkalization. The protection afforded in this manner however will only be effective if the passive oxides thus formed are efficient protectors. At the same time, the presence of certain salts, chlorides in particular, can lead to localized deterioration of the oxides. This means that the protection does not affect the entire surface of the metal, but permits localized corrosion, which can be very important.

Contrary to cathodic protection, protection by passivity can fail if it is not carried out in the most suitable conditions possible, for it can replace a general and relatively weak corrosion by a very fierce localized one. Moreover, the aspects of protection by passivity correspond to the simultaneous stability of iron and water. Protection once effected by passivity can therefore be maintained without any permanent consumption of the reagent.

A third group of processes for the combating of corrosion, which involves no reducing or significant oxidizing action, comprises the use of organic absorption inhibitors, which, while maintaining the electrode potential perceptibly in the corrosion zone, settle on the metal, thereby protecting a certain area from the corrosive action of the water. As J.E.O. Mayne (Biblio. 6) demonstrates, this is the method of the action of minium coating. The effectiveness of these absorption inhibitors will be in general not so high as that of the oxidizing inhibitors when used correctly; but their use will not present the same risks in the event of incorrect usage as with oxidizing inhibitors. The oxidizing inhibitors, which can be perfectly effective, can also be dangerous; and the absorption inhibitors, although in general, not perfectly effective, are in no way dangerous. In general, inferior to chromate "primers" in cases where painted coats have been applied under good conditions (on well pickled metal, protected from such corrosive agents as chlorides), the minium primers will excel in instances where such good conditions of application are not available.

Surface Preparation and Protective Coatings

Using practical application of these basic theories, we shall later examine the reasons that are the basis of the effectiveness of these three groups of protection processes for steel, and in particular those that have been developed in the course of the last 25 years, based respectively on the use of "wash primers," the galvanizing of steel and the aluminium cladding of steel.

Wash Primers

During the Second World War, research carried out in the United States with the support of the American navy with the aim of improving the corrosion resistance of ships, led to the introduction of a number of processes for the treatment of steel, zinc and aluminium surfaces before painting, based on the use of base mixtures of phosphoric acid, vinylic resin and zinc chromate (Biblio. 7,8). Applied in a thin layer (0.01-0.03 mm.) to the clean surface of the metal, these products serve both as an alkaline inhibitor and as a base layer, on which a final layer of paint will adhere very firmly, often achieving out-standing performances. They may also be used as a storage layer for instantaneous action, to afford protection from corrosion during storage and construction. These products, which have been widely developed in the last 25 years, with numerous variations, under the name of "wash primers", have led to most impressive developments in the fight against corrosion.

It is now thought that (Biblio. 9, 3) the extraordinary effectiveness of wash primers is due to the fact that they cause a very high grade of passivity on the surface of the iron. Consisting basically of a compound of phosphoric acid and chromate, they have the effect of covering the metal with a protective film of ferric oxide Fe_2O_3, the weak points of which are sealed by nearly non-soluble deposits of chromium oxide Cr_2O_3 (Biblio. 2,10), which results in an oxidation of the entire surface area, and iron phosphate, which, as shown in experimental electro-chemical studies, improves the quality of these oxides in the presence of the chlorides that make the oxidizing inhibitors dangerous. At the weak points in the film of oxide where the iron tends to corrode, the iron in solution is precipitated in the form of insoluble phosphate, at the same time blocking the pores of the defective layer, thereby preventing any localized corrosion which might arise in the event of deficient passivity. In short, wash primers maintain under a thin layer of resin (for example vinylic) a film of iron and chromium oxides, which, due to the presence of phosphate, give increased resistance to aggressive agents. They constitute a step forward with regard to conventional chromate primers, which function perfectly in the absence of large quantities of chloride and other aggressive agents, but are likely to become ineffective if such substances arise. They constitute a step forward with regard to traditional phosphoric pickling agents, because, when properly applied, their chromium content strongly increases the protective action of the phosphate.

This oxidizing phosphate coating seems to us to be, either consciously or sub-consciously, a fundamental cause of the effectiveness of the majority of phosphate coating protection processes that have been developed successfully in recent years.

Galvanization

A second field in which there have been significant developments is that of galvanizing, for which there are two main reasons. Although zinc itself can be effective protection for steel it is quite clear that in many cases it is better if galvanizing is not considered as an end in itself, but, thanks to the wash primers just mentioned, as the best undercoat that can be applied before painting. A second reason for the development of galvanizing is the progress made in the galvanizing process itself, which is now effected continuously on steel strip that is treated chemically at high temperature with a mixture of hydrogen and steam, resulting in the elimination of calamine and a certain amount of superficial decarbonization. Under conditions that are ideally suited to pre-fabrication, we can thus obtain galvanized sheets with outstanding qualities, particularly with regard to their behaviour during drawing operations.

As we know (Biblio. 11), the protective action of galvanizing acts in two ways: if the zinc coating is continuous, it protects the steel entirely from contact with surrounding influences. If the coating is not continuous, because of a mechanical failure, for example, or through corrosion of the zinc, the steel receives a cathodic protection, as is easily seen by superimposing the corrosion diagrams for iron and zinc, as shown on page 177 (Nos. 25 and 32). Contact with the zinc in general lowers the electrode potential of the iron in its zone of immunity, but at the cost of a certain amount of corrosion of the zinc. In this way, the zinc exercises a cathodic "sacrificial protection", which will last, while any flashing arising through the dissolution of the zinc, or through accidents (from hooks, or knocks during handling) will be kept to a minimum. One of the advantages of galvanizing arises from the fact that because of this remote protection, the coat of paint to be applied to the metal can now be applied without the costly process of pickling, provided that this is done before rust begins to form. Coatings of zinc powder are particularly suitable for the protection of galvanized structures, and also, probably on the basis of research carried out by the Institut Belge de la Soudure and Cebelcor since 1960, for welding primers for electric welding of ordinary or galvanized steel sheet.

In general, zinc itself does not remain unaffected by corrosion, and in the pre-determined conditions of its application, it can be agreed that the viability of a galvanized structure exposed directly to corrosive elements is directly proportional to the thickness of the layer of zinc.

The advantages now offered by wash primers for the application to zinc of coats of paint and plastic cladding that are perfectly adhesive and not liable to "undermining", leads us to conclude that, as stated above, the coating of steel with zinc, either by galvanizing or electrolytically, is one of the best undercoats for such claddings, and also in conditions that are adaptable to prefabrication.

Aluminium Cladding

Together with a number of other metals (including beryllium, tin, silver, gold, titanium, tantalum and niobium), aluminium has the characteristic in the diagrams shown on page 177, that the central median strip of pH to 7 does not cross the zone of corrosion, that is to say in the normal electrode potential circumstances (see figure below; source: "Atlas d'équilibres électrochimiques", p. 72) (Biblio. 2). This means that these metals will not corrode in the presence of pure water, or in the presence of other waters where the content of aggressive elements (particularly chloride) is lower than those that are harmful to the inertia characteristics of the protective film of oxide, failing which, localized corrosion may be expected.

Mounting material

Aluminium-Silcon Alloy

Aluminium-Iron-Silicon Alloy

Steel base

Cross section of a steel plate aluminium coated by immersion in a bath of aluminium-silicon alloy (x 250).

It is this characteristic, together with the protective properties of the aluminium that is formed spontaneously on the surface of the metal, that is the fundamental cause of the outstanding behaviour of aluminium in corrosive atmospheres, which has led to the significant developments that have now taken place.

The cladding of steel with aluminium is carried out nowadays on an industrial scale, chiefly by means of a process of immersion in a solution of molten aluminium with additions of silicon, which, on the same principles as hot dip galvanizing, produces a cladding that is especially adhesive to steel (Biblio. 12). Contrary to galvanizing, aluminium cladding does not give the steel a cathodic sacrificial protection, except perhaps in certain cases where the aggressive elements include chlorides and are harmful to the film of aluminium formed on the metal. The basic function of the aluminium is to protect the steel from contact with surrounding elements, and the permanence of this action is closely connected with the permanence of the quality of the cladding, which according to current jargon, should be described as a "cathodic" and not an "anodic" cladding, as, in the case of zinc. A chance industrial experiment (Biblio. 12) led to the observation that, in exposure to atmospheric conditions that did not contain chlorides, the iron corrosion resulting in the first few years at the weak spots of the aluminium layer, acted progressively as a seal to these spots, resulting in a remarkably good durability of the metal, and allowing the expectancy of significant developments in the field of aluminium cladding. This is relevant not only to rural atmospheres, but also to tropical and industrial atmospheres, as well as to heat corrosion.

Pickling

Returning now to the subject of surface preparation before the application of surface protection, we shall point out — although it may have been said already — that the removal of calamine is advocated in all instances where viability is to be assured in spite of the risk of metal dampness. Where the calamine is cracked, or where it does not adhere perfectly to the metal, the electrode potential is situated in the corrosion zone in the centre of the figure on page 176 with a dissolution of the calamine by the reduction of iron oxides, and corrosion of the metal by oxidation.

It is also advisable to prevent the steel from becoming charged with hydrogen, which can result, during acid pickling, during corrosion from chloride elements, arising for example during storing in the presence of salt spray, or in the course of certain galvano-plastic processes (cadmium cladding), in the metal having a low electrode potential. As P. Bastien (Biblio. 13) has shown, this hydrogen can lead to a certain fragility in the metal. On final removal, and after the application of coating of paint or another cladding, it can also cause blisters, which result in a gradual deterioration of the cladding. It is good to ensure that any hydrogen in the steel is eliminated in good time, by a suitable heat treatment, for example.

We should also like to point out that new pickling techniques have resulted from the prohibition of dry sand-blasting in certain countries, including damp sand-blasting with corrosion inhibitors, and a process involving the projection of lengths of steel wire (Biblio. 14,15).

Techniques for the protection of steel surfaces

New Trends

The most widely used techniques for the protection of steel surfaces at present are, for the greater part, not new. But it is clear that the tendency is for the more and more important development of already tried and approved techniques. This includes development in all fields, and particularly in that of construction, but above all in that of prefabrication. This trend originates from a more general realization that steel must be protected from corrosion, and that the efficiency of this protection must be improved. To increase the life of a steel structure, reduce maintenance costs and surface deterioration, there is a consistant demand for clean material, well prepared, and well protected even though this entails paying more to begin with.

To give an example, heavy framework sections are generally cleaned with a metal brush, and then given one or two coats of red lead in the works. After assembly, the framework is then given a finishing coat. Slowly, but gradually, however, on the request of important clients, the standard of protection of these sections is increased: they are bright sandblasted, and then receive immediately a base coat of high zinc content paint whilst still in the works. In this way they are even protected from knocks or damage during transport or assembly by the action of the high zinc content paint, which has very high adhesion properties to clean metal. It seems that this trend towards higher requirements comes mainly from German clients. On the other hand, this technique has been used for some time by certain naval shipyards.

The very high rate of manufacture of pre-painted steel strip raises possibilities for steel construction: quicker assembly, lower prime costs, higher quality etc.

The material is rolled, then hot dip galvanized or electro-galvanized, phosphated and chromed, and then finally given one or two layers of paint. All these operations can be done successively and at high speed, in closed shops, with a controlled atmosphere and without any intermediary storing period during which corrosion could set in. This ensures an excellent quality of protective coating. These pre-painted sheets are chiefly used in the manufacture of roofs, curtain walls, supports and folded sections.

This continuous manufacturing technique of sheets pre-painted in the works was developed chiefly for aluminium sheet. Even today, in the United States, there is one line for the processing of steel for every three for aluminium. We are now waiting for the time, about 3-5 years from now, when this proportion will be reversed by an increase in the number of lines processing steel. Whereas in the United States it is production that has difficulty in keeping pace with demand, there is a certain lack of demand in this field from customers in Europe. It is clear that this situation is only a temporary one, and that the manifold advantages of this process will boost its development. Here and now, treatment lines, already in existence or under construction, are ready to satisfy the demand (Biblio. 16).

In Belgium, for example, one plant in operation for the last three years, can cope with sheet with a width of 300 mm. at a speed of 24 m./min., and could easily be increased to 600 mm. Another line to be commissioned in the next few months, will be able to treat plates with a width of 1,500 mm. and a thickness of up to 1.5 mm.

Among the reasons why Europe is lagging behind the United States in the production of continuously pre-protected sheet (with paint, enamel or plastics) I would list:

— the greater variety of special requirements indicated by architects or clients,

— the greater difficulty in getting the public authorities to approve new products,

— the lower labour costs.

Consequently, the production lines existing in Europe are mostly designed to treat sheets rather then continuous strip.

Finally we must mention the important evolution of a rather older protection technique: hot dip galvanizing, for which one client, the automobile industry, has been the cause of increased consumption. In the United States, production of galvanized steel has increased from 124,000 tons in 1957 to some 476,000 tons in 1962 (Biblio. 11). The upsurge of galvanizing is explained by the fact that apart from its normal role as a protector, zinc also constitutes an excellent adhesive base for paint, after treatment with a wash primer. When the painting of a galvanized and painted structure begins to deteriorate, there is still time, before the steel is affected by corrosion, to proceed with retouching work, by means of a straightforward washing, followed by a coating of wash primer, and the application of a fresh coat of paint.

After describing these few general tendencies, we shall examine in greater detail the developments of some of these techniques, including galvanizing aluminium cladding, phosphate coating and the use of alloy steels.

Galvanizing

Galvanizing may be effected by one of two main techniques: hot dip galvanizing, by dipping into a bath of molten zinc, and electrolytic galvanizing, or galvanizing by electrolysis. The first method, hot dip galvanizing, requires vessels of large dimensions, if structural pieces or boilers are to be treated. It is often the size of the tank which restricts the application of the process which is, however, rapidly gaining ground in various fields, *e.g.* for the protection of the pylons for overhead electric high-tension transmission lines, supports for overhead contact lines for electric locomotives, supports for television transmitter aerials, etc.

Hot dip galvanizing has developed at an increased rate, however, since the introduction of continuous strip galvanizing. These lines can treat rolls of steel in coils at high speed, as they unroll through different baths. Different methods of hot dip galvanizing are distinguished by the preparation of the surface (Biblio. 17): it is prepared, for example, by deposits after treatment in an acid bath, an alkaline bath, and then an acid bath once again, of flux, obtained by passing the material through a bath containing chloride of zinc and ammonium, and then drying this flux in a furnace at a temperature of 230°C. Another technique prepares the surface initially in a furnace with an oxidizing atmosphere, in which mineral oils are burnt resulting in a slight oxidation of the surface of the steel. After this, the oxide is reduced to pure iron in a reduction furnace (hydrogen, nitrogen), and the metal is annealed at the same occasion after rolling. In the same controlled atmosphere (hydrogen, nitrogen), the material is partially cooled, and the remaining heat serves to maintain the temperature of the galvanizing bath. The last stages are the same in the different processes:

a layer of zinc is applied, fairly thinly forming an alloy with the iron and producing a relatively weak alloy. The rest of the layer deposited remains as zinc, as formed in the galvanizing bath.

The steel strip is uncoiled along the line at a speed of between 60 and 90 m./min.

We have already mentioned the increasing application of galvanizing in general. In the United States, 45 lines for galvanizing in the continuous system were commissioned between 1945 and 1963, nine of these since 1960. The most significant development in this field is undoubtedly the automobile industry, where the widespread use of chlorides in winter to melt ice on the roads, has resulted in particularly effective methods of protection (Biblio. 11).

Electrolytic galvanizing is also effected continuously. But whereas the hot dip method can result in deposits with a thickness of up to 50 μ on each surface, a thickness of 2.5 μ is rarely exceeded in the electrolytic method. In general, electrolytic galvanizing is not sufficient for the protection of metals exposed to outdoor atmospheric conditions, and an additional coat of paint is necessary.

Electrolytic galvanizing does not affect the properties of the material, whereas, generally speaking, the layer of zinc obtained by immersion, particularly in the case of continuous treatment, hardens the steel, thus making, for example, deep drawing more difficult. Elongation, between 40 and 48% before galvanizing, falls to between 25 and 34% after continuous hot dip galvanizing, especially if no particular treatments are applied. Equally, the Erichsen value will fall from 10.8-11.5 mm. to 9-9.5 mm. for sheet with a thickness of 1 mm. Nowadays however we are able to restore the properties of the original material by means of special annealing processes (Biblio. 18). This is a development from which industry has been able to profit, and this is reflected in the ninefold increase in production of continuously galvanized hot dipped strip.

Before being painted, galvanized strip or sheet must be treated either with phosphate coating or with a wash primer. Failing to do this will inevitably result in the paint peeling. But it has already been shown (Biblio. 11) that the zinc coating can be transformed by means of thermal treatment into a ferro-zinc alloy ("galvannealed coating"). A surface of this kind, of a clear grey appearance, may be painted without an initial phosphate coating.

When the problem of protection from corrosion in prefabricated structures arises, one is always faced with the difficulty of assembly. If the best solution to this problem is joining and assembly by bolts, on the condition that special precautions are taken against corrosion — as Layton recently pointed out (Biblio. 21) — the welding can often be a matter of choice, but spot welding is recommended.

In general, welding is not easily carried out on galvanized steels. The use of special electrodes enables welding to be done, but at the cost of increased welding time and a higher consumption of current. Spot welding on electrolytically galvanized steel is, of course, much easier than on hot dip galvanized material.

Apart from the difficulty of welding, there is also the problem of the destruction of the protective coating through vaporization of the zinc during the welding process. These problems can be overcome to a certain extent by the use of welding primers. For example, there are primers with high zinc contents with a delayed hardening action, which are calculated to remain in a slightly liquid state when welded, and do not form resistant barriers to the current, and then, later, when drying, ensure the welded spots with a certain amount of protection. Inhibitor strips may also be used. These are placed between the materials to be welded and are good conductors of electricity. This problem in the assembly of galvanized steel by welding is at present the subject of promising research.

Aluminium coating

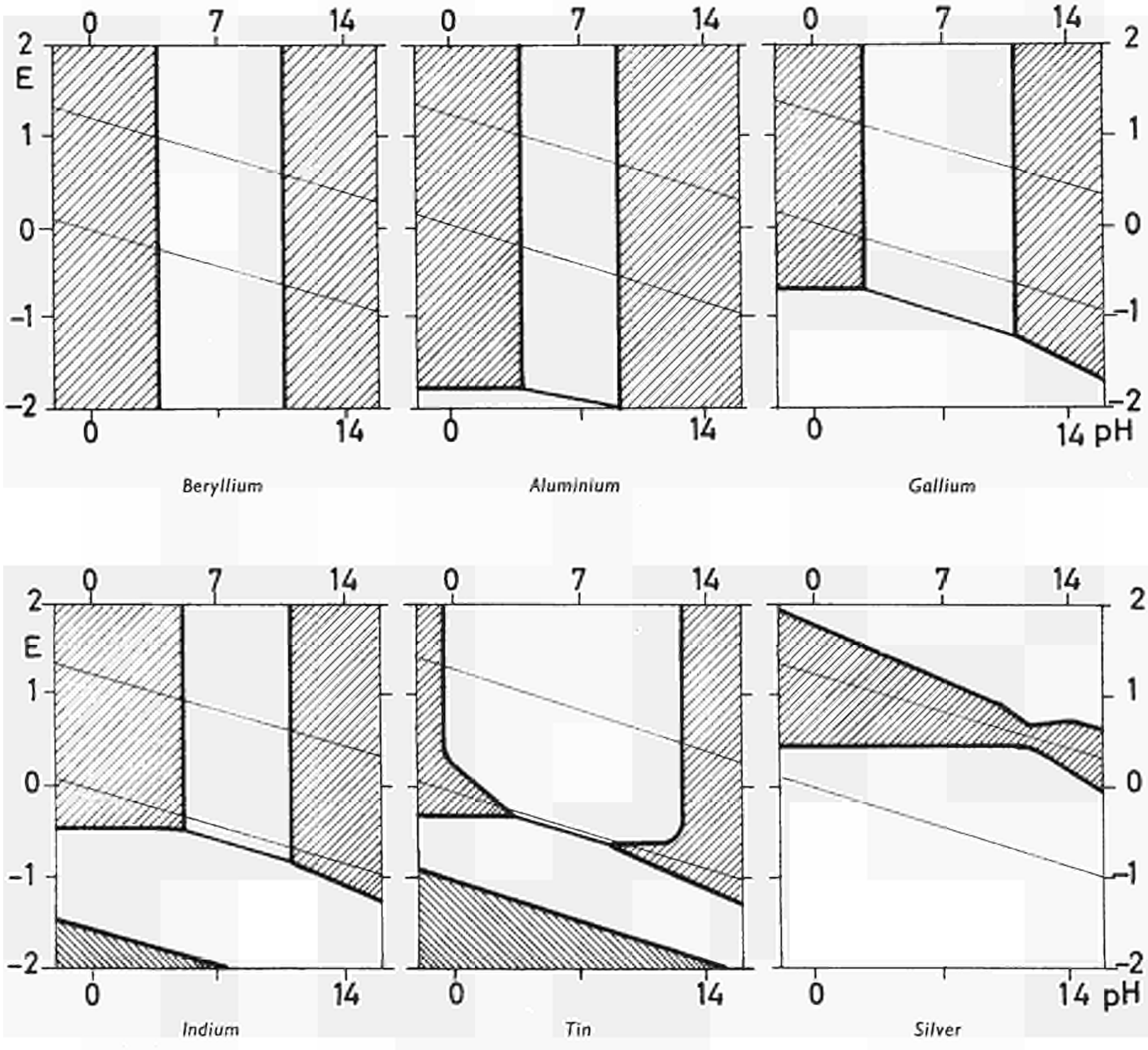
The method of protecting a steel surface by the application of a layer of aluminium is fairly recent. Aluminium metallization — or shoopage —, which is the diffusion of molten aluminium through a pipe, is widely used for the coating of structural sections at Usinor, Dunkirk.

The steel may also be coated with aluminium by immersion in a bath of molten metal, just as in the hot dip galvanizing process. Here too, the process can be executed continuously. There are already a number of plants in operation for the continuous coating of wire, plate and strip.

The bath contains an alloy of aluminium and silicon which, while ensuring a coating with corrosion properties as good as those of pure aluminium — and in fact even better in polluted atmospheres — will have much better adhesive properties to the steel. As shown in the figure below, this results in a primary alloy zone of Al-Si-Fe, covered with a thicker layer of the alloy Al-Si.

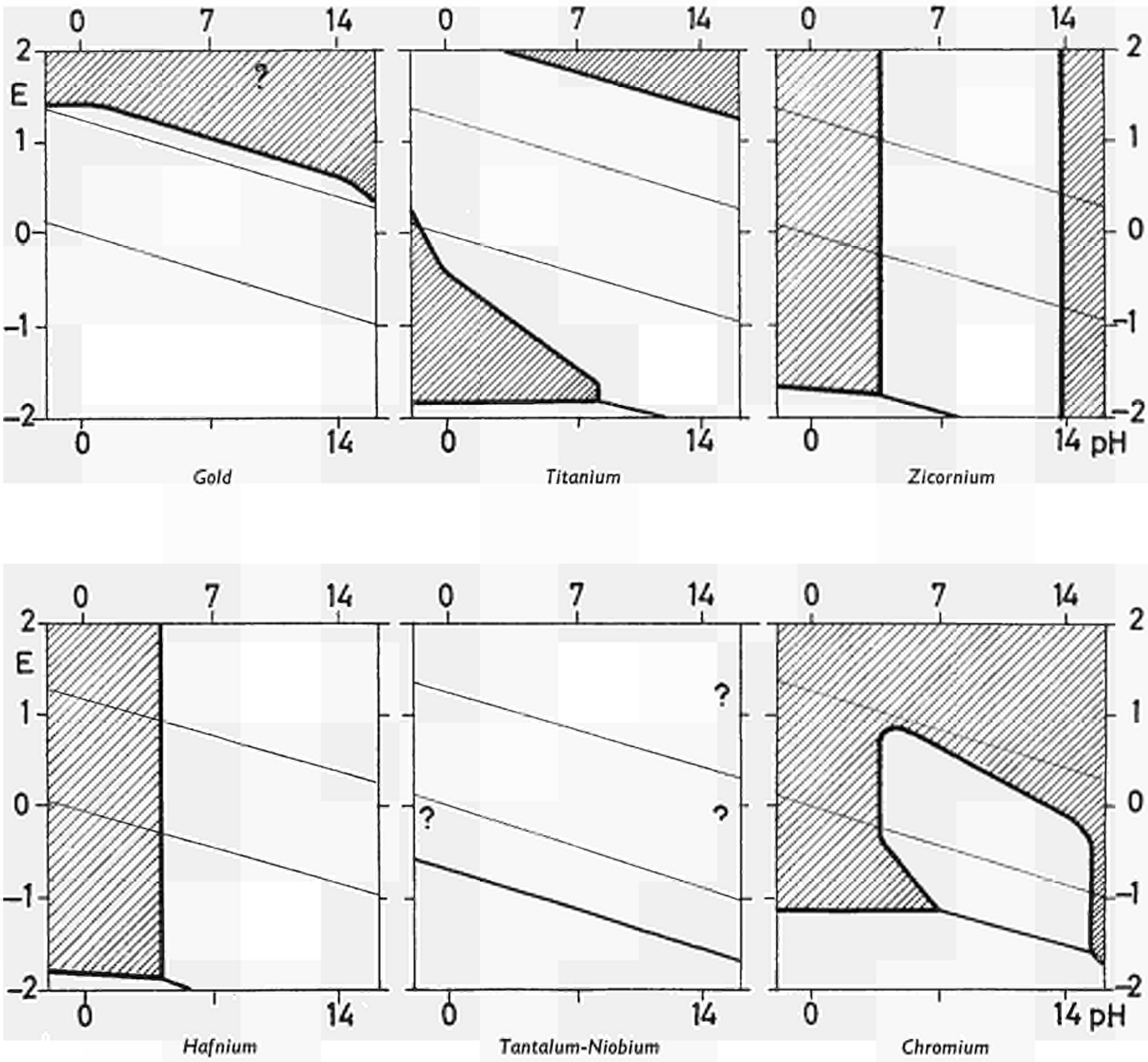
As far as we are aware, the processes of aluminium coating by immersion are not yet carried out in industry on a large scale, at least, not in Europe.

Experiments involving exposure to normal atmospheres have been actively carried out in the United States since 1933. The results of these experiments have been very promising, particularly in non-marine atmospheres.



Metals resisting to pure water.

Hatched areas indicate the theoretical corrosion zones; non-hatched areas indicate the theoretical immunity and passivity zones.



Metals resisting to pure water
(See remarks on page 189.)

More often than not, steel that has been coated with aluminium, or with aluminium-silicon alloy, does not require painting, but in a marine atmosphere, as the protection is acquired by the sacrificial consumption of the aluminium, a further protective coat of paint is advisable. To prepare the surface for painting, initial treatment with phosphate or a wash primer is required, as in galvanizing.

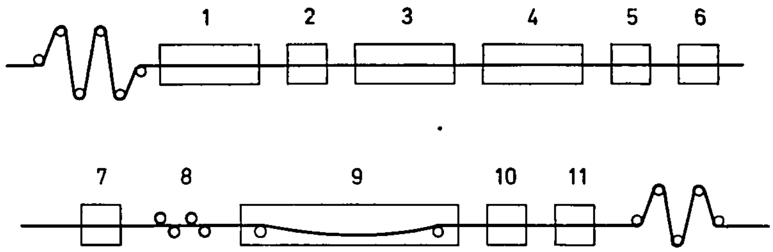
Phosphate coating

Phosphate coating is an excellent preparation for painting and much progress in recent years has resulted in lines, just as in continuous galvanizing, that can treat steel in a continuous strip, either at high speed through the baths or by spraying.

A phosphate coating line is usually linked with a painting line. In this way, the steel passes through one single operation strand and emerges with the desired qualities and colours.

Depending on the required degree of protection, these lines are fed with either plain, untreated steel, hot dip galvanized steel or electrolytically galvanized steel. In the United States, some three quarters of the phosphating lines treat plain steel, which is intended for indoor uses (furniture, etc.). About a quarter treat hot dip galvanized steel. One works is equipped with a single line for phosphate coating and painting electrolytically galvanized steel continuously.

The following figure shows a continuous line for the phosphate coating and painting of strip. Since the technique of phosphate coating has resulted in a number of different patents, this figure can only be one example from many.



Example of a diagram for a phosphating and painting line

The material is first cleaned in an alkaline cleansing bath (1), and then rinsed in two stages (2). It then enters the phosphate bath (3), or the spraying platform, whichever is the case. The bath requires regular regeneration on account of the disequilibrium of the agent induced by the reaction of the phosphate on the metal. Automatic analysers currently control the feed pumps, thereby maintaining at all times a constant composition in the bath.

After another rinsing, the phosphate-coated plate undergoes a passivating treatment by chromating (4), then another water rinse (5) and then a chromic rinse; the latter has usually a base of chromic and phosphoric acids (6) and serves the dual purpose of enhancing corrosion resistance by filling in the pores of the phosphate coating and of preparing the surface for painting (7) by neutralizing all residual alcalinity (8, 9, 10, 11).

The paint is then applied by rollers, in one or more layers, and dried in a furnace.

There may be important variations at the beginning of this process, but we maintain that of particular interest is the fact that these operations are all carried out in the works themselves, sheltered from rain and humidity, and that painting follows immediately after the preparatory stages, and lastly, that these operations are easily carried out, and can even be entirely automated.

Figure 1, p. 201, shows an automatic line for electro-galvanizing and phosphate coating steel sheet. These are far removed from the difficult working conditions of the sandblaster and the painter in the works.

When the galvanized sheet is to be used for curtain walls or supports, they may be assembled, phosphate coated and painted, quite easily by folding and hooking, or by bolting onto a supporting structure. The treatment is then effected after the material has been punched in the desired places; the screws and bolts are also treated. They are often coated with neoprene, and neoprene washers are also used. The purpose of this is to prevent the protective properties acquired during prefabrication from being reduced.

Figure 2, p. 201, shows the hall of a works, where the stanchions have been treated with continuous electrolytic galvanizing, after initial phosphate coating and a thin layer of chrome, and paint. These, exposed to the corrosive atmosphere of a steelworks, have shown no signs of deterioration in the six years that they have been in existence.

In cases where it is not possible to make use of the products from these continuous preparation lines, an efficient method of preparing the surface for painting is by treating it with a wash primer, which is applicable by brush. Such primers usually comprise a mixture of polyvinyl butyl, zinc chromate, ethanol and phosphoric acid (Biblio. 19).

Other methods of protection

We cannot pass over in silence other such methods of protection as painting alone, plastic cladding, enamelling and cathodic protection. As other participants will be dealing with these subjects in greater detail, we shall only consider them briefly.

The market for new paints is continually in a state of movement. There are repeated attempts to improve the adhesive properties of paint on metal, or on older coats of paint, and to increase the impermeability of paints, and to a certain extent their "flexibility" to adapt themselves to the underlying surfaces, and also their resistance to weather, light and chemical agents.

In the particular case of steel panels covered with vitrified enamel, the sheet used to warp frequently after the firing stage. This can now be avoided by decarbonizing the steel, in such a way that during the firing stage, it is no longer partially austenitized. In the fight against corrosion, vitrified enamel coating is certainly an almost perfect protection, provided that the enamel is of good quality and that it has not deteriorated in the course of the coating stage.

In another paper, to be drawn up by Mr. Genot (see page 255 of the present publication), the subject will be the coating of steel with polyvinyl chloride. These coatings always have the same aim: to protect the steel from direct contact with the atmosphere.

During this session the question of cathodic protection will also be raised. This method of protection, which will ensure complete protection when properly applied, even on plain, untreated steels (in this instance, coatings only serve to reduce the consumption of the current), can only be applied when the structure to be protected is directly earthed (piping, earthing leads) or is immersed in a solution.

Alloy steels

It would be interesting at this point to mention a few low-alloy steels not requiring in general a protective coating, which are now coming to be used more and more.

In Europe, we are quite familiar with copper content steels for their high resistance to atmospheric corrosion. The copper content of these steels is very often as high as 0.2%, and can even be as high as 0.4%.

An increase of 35%, or even 100% in relation to ordinary carbon steel, in the useful working life is quoted by some authors. It is most likely that this will depend to a greater extent on the conditions of the testing.

The copper content steels are of particular interest in rural atmospheres, where they are subjected only to natural climatic factors.

In the United States there has recently been a tendency to develop the production of low-alloy steels adapted to certain special usages. This is to avoid having to make use of stainless steel in each case.

Low-alloy steels in particular have been developed to meet this tendency. They are found in buildings, bridges, pylons etc. Their greatest advantage is that they have the correct resistance to corrosion, even without painting or other kinds of surface protection. (Biblio. 20).

The composition of these steels, and some of their properties compared with those of an A 36 steel are given in the following table:

Composition type of a low-alloy steel with high mechanical properties, in %:

C	*Mn*	*P*	*S*	*Si*	*Cu*	*Cr*	*Ni*
0.09	0.38	0.09	0.03	0.48	0.41	0.84	0.28

	Low-alloy steel	ASTM carbon steel
Elastic limit (kg/mm²)	35	25
Breaking point (kg/mm²)	49	40 - 56
Elongation (%)	22	23

This is, then, a steel, where the Cr, Si, Cu, Ni and P contents are rather more than just traces.

The explanation given for the high resistance properties against corrosion that this steel possesses, is the formation — by the reaction of the additives and the aggressive agents in the atmosphere — of corrosion products, the greater part of which form a thin film, which adheres and protects. Even the sulphurous compounds that are present in the atmosphere contribute therefore, towards the formation of this film. During the first two or three years, the film forms and the colour of the steel is gradually modified, eventually settling at a dark brown. The soluble corrosion products are also washed away by the rain at first, causing streaks of rust. The resistance of these steels to corrosion is about 5 to 6 times — sometimes more — than that of an ordinary carbon steel.

In the United States, and other countries, steel of this type has been used in architectural structures (see also, Mr. Dinkeloo's Report on "Weather-Resisting Steels for Architectural Purposes", p. 291 of this publication). Besides the advantage of reduced maintenance, there is also an undeniable decorative value. It is simply a matter of ensuring that, by the design of the structure, the streaks of rust formed in the first few years are prevented from spreading to the concrete, the porous bricks or to the galvanized steel. These materials, in an alkaline reaction, deposit soluble salts of iron in neutral or slightly acidic solutions, which can damage the outward appearance of the building.

These steels containing Cr, Si, Cu, Ni and P, as well as, in fact better than the copper content steel, prove to be good adhesive bases for paint. Figures 3 to 8 (p. 202 and 203), show the result of a six month exposure to a marine atmosphere of a number of test pieces, that are painted and then scratched, of ordinary steel, copper content steel and low-alloy steel, on the one hand, with an unprimed surface, and on the other with a bonderite primed surface.

The protection mechanism of these steels of the formation of a complex protective film, does not function properly in a marine atmosphere: the chlorides, the terribly aggressive salts opposed to the numerous protective oxides prevent the formation of a high quality film. In this case it is advisable to galvanize or paint the film.

We should also like to point out that, following the same policy as many American steel companies, which is to use low-alloy and cheap steels, another steel is being produced to resist the action of sea water, especially in the spray zone below high tides.

The composition of this steel is (in %):

C: 0.14% — Mn: 0.44% — P: 0.12% — S: 0.023% — Si: 0.44% — Cu: 0.52% — Ni: 0.54% — Cr: 0.009%

Conclusion

New processes, several of which are still in the development stage, have led to significant developments in the field of strength against corrosion for steels used in metal structures. From now on, it is possible to manufacture prefabricated structural components with excellent resistance to corrosion, in favourable technical and economic conditions. These processes result mainly from progress achieved in the field of galvanizing, aluminium coating, phosphate coating, and in the development of low alloy steels.

The science and technique of combatting corrosion have made such great strides that the word "rust" should in future no longer be used in connection with steel. It is up to the producers, manufacturers and consumers to make this come true.

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Rolf HAARMANN

Remarks on the Problem of the Corrosion Protection of Steel Structural Members

(Translated from German)

According to a newpaper report which appeared in the autumn of 1964, a well-known German architect, Professor X, has accused the steel industry of increasingly urging the use of steel as a structural material, without taking any interest in the possibility of protecting the steel against weathering. The Steel Construction Congress of the High Authority in Luxembourg has produced no answers to this problem. It is also asserted that the "zinc coating process" of a firm in Bühl (Baden) is so far the unique type of steel protection in use in Europe.

It seems appropriate to examine and discuss these accusations against the High Authority at what in my opinion is the competent forum, i.e. this year's Steel Congress.

The last assertion about this "unique" European type of "zinc coating process" can be disposed of very quickly. This process refers to one of the many zinc-rich paints which — emanating from Great Britain and America — have been known for about 15 years, and have been marketed in European countries under more or less appropriate titles and fanciful names. Whether or not paints of this kind, which contain in the dry a proportion of 30% or more of bonding material, can be termed "zinc coating" is a problem which is now being considered in Germany, where it is the subject of a court action.

In my opinion, Professor X has been the victim of dubious and very questionable propaganda statements, which can only do harm to these high-zinc paints (which are undoubtedly excellent when suitably and correctly used) by arousing excessive hopes. In the course of these brief remarks one cannot go into details of the technical and economic advantages and disadvantages in the use of these high-zinc paints. Reference may be made in this connection to the technical literature, in which, among other topics, cost comparisons are made with other corrosion protection processes, such as hot-dip galvanizing.

When reference is also made to the lack of possible methods for protecting steel against weathering, it can be shown that a whole series of possible protective measures exist many of which have already been in use for some time.

Of course, no general formula can be given, and the architect, design engineer or contractor avoid the duty of selecting the protection best suited to a particular structure, taking into account the corrosive attack to be expected. In view of the very complex field of corrosion, it is appropriate to do this in co-operation with experts on corrosion.

Some important methods by which steel can be protected against corrosion are as follows:

1. Increasing the corrosion resistance of the steel itself by the addition of alloying elements, for example:

(a) in the stainless steels,

(b) in steels with increased corrosion resistance.

2. By depositing organic protective layers on the steel surface:

(a) by painting,

(b) by plastic coatings.

It may be mentioned in this connection that metallic pigments such as aluminium and zinc powder have frequently been added in recent years to the paints referred to under (a).

The plastic coatings (b), the use of which is mainly confined, at least at present, to steel in the form of sheet, strip, or wire, are frequently deposited on a zinc layer applied to the steel surface (electrolytically or by hot-dip galvanizing) when strong corrosive attack is to be expected.

3. By metallic coatings on the steel surface.

My further remarks will deal mainly with these metal coatings, and in particular with the deposition of zinc by immersion in a fused bath. This so-called hot-dip galvanizing process has developed remarkably in the most varied fields of application.

This may be illustrated by a few figures: The world production of hot-dip galvanized sheet and strip amounted after the last war to about 2.5 million metric tons, and rose to about 8.25 million metric tons by 1964. The production of hot-dip galvanized sections and structures however has also increased very rapidly. Thus the output of the so-called jobbing galvanizing plants in Germany grew from 179 000 metric tons in 1959 to about 270 000 metric tons in 1964. This rise is attributable to a very great extent to the increased use of hot-dip galvanizing as a protection against corrosion in steel structures. These figures do not include galvanizing carried out by the steel construction firms in their own galvanizing plants.

As you know, the masts for the electrification of wide stretches of the Federal Railway in Germany carried out in recent years were almost exclusively protected against corrosion by hot-dip galvanizing. High voltage masts of the energy supply plants are also being hot-dip galvanized to an increasing extent.

What explains the surprising increase in use of this process in so many fields in the last 10 to 15 years, when it has been known for about 200 years and been used industrially for 150 years?

The most important grounds, which were pointed out at the European Symposium : "Protection of Steel Structures by Metallic Coatings" (organized by the European Corrosion Federation under the auspices of the Austrian Steel Construction Association in Vienna in September 1964) can be cited briefly as follows :

1. The economic importance of good corrosion protection has been widely recognized, and it has been established that, generally speaking, expenditure on a reasonable degree of protection is a form of rationalization. The invested capita value of the structures is protected against loss due to premature failure caused by corrosion.

2. Protection of steel structures against corrosion has become a matter of urgency, not least because the contamination and hence the aggressiveness of the atmosphere has increased, at least locally. On the other hand, there is a tendency to employ lightweight construction, in which wall thickness losses due to corrosion can often no longer be tolerated; accordingly reliable protective measures against corrosion have become vital.

3. The considerations dealt with under 1. and 2. are met to a large extent by hot-dip galvanizing. Important also is the fact that the cost relationship between this process and other processes of corrosion protection has moved significantly in favour of hot-dip galvanizing. In the first place galvanizing is less wage-intensive in itself than part of the other processes, and is therefore less affected by wage increases. In addition, both the fixed costs (higher output per hour) and the proportional costs (smaller wage costs per ton of product) have been lowered by rationalization and mechanization. On the other hand, experience has shown that preliminary cleaning of the surface is necessary, and is therefore often specified for sprayed metal coatings and painting when a long life is to be ensured. (The rust specifications of the German Federal Railways may be mentioned in this connection.) An operation of this kind involves substantial additional expenditure.

Thus BOR Seils in 1964 gave costs for the hot-dip galvanizing of masts and railings with a surface of 25 to 30 m² per metric ton (to Federal Railways Specification of 100 μm zinc coating, with a minimum of 80μm) as about 8.00 DM/m². Comparable costs for a paint system (Federal Railways paint) whatever the type, are given as about 10.00 DM/m². According to the same author (European Symposium : "Protection of Steel Structures by Metallic Coatings," September 1964, Vienna) the galvanizing of supporting structures (stanchions, trusses, purlins), with a surface of 15 to 20 m²/metric ton, is more economic than a paint system. This does not take into account the greater durability of a zinc layer.

The following statement should also be of interest for the economic assessment of hot-dip galvanizing : Abroad—and to an increasing extent in Germany in the past few years—steel products such as light masts and high voltage pylons, as well as other steel structures, have been dismantled after years of use after the original corrosion protection had been exhausted and removed to galvanizing plants for hot-dip galvanizing. In Switzerland, for example, a special furnace has been constructed in a galvanizing plant, to burn off residual paintwork, which must in any case be removed before galvanizing.

4. Hot-dip galvanizing is carried out in special workshops, so that all operations are completely independent of weather conditions. This is not the case with painting. For example: Even when structures have been painted in the workshop, the coating must be touched up after erection, and given one or more top coats. The process is very dependent on the weather, as painting cannot be done in rain or in frosty conditions. According to many specifications, painting must only be done when the relative atmospheric humidity is less than 70%. As far as the operation itself is concerned, painting is very much dependent on the reliability of the painter himself, which is not always easily controllable. Quality control of hot-dip galvanizing on the other hand is relatively simple.

5. Some years ago the influence of hot-dip galvanizing on the mechanical properties of the base material was established by comprehensive investigations in several independent Institutes. With the increased application of hot-dip galvanizing for steel structures, doubts arose as to whether the strength characteristics could be impaired by the treatment. In particular, it was feared that the influence of heat during the galvanizing of cold-worked material could lead to "ageing" of the steel with consequent decrease in notch mpact strength. However, these fears were put to rest by the above-mentioned investigations. Thus, Dr. Rädeker summarized his researches by saying "It can be concluded

from the experimental results that hot-dip galvanizing does not impair the toughness characteristics of structural steel components, but indeed improves them in every case." This can be expressed differently in words, similar to those used by Professor Wiegand : When a steel subjected to cold working—by straightening or welding, for example—becomes susceptible to ageing, it will age, whether it is galvanized or painted or untreated. During galvanizing, necessarily accompanied by heating, ageing is accelerated. This would normally develop over a period of weeks or months at normal temperatures, but which would certainly take place in any case. In general, however, the low notch impact strength values associated with natural ageing are not found with galvanized steel, as the steel, after passing through the temperature range of artificial ageing (250 to 300°C), is raised to the temperature of the zinc bath (about 450°C); in this way a certain amount of recovery can take place. In spite of the wide use of hot-dip galvanizing, which has now extended over several decades, no cases of damage have been reported which could be attributed to the influence of the treatment on the base material.

Corresponding investigations have also shown that welded joints are not unfavourably influenced by hot-dip galvanizing. Welding carried out in practice in the erection of structures from galvanized sections has to a large extent confirmed this. It is of course necessary to renew corrosion protection in the weld zone, as the zinc layer in this area boiling point of zinc 907°C) is destroyed. The repair can be made by high-zinc paints, by zinc spraying or by soldering.

6. Just as the use of welded joints instead of riveted joints was delayed until design engineers became aware of the possibilities of the new technique and the way was opened to technically and aesthetically satisfying structures, so the transition to structures needing corrosion protection could not be accomplished without initial difficulties. The saying "corrosion protection begins on the drawing board" has meanwhile become familiar to many design engineers, and a great deal of exploratory work has been successfully accomplished in the field of design relevant to galvanizing. It is known that the danger of distortion caused by hot-dip galvanizing can be largely overcome by measures such as the prevention of welding stresses, avoidance of the use of unsymmetrical sections and the welding of very different wall thicknesses. It is known that the molten zinc must wet the whole of the surface when the steel is immersed in the zinc bath, but that it must run off the work on withdrawal from the bath, i.e. no corners and angles must be present in which large amounts of zinc are trapped. Details cannot be considered here however. Merkblatt 359 of the Beratungsstelle für Stahlverwendung (Düsseldorf) may be consulted in this connection.

7. Last, but not least, galvanizing plants have largely adapted themselves in recent years to the requirements arising from the widespread introduction—once expected and now an accomplished fact—of hot-dip galvanizing as a means of corrosion protection for larger steel structures.

A large number of pots from 10 to 15 m. long are now available in Europe; in fact several 20 m pots have been installed in Switzerland. Transport equipment is also adjusted to the increased weights of the material to be galvanized, so that single parts up to 10 metric tons in weight can be galvanized. All the influencing factors which have been described have led to this increase in hot-dip galvanized structures.

The protective value of zinc coatings can be illustrated by a large number of practical examples, only one of which will be mentioned here. Figure 9 (p. 204) shows the 10 m. high cross in the Haute Fagne (about 40 km. south of Aachen). It was erected in 1890 from hot-dip galvanized components. When the zinc coating had worn away on the weather side by 1959—almost 70 years afterwards—and rusted areas appeared, the cross was dismantled, regalvanized and erected once more. The diagram shows the cross after the second galvanizing treatment.

As a result of numerous natural corrosion tests it has become possible to some extent in recent years to make quantitative statements regarding the effect of the different factors determining the level of corrosive attack, and to give figures for the life to be expected—naturally with some degree of scatter. Details cannot be given here; only two of the most important influencing factors will be named :

1. The depth of the zinc deposit (or in other words the thickness of the zinc layer). The life of the zinc layer is almost directly proportional to its thickness.

2. The impurities in the atmosphere acting on the zinc layer, especially the SO_2 content in this case. The relationship is practically linear. When the amount of SO_2 (given for example in the amount taken up by the Liesegang bell, in which the function of air movement is also taken into account) is plotted on the ordinate of a system of coordinates, and the zinc removed on the abscissa, the amount of zinc removed grows with increasing contamination, and the values lie on a straight line.

   As the degree of purity of an atmosphere cannot normally be influenced (apart from State measures, such as a statute for maintaining the purity of the air), it is natural to wish to control the desired life of a zinc layer by its thickness. There are however limits beyond which the thickness of the zinc layer cannot be influenced; these are dictated to the galvanizer by natural laws.

   The German Federal Railway, for example, requires a zinc coating of 700 g./m.^{2} for masts, although thinner positions down to 560 g./m.^{2} are tolerated. With siliconized material, thicker zinc coatings can be achieved (1000 or 1500 g./m.^{2}). In this case, a changed appearance (matt grey) and a certain sensitivity of the zinc layer to shocks and impacts must be accepted.

   A marked increase in the corrosion resistance of normal zinc deposits can be obtained however by supplementary painting. This combination has proved extremely satisfactory. Here again details must be omitted; a full account is given in a Dutch publication which appeared in August 1965 : "het schilderen van thermisch verzinkt staal" ("the painting of hot-dip galvanized steel"). (Publisher : Stichting Doelmatig Verzinken, Jan van Nassaustraat 93, The Hague.) In every case the finding is justified that the life of such a combination—given a suitable paint— is greater than the sum of the separate lives of the zinc and paint coatings, or, expressed as a formula :

   $L = a \cdot (lz + lp)$

where

L = total life,
lz = life of zinc coating,
lp = life of the paint coating.

a is then a factor which is much larger than 1, and in some cases can be a multiple of 1.

Some examples of unusual hot-dip galvanized steel structures may lend support to these statements.

Figure 10, p. 204, shows a diagram of a chimmey stack tower 220 m. in height (cf "der Stahlbau", No. 3, 1965, p. 76 : "The chimney stack in Stade" by Dipl.-Ing. W. Riese). It will be appreciated that a structure of this kind must be given especially reliable protection against corrosion, since subsequent renewal can only be carried out with difficulty and at considerable cost. The contractor therefore decided to galvanize the whole of the supporting structure, and after depositing an adhesive coat, to apply a paint system of two undercoats and two top coats. As at the time the layout of the installations of the hot-dip galvanizing shops was inadequate for galvanizing the corner posts (maximum width 1.20 m., maximum height 1.70 m., with lengths of up to 12 m. and weights per m. of up to 1 metric ton) and as warping of the unsymmetrical sections was expected, these were protected by spray galvanizing, all other sections being hot-dip galvanized. In an investigation which was carried out four years after erection, no defects of any kind could be found. The stack itself was site welded from hot-dip galvanized curved sheet, and the welded joints re-isolated.

In the case of a similar tower which is shortly to be erected in the Ruhrgebiet, it is also intended to hot-dip galvanize the corner posts; this can be done because of the improved possibilities and greater experience which have meanwhile been attained by the galvanizing shops.

Figure 11, p. 204, shows a stanchion for a transformer station, with a length of 20 m., after hot-dip galvanizing. The trusses for this transformer station, which were about 24 m long and weighed 4 metric tons, were also hot-dip galvanized (in both cases with double dipping).

Figure 12, p. 204, shows the table of a wagon weighbridge after galvanizing: length 14 m., greatest width 1.6 m., height 0.48 m, weight 9.5 metric tons. It can be seen that the table, which was photographed after galvanizing, while still hot, had warped slightly. After cooling the deflection was corrected again.

These remarks should show, using hot-dip galvanizing as an example, that :

1. It is quite possible to protect steel structures against corrosion.

2. This is widely carried out in practice and — as shown by examples — very large and heavy structural steel members can be hot-dip galvanized.

In my opinion, it still remains for the steel industry or steel construction industry to take the following action. Design engineers (and also architects) should take into consideration, more than they have done in the past, the necessary pre-conditions for the design of structures which are adapted to galvanizing, and so make it possible for the contractor to make use of the advantages offered by hot-dip galvanizing. Then the criticism mentioned at the commencement of this paper, that the steel industry was not sufficiently concerned with the protection of its products against corrosion, would automatically be weakened. For the rest, it could be expected that critics, before making such accusations, would first acquaint themselves with the technological position. This could readily be done by consulting the literature or by discussion with corrosion experts; it is completely unnecessary to draw upon biased sources of information.

DISCUSSION

Pierre BLANCHETEAU

(Translated from French)

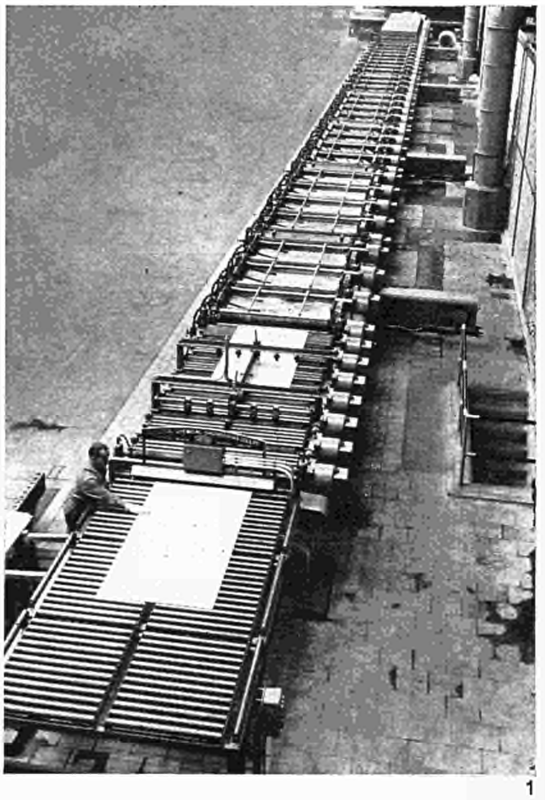
We have heard a good deal about the profitability aspects of the industrial processes for the corrosion protection of steel.

I think it is important to bring home to consumers which characteristics steel definitely must possess to enable these processes to be used; these are: homogeneous composition and sufficiently high mechanical and physical properties.

Surface homogeneity is ensured by making constant checks during the actual steelmaking and by taking all possible care in the various subsequent processing operations.

The necessary mechanical properties such as hardness and elasticity need not be impaired by mechanical cleaning of the surface, which will not damage the main mass of the metal below. The essential physical property is sufficient resistant to heat to allow medium-temperature operations, such as hot pickling and furnace polymerization of varnishes to be effected without causing the structure of the metal to deteriorate. The steel should also be non-porous and chemically neutral, points which are greatly valued by the manufacturers and users of anti-rust preparations.

List of illustrations



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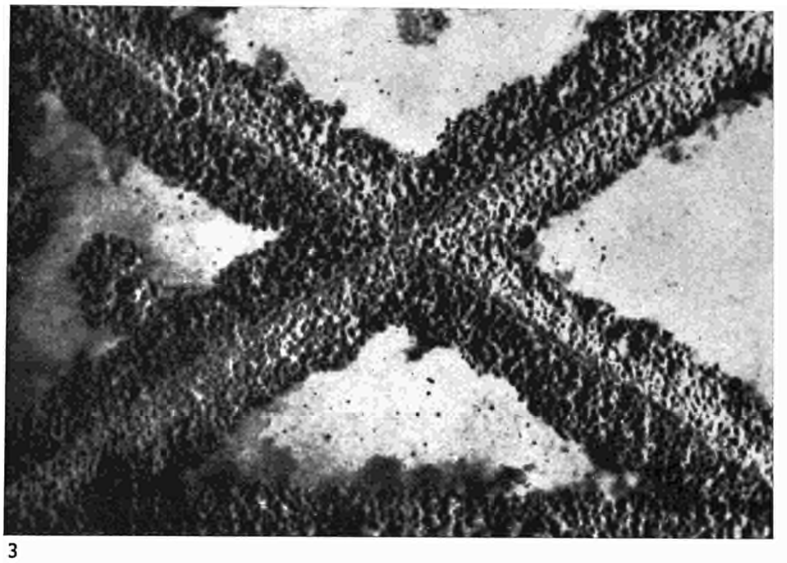

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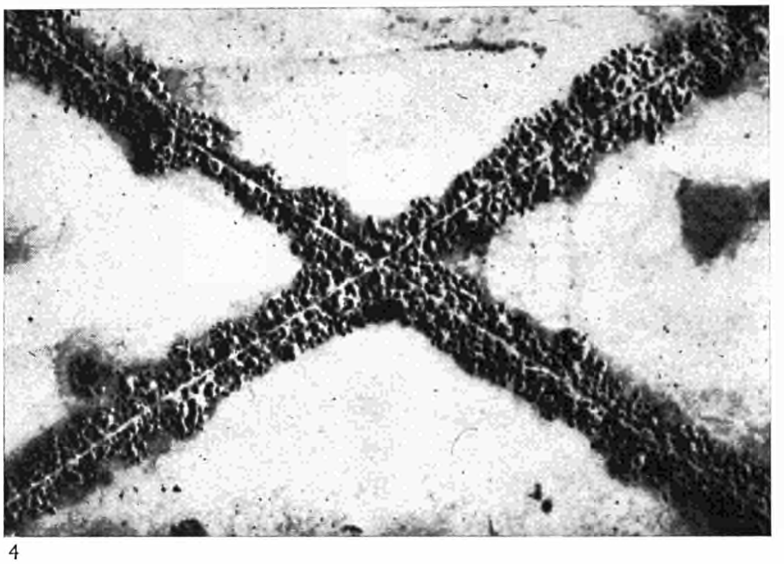

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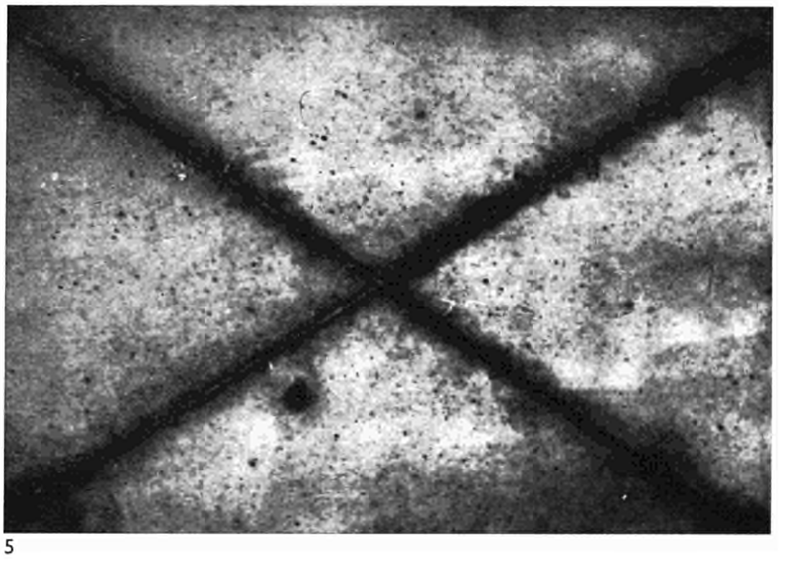

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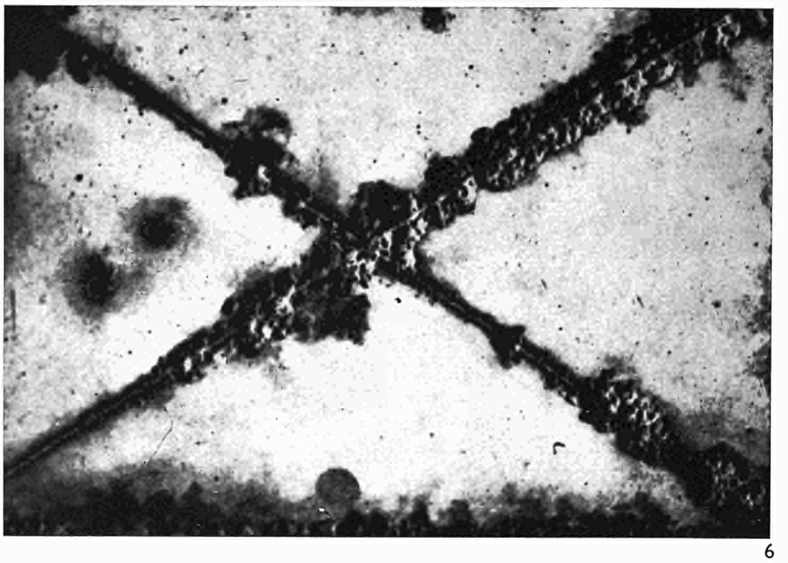

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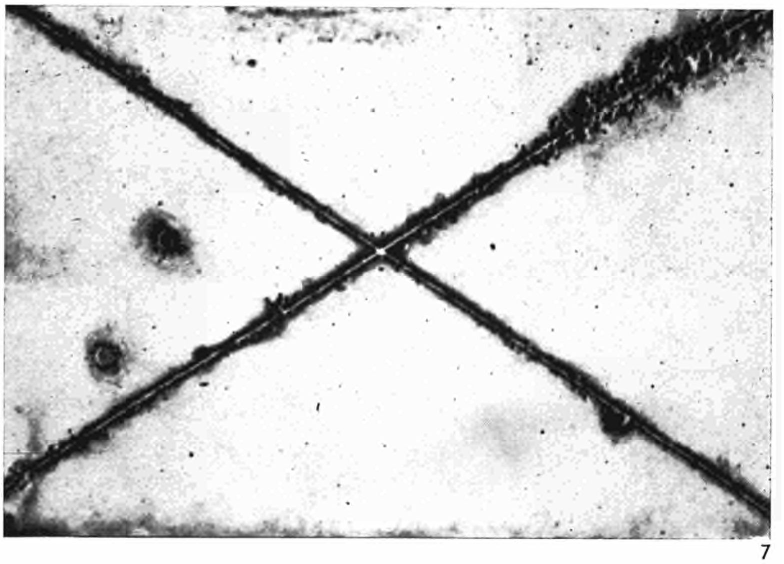

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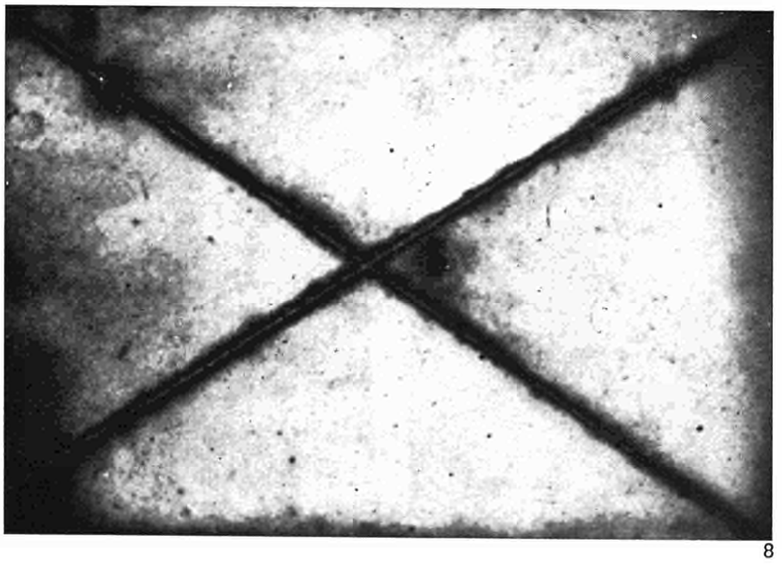

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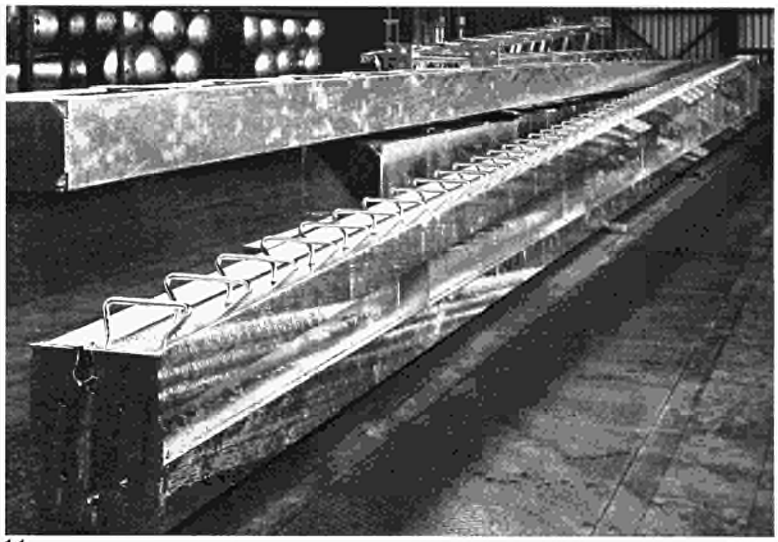
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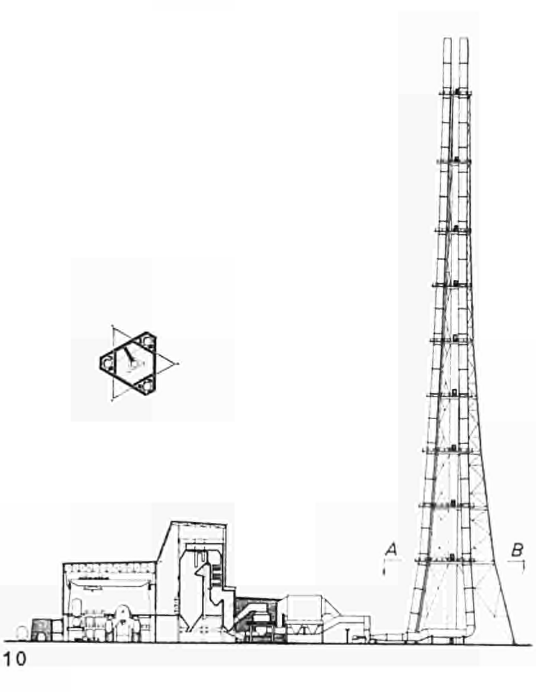

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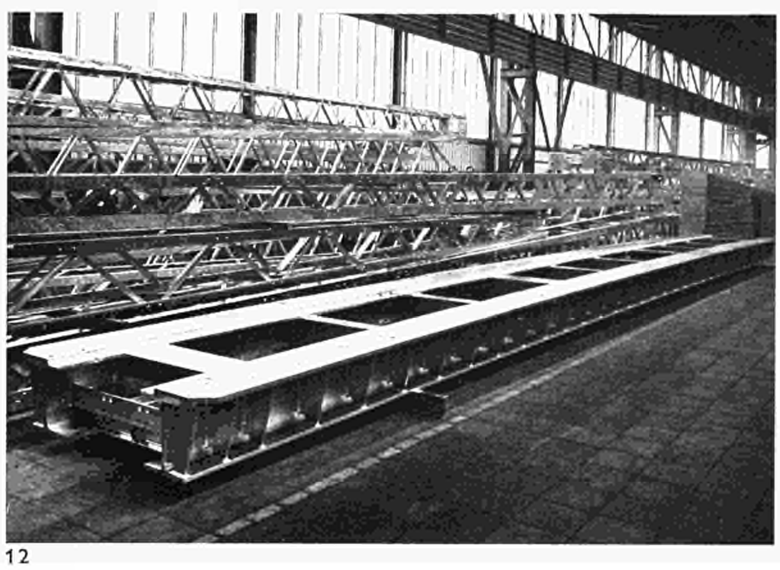

12

Giovanni ODONE

Modern Galvanizing Processes for Steel

(Translated from Italian)

Of the metals used to coat steel and protect it against corrosion, zinc is the cheapest and, next to tin, the one most commonly used.

The anti-corrosion protection offered by zinc is, of course, of the anodic type; due to the relative positions of Zn and Fe in the electro-chemical series, zinc acts as a soluble electrode in all Zn/Fe couples and is sacrificed in favour of the iron.

The corrosion resistance of galvanized steel depends both on the weight of the coating and on the ambient conditions, and can be reckoned in years. For a normal coating weight (about 300 g./sq. m.), it is effective for 15 to 20 years in a rural atmosphere, 10 to 15 years in a marine atmosphere, and 3 to 5 years in an industrial atmosphere.

Galvanized steel has a very extensive range of application, which can be divided into the following four groups:

(1) The building industry — gutters, flue stacks, corrugated roofing, pipes, prefabricated components, offices, farm buildings, silos, collector tanks, tubs, buckets, etc..

(2) The automobile industry — for parts particularly susceptible to corrosion, such as the chassis of vehicles, and for special types of vehicles such as refrigerated trucks.

(3) The metal-furniture industry — modern kitchens, office furniture, etc.

(4) The smaller industries manufacturing various articles such as oil containers, tanks, buckets, ice-boxes, cases, parts for washing-machines and refrigerators, traffic signs, sections for door and window frames, etc.

Galvanizing systems

Zinc was not used for protective coatings until comparatively recent times (1800-1850). It is not my intention here to go into details concerning the various systems of zinc coating — by cementation (sherardizing), by spraying, and by painting — which have gradually developed, but instead to consider those processes of greater importance to-day; the electrolytic and hot-dipping processes of galvanizing, with special reference to the continuous processes for strip and in particular the Sendzimir process, which has been adopted in our company's plants.

Electrolytic processes

Until a few years ago, electrolytic galvanizing was successfully used for, predominantly, small articles and wire, but to-day it is being used with excellent results for steel strip. This new product has found some advantageous applications, especially for painted material intended for indoor use.

The coating weight obtained by electrolytic galvanizing, markedly less than that obtained by dipping, varies in general from 40 to 70 g./sq. m. As the corrosion resistance is proportional to the thickness of the coating, its anti-corrosion performance is not as high.

Many companies who use the dipping method have been induced by the economy of the electrolytic galvanizing process, due to the very low consumption of zinc, and by its flexibility, to install electrolytic lines in addition. This process permits coatings to be obtained of many intermediate thicknesses, which, in the case of strip, can be different on the two sides.

We can classify the electrolytic processes into:

(a) *Acid bath:*

Intended for strip and wire; the characteristics of the process are a high rate of coating and low penetrating power, so that it is difficult to achieve uniform coatings on articles having a complicated shape.

(b) *Alkaline bath:*

Particularly applicable to articles of complicated shape; the characteristics of the process are a low rate of coating but, compensating for this, high penetrating power even in the less accessible areas and in cavities.

As in all electrolytic processes, surface preparation is of the highest importance. This is especially so where acid baths are used, because the acids, unlike the alkalis, have no detergent action. Adhesion will be unsatisfactory if the surface is contaminated by oxides, traces of pickling inhibitor, or oil.

For steel strip, it will therefore be necessary to carry out a preliminary cycle of operations of the following type:

(1) Alkali cleaning.

(2) Water rinsing.

(3) Acid pickling.

(4) Water rinsing.

The electrolytic galvanizing line consist of the following:

(a) uncoilers;

(b) shears (at entry section);

(c) welder;

(d) cleaning and pickling tanks;

(e) electrolytic galvanizing tanks;

(f) washing tanks;

(g) phosphating and drying; and
shears and coilers.

Special attention must be given to the pickling; faces subjected to excess pickling do not give satisfactory results. Water used for rinsing must comply with certain standards of purity, and certain harmful ions must be reduced to a safe limit.

We shall now consider the electrolytic baths most commonly used in the industry.

Acid electrolytes

These can be divided into two classes; those used for coating large articles, i.e. for discontinuous processes, and those suitable for the high-speed galvanizing of strip and wire.

It is not intended here to deal with the first class, and we shall confine our attention to those used in the continuous process.

Sulphate baths

There are various formulae and practices in use. Because of the high anodic efficiency and the tendency of the anodes to go into chemical solution even without the passage of current, the pH of these baths increases slowly and it is necessary to adjust it to the correct value by periodic additions of sulphuric acid. To indicate when such action is needed, it is usual to add aluminium chloride, which precipitates as the hydrogel $Al(OH)_3$ when the pH value rises. In general, a pH of 3 to 4.5, at 21 to 30°C, is used.

Sulphate baths are also used in the Trainton process, employed for coating wire; the anodes are insoluble (Pb with 2 to 3% Ag).

Chloride baths

These have a conductivity greater than that of sulphate baths, for whereas the latter have an internal resistance of 18 to 23 ohms/cu. cm., chloride baths have a value between 3 and 5 ohms/cu. cm. The higher conductivity permits much greater current densities without excessive heating.

Alkaline electrolytes

As already mentioned, these are particularly suitable for galvanizing articles containing re-entrant angles. They are therefore used, for the most part, in discontinuous baths. Among the various types are sodium zincate electrolytes and those with a sodium pyrophosphate base.

The cyanide bath is the one most commonly used at present for strip; it has the characteristic of being comparatively easy to control. The typical electrolyte is a solution of $Zn(CN)_2$, NaCN and NaOH.

Continuous hot-dip galvanizing processes

Before dealing with the modern strip processes, it is necessary to say something about the process of galvanizing separate sheets; this supplied the market with galvanized flat products for several decades.

The process employs lines, on the pattern of tinning machinery, which consist of the following components and procedures:

(a) feeder (mechanical or manual);

(b) HC1 pickling (the sheets have previously been pickled in a rotary machine, and then rinsed);

(c) galvanizing pot, covered by a layer of ammonium chloride flux. This has two pairs of rolls; the thickness and uniformity of the coating are regulated by varying the level of the zinc in relation to the second pair;

(d) cooling conveyor; at this stage, the sheet can be subjected to air jets for controlling the spangle;

(e) washing bath: hot water is used to eliminate any flux residues which may lead to corrosion;

(f) drying: this is effected with hot air;

(g) flattener and piler.

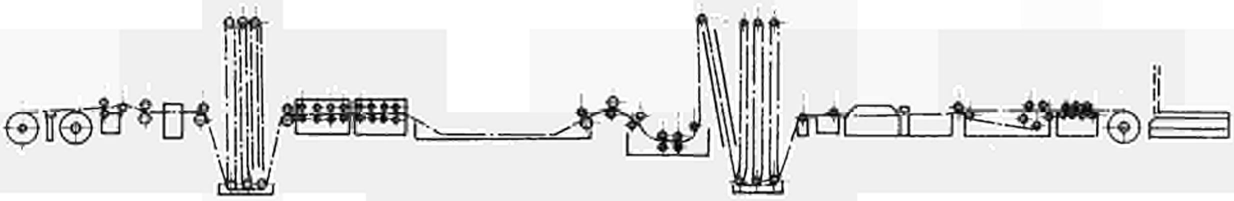
Immersion processes for strip galvanizing can be divided into two main categories: those which deal with material which has already been heat-treated, and those which are fed with strip in the "as cold-rolled" condition.

The most typical processes of these two main categories are, respectively, the Cook-Norteman process and the Sendzimir process.

Cook-Norteman process

Before entering the line, the strip to be galvanized undergoes heat treatment and skin passing to suit the required characteristics.

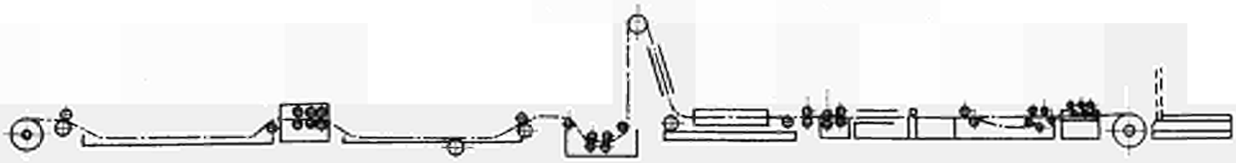
The line consists of an uncoiler, a welder, a looping tower, an alkali cleaning tank (following which the strip is washed), and a pickling tank; the strip then enters the zinc pot and passes through the galvanizing rolls. After coating, the strip is cooled; then, via a looping pit, it passes on for washing and subsequent drying. In the exit section of the line, machinery is provided for cutting the strip into sheets or for re-coiling it.



Continuous galvanizing line, Cook-Norteman Type

The line shown schematically in the figure above is suitable for material of comparatively light gauge and can, justifiably, be classified as continuous.

That shown in the figure below is, on the other hand, semi-continuous. The absence, at each reel end, of looping arrangements, which would permit the continuity of the process, will be noted. This line has no small-radius curves, and can therefore be used for relatively thick strip.



Semi-Continuous galvanizing line, Cook-Norteman Type

As already seen, the Cook-Norteman lines are equipped for hot alkaline washing followed by acid pickling. Consequently, the strip arrives at the zinc pot with a perfectly clean and slightly keyed surface which facilitates the adhesion of the coating.

The machine normally has two pairs of coating rolls; the first pair removes the flux from the strip, thus permitting the second pair, which is kept clean, to ensure a correct coating. In general, the flux consists of ammonium chloride (NH_4Cl), sometimes mixed with zinc chloride ($ZnCl_2$).

The zinc contains sufficient aluminium to prevent the formation of brittle alloy.

The Sendzimir process

Following the brief review of the above processes, we shall now deal in greater detail with the Sendzimir process both because, as already mentioned, it is the most important process as far as strip is concerned.

The Sendzimir process differs considerably from the Cook-Norteman in that part which precedes the coating, as it includes the oxidation and subsequent reduction of the strip before it is galvanized. This "gaseous pickling" operation allows the strip to be normalized or annealed at the same time.

The first plant was built in Poland in 1931 by the engineer Sendzimir. In the following years, the idea was vigorously pursued and designed and built lines of higher and higher productivity. To-day, some lines can galvanize strip up to 1800 mm. wide at a speed of 50 to 70 m./min. Other plants, for thin strip (about 0·3 mm.), regularly operate at rates above 90 m./min.

We have seen that, in all galvanizing processes, to ensure complete success it is essential that the base metal is perfectly clean. As already mentioned, in conventional galvanizing this can be achieved by alkali cleaning, by acid pickling, and through the action of the flux floating in the zinc bath.

The Sendzimir process has solved the problem of cleaning the surface of the base metal by a method which is very different from that of the conventional processes, and which is undoubtedly better. Surface preparation is done in two stages: first, by means of an open-flame furnace, the rolling oils are burned and a light film of oxide is thus produced on the surface of the strip; then, by annealing in a radiant-tube furnace, the oxide is reduced in a hydrogen-rich atmosphere, and the strip is maintained in a reducing atmosphere until it is dipped in the molten zinc. It is evident that this system, apart from obviating (as do other processes) any possible contamination of the strip after it has been prepared for coating, ensures consistent and uniform characteristics at the layer of ferro-zinc alloy. This is because the formation of the alloy is also dependent on the respective temperatures of the two metals; while, in the conventional processes, the sheet or strip comes into contact with the zinc at ambient temperature, in the Sendzimir process this strip enters the pot at a temperature slightly above that of the zinc, and the reaction between the zinc and the iron therefore takes place very rapidly. The Sendzimir process also offers definite economic advantages, which can be summarized as follows:

(1) Four operations are eliminated: annealing, skin passing, cleaning and pickling, as the lines are fed only with cold-rolled strip.

(2) The absence of pickling eliminates both expensive equipment and its maintenance, together with the base-metal losses and irritating gases.

(3) The absence of flux is an economy, and there is less zinc consumed, as a much smaller quantity of dross is formed.

(4) The uniformity of the coating is improved because the strip leaves the coating rolls vertically.

(5) The substantial contribution of thermal energy from the hot strip to the zinc bath has the following results:

   (a) a much smaller quantity of heat has to be transferred to the bath through the walls;

   (b) the quantity of molten zinc in the pot (forming a reserve of heat) can be reduced;

   (c) the run of the strip in the pot is shorter;

The pot will therefore have a longer life, and a much smaller quantity of dross will be formed in it.

Description of an Armco-Sendzimir line and of the process

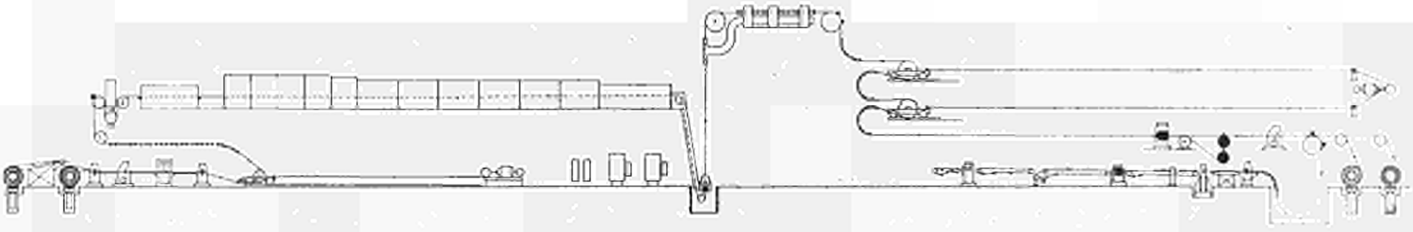
The plant can be divided into four main parts, for the purpose of explanation, according to their functions (see fig. 1 on p. 229):

(1) Entry section.

(2) Thermal treatment section.

(3) Coating section.

(4) Exit section.



Continuous galvanizing line No. 1

The entry section consists of:

(a) two uncoilers which work alternately;

(b) a shears, and a welder for joining the tail end of one coil to the leading end of the next;

(c) a looping car in which the movement is horizontal; good use is thus made of the long space under the furnace in the thermal treatment section.

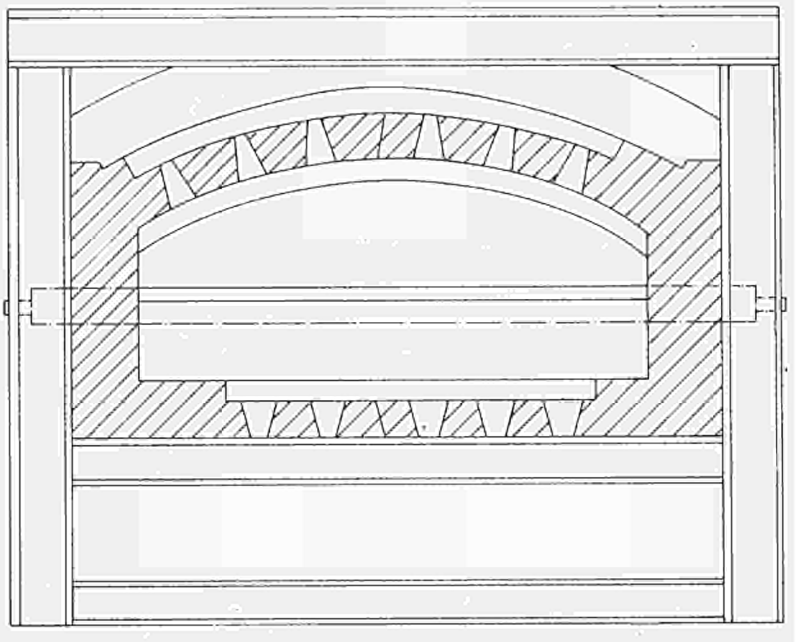
Continuous galvanizing line No. 2

Thermal treatment section — From the looping car, the strip enters an oxidizing furnace which has open-flame burners. On leaving this furnace, the strip has a uniform covering of oxide, blue in colour.

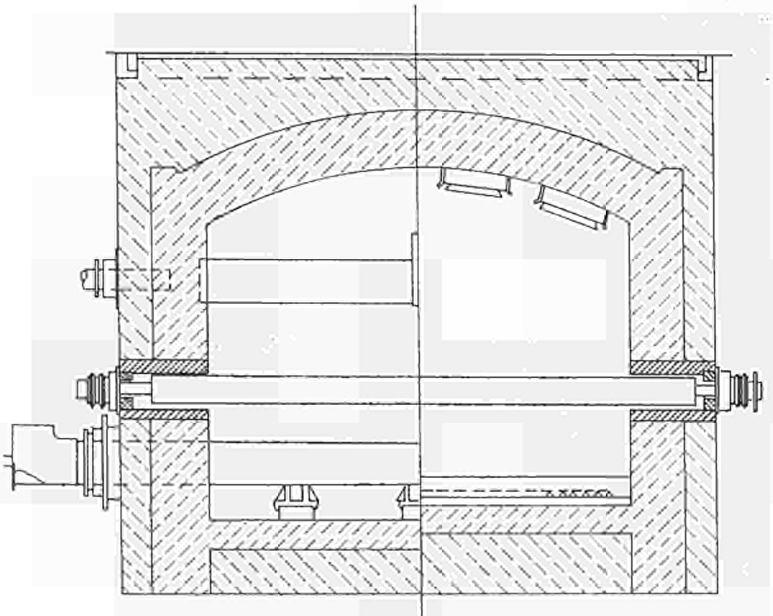
Immediately after this, the strip, prepared as described above, enters a 116-m. long reducing furnace and runs counter to a flow of dissociated NH_3 in which the high hydrogen content effects the complete reduction of the oxides on the surface of the strip.

The reducing furnace is divided into heating, controlled cooling and final cooling zones. The thermal cycles used (i.e. the strip speed and the furnace-zone temperatures) depend on the thickness of the strip, and help to achieve smoothness in the finished product as well as good mechanical properties; in addition, they bring a quantity of heat to the bath so that the need for an external supply of heat is minimized.

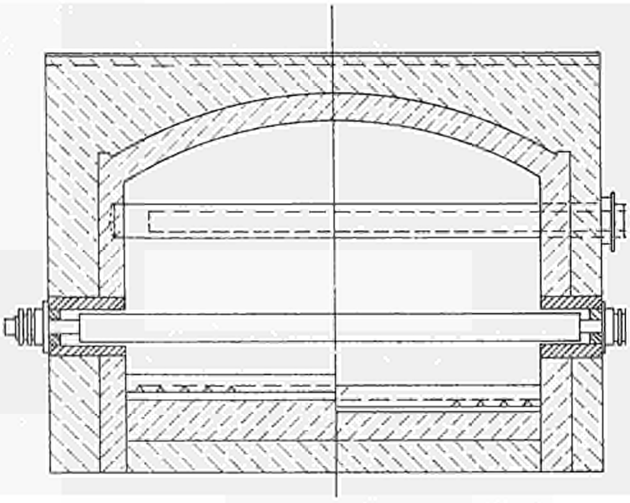
Width	*internal:*	*5'-8"*	*=*	*1,727 mm.*
	external:	*7' 2½"*	*=*	*2,196 mm.*
Length	*internal:*	*14'*	*=*	*4,267 mm*
	external:	*15' 6½"*	*=*	*4,737 mm*



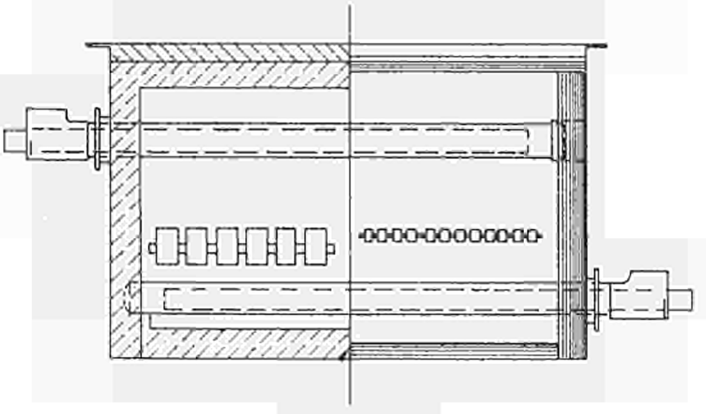
Sectional View of Oxidizing Furnace



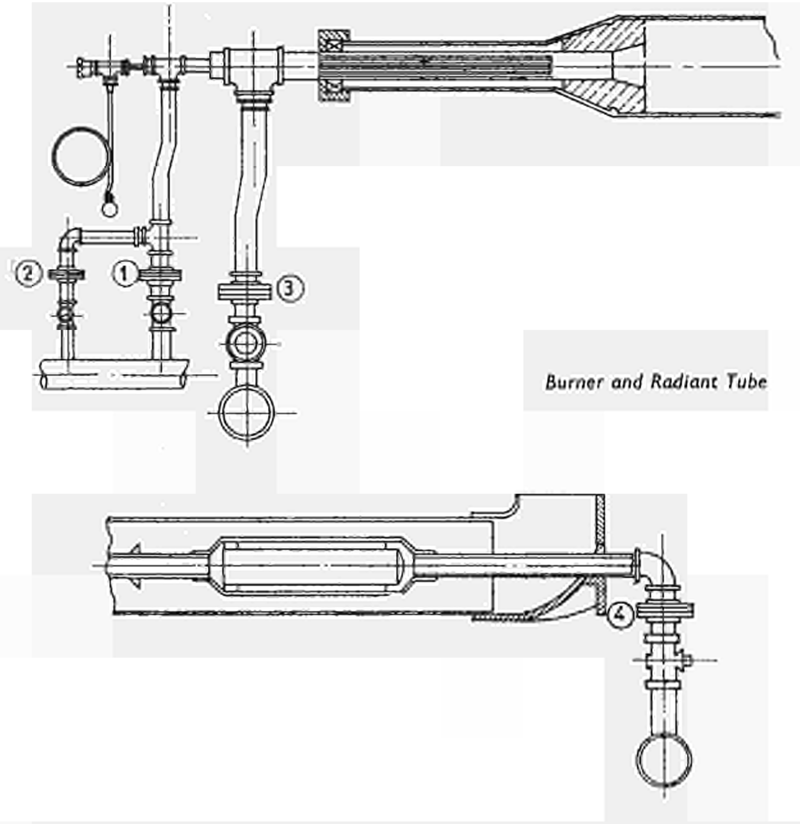
Heating



Controlled cooling



Final cooling



Burner and Radiant Tube

Coating section — The exit from the reducing furnace is sealed off at the zinc bath, where the strip is immersed and then moved upwards again by a submerged roll. Removal of the strip from the bath is effected between the two semi-submerged coating-rolls. Air jets at the bath exit, a long run in free air and forced-draught hoods ensure rapid and controlled cooling of the coating strip. (fig. 2, p. 229)

The exit section consists of:

(a) a two looping-car arrangement to facilitate the cutting of the coils or the delivery of packs of sheet;

(b) chemical treatment by sprinkler, using a CrO_3 acid solution (this protects the strip from white rust during storage);

(c) first flattening machine, for strip;

(d) shears, for coils.

If the strip is to be sold in coils, it is conveyed to the re-coiler reels; there are two of these, working as a pair. If the product is to be sold as sheets, the strip continues along the line via:

(a) a looping pit;

(b) guillotine shears, for cutting to the required dimensions;

(c) second flattening machine, for sheets;

(d) inspection bench, with a conveyor to the reject piling machine;

(e) oiler, if required;

(f) piling machine, for first-grade sheet.

With the long path of the strip along the line (about 450 m) and the large number of operations which it undergoes, one may naturally wonder how many problems it encounters during its long passage. Actually, the high standard of construction of the line (fig. 3, q. 229) ensures consistent and reliable operation for long periods, provided it receives careful and correct planned maintenance.

Operational data

The design and operational characteristics of our two lines are:

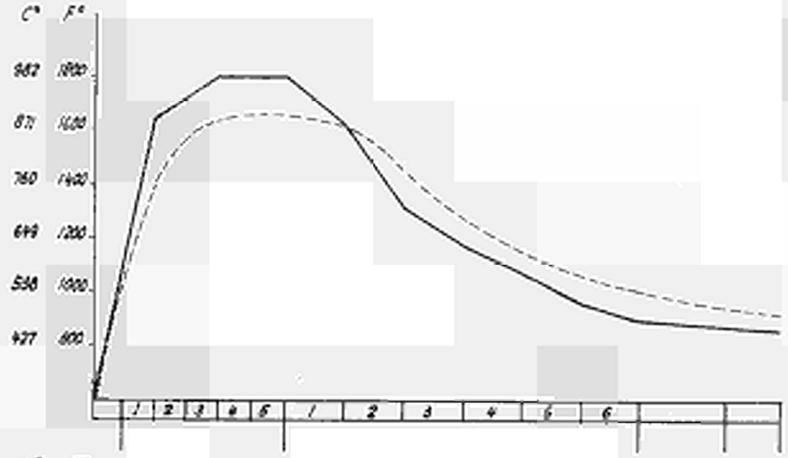
	No. 1 Line	No. 2 Line
Thicknesses which can be treated	0·28-2 mm.	0·28-2 mm.
Thicknesses normally treated	0·30-1 mm.	0·60-2 mm.
Maximum width	1,220 mm.	1,524 mm.
Max. diameter of coils	1,524 mm.	1,524 mm.
Speed, entry section	61 mm./min. max.	120 mm./min. max.
Speed, furnace section	9·1-76·2 mm./min.	15-90 mm./min.
Speed, exit section	99 mm./min. max.	120 mm./min. max.
Length of sheet product	1,200-4,470 mm.	914-5,000 mm.
Working speed	15-45 mm./min.	15-50 mm./min.
Average output	10.5 tons/hr.	17 tons/hr.

The amount of zinc which is actually applied as a coating for the strip is a little above 93%; the remainder is lost as dross or bottom slag. In the immediate post-war period, the average utilization of the zinc for strip coated in Cook-Norteman systems was 83·2%.

Ample adjustment of coating weight per unit of area is obtained by means of the following variables:

(a) immersion level of the coating rolls in the bath;

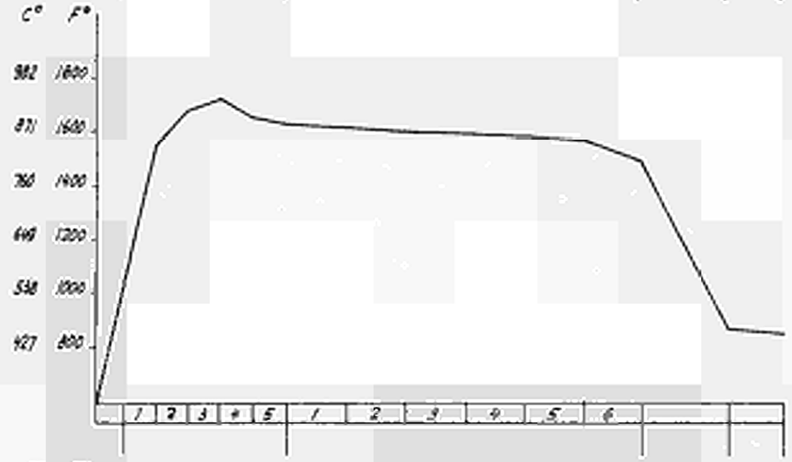
(b) diameter of coating rolls and the form of their grooving;



Cycle 1

Speed; 20 m./min.

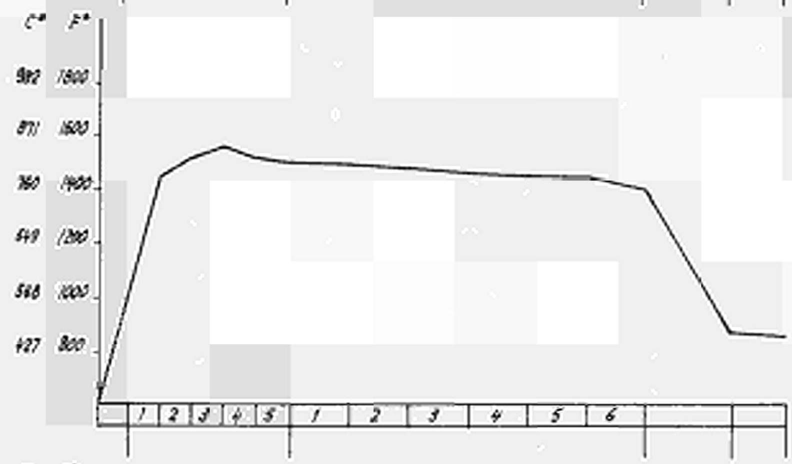
Thickness 1/10 mm.



Cycle 2

Speed; 43 m./min.

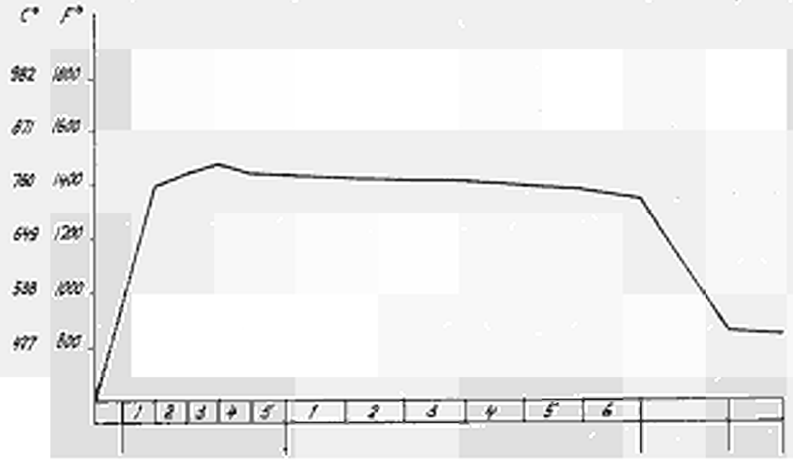
Thickness 5/10-7/10 mm.



Cycle 3

Speed; 39 m./min.

Thickness 4/10-5/10 mm.



Cycle 4

Speed; 36 m./min.

Thickness $<$ 4/10 mm.

--- furnace temperature

- - - - strip temperature

Thermal Cycles for Thickness Ranges

(c) speed, roughness and temperature of the strip;

(d) Al content of the bath (aluminium acts as a fluidifier in the molten bath).

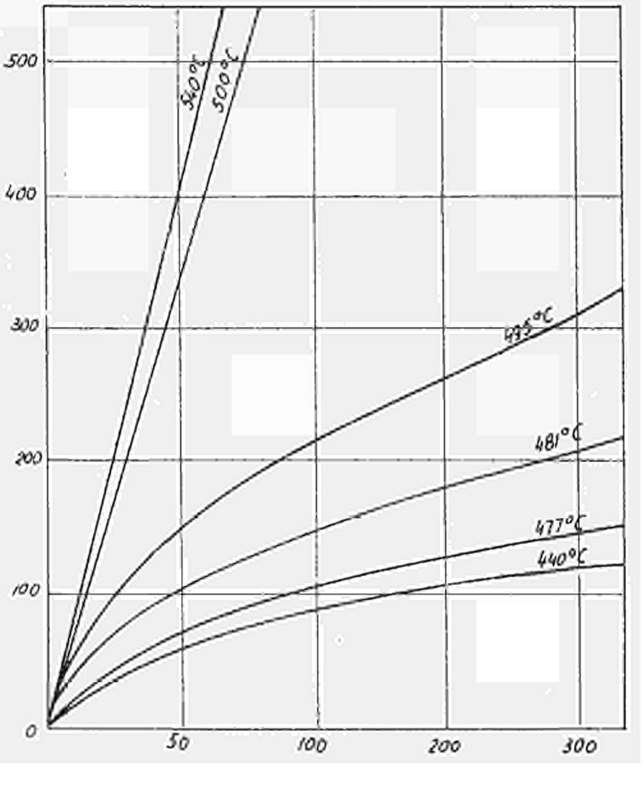
The adhesion of the coating is a function of the quantity and type of alloy present at the iron/zinc interface. The zinc does not adhere to the strip by a simple physical mechanism, but through a series of Fe/Zn intermetallic compounds, each of which has a melting point above that of pure zinc.

The examination of the components of the intermetallic layer, with the electron microscope or by X-ray diffraction, has enabled a complete knowledge to be obtained of the composition of the Fe/Zn alloys, which is seen to consist of various phases. The inferior adhesion values encountered in material galvanized by the conventional process are due to the presence of all these phases and to the value of the total thickness of the intermetallic layer, which is 40-50% of the total thickness of the coating. In material coated by the Sendzimir process, this thickness is only 5-10%.

The reduction of the Fe/Zn layer is attained, in the Sendzimir process, through decreasing the diffusion of the zinc in the iron by the following means:

(1) The formation, on the steel base, of a film of pure iron, which is much more resistant than steel to the diffusion of the zinc. This film is the result of the oxidizing and subsequent reducing operations which the steel undergoes before entering the zinc bath.

(2) The presence, in the reducing gas (consisting of dissociated ammonia), of a minimum percentage (0·015 g/l) of free NH_3, which results in the nitriding of the steel surface and thus impedes the diffusion of the zinc in the iron. It must be pointed out that excessive nitriding has the opposite effect and makes the Fe/Zn alloys very hard and brittle.



Iron losses (m.²)

Immersion time in minutes

Relation between Time, Temperature, and Attack on Iron by Molten Zinc

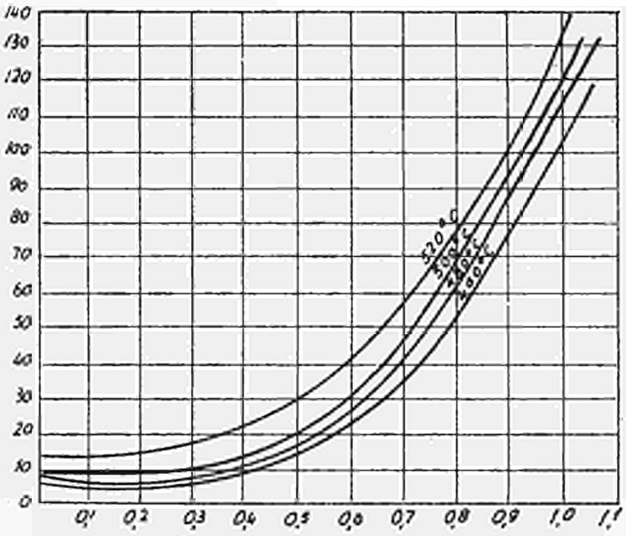
(3) The low temperature of the zinc bath (454-460°C) and the very brief holding time for the steel in the bath (1-2 seconds). See preceding figure.

(4) Immediate and rapid cooling of the coated steel on leaving the bath.

(5) The low C and Si contents of the steel to be coated. These two elements promote the formation of the alloy layer through increasing the reaction between the Fe and the fused Zn (see figures below). Inferior adhesion values are encountered with the semi-killed steels (0·10-0·18% C).

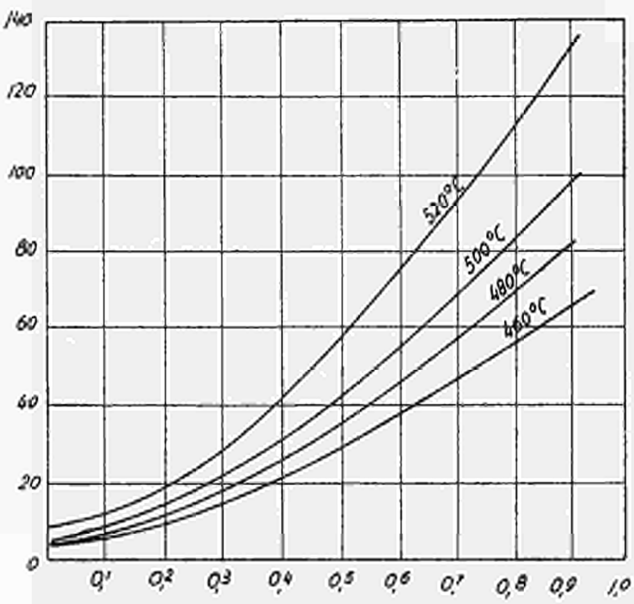
Composition of the bath

The zinc bath consits of electrolytic zinc, with aluminium and lead added in the form of Zn/Pb and Zn/Al eutectic alloys. Other elements which can be added are: antimony, tin, copper, manganese and cadmium. These elements have a particular influence on the adhesion, quality and thickness of the coating; some of them call for comment.



Loss in weight (gr./dm.²)

Influence of the Carbon in Steel upon Attack by Molten Zinc (in %)



Loss in weight (gr./dm.²)

Influence of the Silicon in Steel upon Attack by Molten Zinc (in %)

Aluminium

This acts as a reaction inhibitor for the molten zinc. While the steel to be coated is immersed in the bath, a reaction occurs between the iron and aluminium owing to the greater affinity between Al and Fe than between Fe and Zn. This causes a buffer layer of Al and Fe which impedes the diffusion of the zinc in the iron and the consequent formation of layers of Fe/Zn alloy.

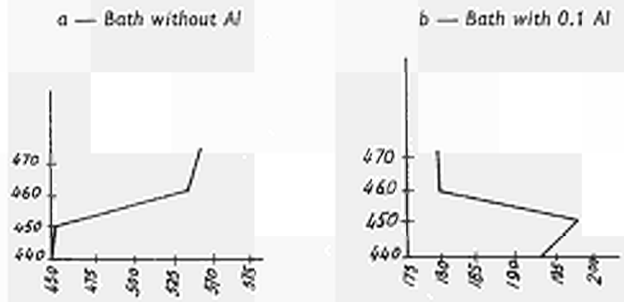
In practice, aluminium is usually present in the bath in percentages from 0·15 to 0·25.

In addition, the presence of Al in the galvanizing bath:

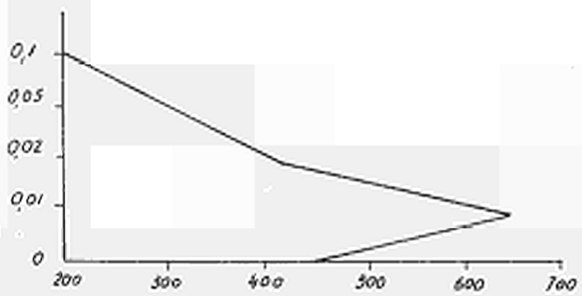
(a) makes the bath more fluid and impedes oxidation of its surface;

(b) gives the coating a bright appearance and improves its corrosion resistance;

(c) reduces the influence of temperature on the action at the surface of the strip (see figures below).



Influence of Aluminium upon Diffusion of the Zinc at Various Temperatures



Variation of Coating Weight in Relation to Al Content in the Bath for an Immersion Time of 20 sec at 450° C

Lead

This serves only to produce the characteristic spangle of the finished product. In general, 0·10 to 0·15% is present in the bath. The size of the spangles is directly proportional to the percentage of lead.

Tin

A very small amount (0·02 to 0·08%) may be present. It reduces spangle size and makes the coating particularly attractive and bright.

Characteristics and applications of galvanized sheet

Coating and Finish

Hot-dipped galvanized sheet can be produced with various weights of coating per unit area and with various surface finishes.

Coating weight can be classified in three groups:

(a) Light: corresponds to 305 g./sq. m. nominal (229 g./sq. m. average). After skin passing followed by stretching, it is employed for painted or enamelled articles (kitchen equipment, enamelled furniture, etc.).

(b) Regular: corresponds to 381 g./sq. m. nominal (305 g./sq. m. average). It is intended for material subject to normal usage, including roofing and sections used in building.

(c) Heavy: corresponds, usually, to 458 g./sq. m. nominal (381 g./sq. m. average), but various coating weights exist. It is used in environments where major corrosion may be expected, e.g. refrigerated vehicles, conduits etc..

The regular type of coating is by far the most common.

The coating weight produced by electrolytic galvanizing is usually from 40 to 70 g./sq. m. and can be as little as 4 g./sq. m. It will be seen that the zinc layer is not thick enough to compete with the hot-dipped product in the market where the latter has its most important trade outlets. Consequently, the use of electro-galvanized products is limited to applications in which there is no exposure to the weather, and is of interest in the furniture industry, to makers of sound-insulation installations, and in the automobile industry, etc.. Turning now to surface finish, we have the following types:

(a) *normal spangle:* with the classical marbling effect; this is the most usual type, and is used as received, without any paint coatings;

(b) *minimized spangle:* obtained directly, during manufacture, by creating a large number of crystallization nuclei at the instant when the zinc solidifies and so producing a decrease in the crystal dimensions;

(c) *smooth:* obtained by cold-rolling the normal-spangle or minimized-spangle product, or by treatment in the final phase of manufacture either by remelting the zinc coating or by shaving the zinc while it is still in the molten state; if this last method is used, it is possible to obtain differential coatings, i.e. a thicker coating on one side than on the other.

For electro-galvanized sheet, the finish is always of the smooth, mat type.

The types of galvanized sheet with a smooth surface, whether hot-dipped or electrolytic, have a particular application for panels which are to be painted.

For applications in which the galvanized surface is stove-enamelled (e.g. kitchen furniture), electro-galvanized strip has undeniable advantages over the Sendzimir product as the characteristic spangle on the latter will be visible on the finished article. To meet such requirements, in the last few years a new Sendzimir galvanized product without spangle has appeared on the market. This is Armco Zincgripp-A, and is obtained directly off the line, which is provided, for this purpose, with cooling arrangements for the strip at its exit from the tank.

Mechanical characteristics and pressing capability

The adhesion of a Sendzimir galvanized coating is such that it withstands all the operations of forming, drawing and beating compatible with the mechanical properties of the base metal. The short thermal treatment cycle (average total time held in the furnace is 4 min., including cooling time) is insufficient for providing a product suitable for very deep drawing. However the product is suitable for light presswork, and if a suitable type of steel is chosen it is suitable for medium presswork.

The main reason for the limited pressing characteristics of Sendzimir galvanized products is the high cooling rate to which the strip is subjected between the annealing or normalizing temperature and the zinc-bath temperature (about 460°C). Such an abrupt cooling results in incomplete separation of the C from the ferrite lattices; in time, this C will separate by precipitating as submicroscopic particles in the ferrite lattice, deforming it and lowering the mechanical characteristics (ageing by solution hardening). This precipitation is presumably initiated in the zinc pot, and its rate increases with the strip temperature.

The use of annealed material for Sendzimir galvanizing is therefore of no advantage, because the ageing described will still occur. The use of killed steel can also be rejected, since such steels are also subject to carbon ageing.

What has been said does not constitute a market limitation for Sendzimir galvanized products, because high pressing capability is not usually required in galvanized products and, furthermore, for special applications it is possible to improve this capability by suitable processes subsequent to galvanizing.

Galvanized material for deep drawing

If material which has undergone, or is undergoing, precipitation ageing of the type described above is taken to a sufficiently high temperature and is held there for long enough, the particles originally precipitated can coagulate by migrating to a limited number of growth nunclei. The causes of distortion are thereby eliminated, and the mechanical properties of the metal are distinctly improved ("super-ageing").

Our own practice is to submit the material, which has been galvanized in the normal way, to super-ageing heat treatment in the annealing furnaces. The distinct improvement in the mechanical properties makes the material suitable for rigorous drawing operations, while the coating retains its very good adhesion characteristics as the temperature and holding time for the heat treatment are not excessive.

Some notes on methods of using galvanized material

Welding

Before the advent of continuous galvanizing lines, it was usual to make an article, welding it as necessary, and then to galvanize it by hot dipping.

In industry to-day, this process is obviously not very economical, and it is necessary to make the article by welding sheet which has already been galvanized.

The good weldability of Sendzimir galvanized material is well know. Below, we give the results of some tests made on different welding processes applied to sheet from our own production:

(1) Oxy-acetylene brazing (silicon brass filler-metal): Satisfactory results; slight corrosion at sides of bead limited by the white corrosion products.

(2) Arc welding (mild steel electrodes): Better results from the mechanical point of view; lower corrosion rate, but corrosion occurring over greater area. The use of 18/8 stainless steel electrodes significantly improves the corrosion resistance of the welded zone.

(3) Resistance welding (copper/cadmium electrodes; as compared with uncoated sheet of the same gauge: pressure increased by 35-40%, current density increased to 450 A/sq. mm., welding time reduced to 6 cycles). Satisfactory results, with an adequate layer of zinc maintained at the welds.

The corrosion tests were carried out in salt-spray chambers, by immersion in an aqueous solution of NaCl, and by exposure to a marine atmosphere. The welded zone is always the weakest point as far as corrosion is concerned, and it is often necessary to ensure that, as far as possible, it behaves in a similar way to the remainder of the sheet. This can be achieved by the use of suitable protective coatings, as follows:

(a) *For the welded area only:* Excellent results are obtained by metal-spraying with zinc; this is preceded by sand-blasting the area to be sprayed, such preparation being necessary to ensure good keying for the zinc coat.

(b) *For the whole surface:* In this case, the welded area remains the preferential area for attack since the unfavourable surface characteristics make it difficult to cover this area uniformly. Painting with a wash-primer system can be successfully used where the environment has low or average corrosive properties.

(c) *For the whole surface, but with preliminary treatment for the welded area:* This the most effective system. Covering the welded area with an undercoat of polyester filler, and then painting the whole surface with a wash-primer system, will give outstanding results even in highly corrosive environments.

Painting

Whether for protective or for decorative purposes, painting is often necessary for present-day products. However, paints and varnishes of normal composition do not, in general, adhere well to galvanized sheet. If we paint a galvanized surface, the adhesion appears to be good at the time, but it gradually diminishes until it is almost non-existent after a period which may vary from three to six months. This remarkable decrease in adhesion has been explained by some people as being due to a selective absorption of some of the paint constituents by the zinc; this would, of course, be accompanied by a disturbance in its crystal lattice. In other cases, with oil paints containing driers for example, there are secondary reactions with the zinc; the reaction products, which have a much lower density, produce a considerable increase in volume which causes the still intact layer of paint above it to become detached. Because of these considerations, it is evidently necessary to prepare the surface of the zinc by special treatments, or to use paints of a particular composition. The most common preparation treatments for galvanized surfaces are:

(1) Roughening:

Increasing the roughness of the surfaces to be painted gives a distinct improvement in the mechanical adhesion and keying of the paint. A primitive method is to leave the galvanized sheets exposed to the air for at least three months, so that they become covered with a patina composed of $Zn\,(OH)\,CO_3 \cdot ZnO$, which is then brushed off.

A better roughening is obtained by sand-blasting (10-15 micro-inches).

These treatments are not much used as they damage, to some extent, the zinc coating.

(2) Bonderizing:

The process of bonderizing, called "Paintgripp" in the United States, consists of applying a thin layer of zinc phosphate to the surface of the galvanized sheet. The material then presents a mat grey appearance, and can be easily painted.

The process can be carried out on a line similar to that used in electro-polishing. The strip first enters a bath of hot water, the purpose of which is to ensure uniformity of the following treatment, and the whole surface is washed. Next comes immersion in a second bath for 20-30 seconds; this contains a solution of salts, know as "Bonderite" (Armco process), at about 60°C.

The material is then subjected to a thorough wash. After being roller-dried, it is ready to receive the second treatment, consisting of spraying for 8-10 seconds with a solution of hot (60°C) chromic acid. Roller-drying and drying complete the cycle.

The reactions occurring in the process are complex, owing to the presence of numerous reagents in the Bonderite.

After immersion in the salts, a layer of zinc phosphates is present; the subsequent treatment in chromic acid passivates the surface of the strip through the precipitation of chromates between the zinc phosphate crystals. The zinc phosphate coating produced on the two surfaces of the material varies from 4 to 8 g./sq. m. according to the times of immersion, the temperature of the baths, and, apparently, the Pb and Cd contents of the zinc tank.

The considerable capacity of Bonderized surfaces for absorption of paints and enamels leads to a large increase in the already vast field of galvanizing applications.

In electro-galvanizing plants, Bonderizing is included in the galvanizing line.

(3) Wash primers:

This system consists of applying priming coats of paint (called wash primers) prior to the painting proper. These primers are vinyl butyral resins in solvents, with the addition of phosphoric acid, basic zinc chromate, and a catalyst for subsequent polymerization. The wash primers, with their excellent adhesion, provide a very superior priming coat which can be followed by any type of paint. Within about 15 minutes of their application, polymerization is complete and the sheet is ready for final painting. The thickness of wash primer coats varies from 5 to 10 micro-inches (1-2 microns).

Special paints

Special paints exist which will adhere when applied directly to galvanized surfaces. Products now on the market are generally resins with a base of amines, polymethyl-acrylate, polyurethane or phthalic acid. Of the inorganic compositions, there should be mentioned a pigment consisting of calcium plumbate in linseed oil.

This field is being investigated by many research workers, as the possibility of direct painting without surface pre-treatment undoubtedly offers considerable practical and economic advantages.

With respect to the system of drying, paints can be grouped as follows:

(a) Oven-drying (stove-drying). These paints are generally of the alkyd or glycero-phthalic type; they are used for office and kitchen furniture, etc., and require a smooth surface (without spangle). For environments which are not very corrosive, as in the applications mentioned, electro-galvanized material can be used with advantage.

(b) Air-drying. These are generally epoxide or epoxy-phenolic paints, and are used for protecting heavy structural steelwork and, in general, objects exposed to the weather.

Stove-drying paints have been less favoured by users because they have the following disadvantages:

(a) Lower elasticity and a tendency to crack when the sheet is subjected to stresses due to abrupt temperature changes (e.g. in prefabricated parts used in buildings).

(b) Whenever, after some years in service, it is necessary to apply a new coat of paint (which will naturally be of the air-drying type), the new paint does not adhere perfectly to the old. The same consideration applies when touching up (cold) any surface damage occurring during assembly or erection.

(c) The stoving process is more expensive. On the other hand, stove-drying paints are harder and more resistant to abrasion.

Conclusion

In this necessarily brief review, we have dealt with the characteristics of modern galvanizing processes for steel; processes which offer high quality production at a low cost.

As compared with the past, it is now possible to obtain a product in which the well-know corrosion-resisting features of galvanized sheet are combined with the advantages of being able to carry out all the plastic forming processes appropriate to the steel base-metal. Good weldability and the efficient paint systems which have been developed have contributed not a little to acceptance of the product.

During the past few years, the increasing use of these products in various fields of application (building, agriculture, the automobile industry, and domestic equipment) is proof of the esteem in which they are held by the users.

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Michel PUECH

Zinc Protects against Corrosion

(Translated from French)

Although it would be inappropriate on this occasion to consider zinc and its metallurgy at length, this seems to be a suitable opportunity to recall one of the essential characteristics of this metal, which enables it to give steel effective protection against corrosion, namely its anodic position relative to iron or steel.

Outline of the principle of corrosion

In most cases corrosion is the result of an electro-chemical phenomenon resulting from the potential difference which exists between dissimilar metals or between the impurities or components they contain, when they are electrically connected. This is the principle of the galvanic pile.

Function of zinc

The anodic or electro-negative position occupied by this metal in the electro-chemical potential series gives it a sacrificial role in relation to all the metals which are higher in the series; hence it protects the steel as a sacrificial anode, either in the form of a reactive anode or as a protective coating.

Methods of protection

These are five in number, each method having fields of application which cover all the uses of steel where the protection can be applied :

(a) hot-dip galvanizing,

(b) metallization with the spray pistol,

(c) electrolytic deposition of zinc,

(d) paints with a high zinc content,

(e) cathodic protection.

Hot-dip galvanizing

In this process, steel, the surface of which is first given a rigorous chemical preparation (pickling with hydrochloric or sulphuric acid), is immersed in molten zinc at a temperature of 440/450°C. At this temperature full use is made of the affinity between iron and zinc, intermediate layers of iron and zinc alloys being produced within the metal.

The galvanized steel sheet, tube and wire-drawing industries have galvanizing plant integrated into their production lines.

France also has more than 200 "jobbing" hot-dip galvanizing shops, where all kinds of finihed products are treated.

Metallization with the spray pistol

In this process, fused and atomized zinc is projected on to the surfaces to be protected — these having first been prepared by sand- or shot-blasting.

The size of the workpieces does not raise any problems in this process, so that large pieces may be treated by this technique — in particular bridges and similar structures.

Many French constructional steelwork plants have workshops equipped with metallizing lines.

The work is often undertaken on the site by specialist firms possessing mobile equipment consisting of two stations : sand- or shot-blasting and metallizing.

Automatic installations also exist for the batch treatment of sections, metal casks and poles, liquid-gas containers, etc.

Electrolytic galvanizing

Here the steel is treated by electrolysis. This proces is applied to a wide variety of small- and medium-size workpieces, but has also for some years increasingly been used for steel sheet of the type known as "electro-galvanized."

The use of electro-galvanized sheet has developed on parallel lines to hot-dip galvanized sheet, each having separate and distinct applications, the properties of the coating having only one element in common, namely the zinc.

Paints with a high zinc content

These paints contain at least 92 to 95% of extra pure zinc powder with 5% of binder. They are applied by brush, compressed-air pistol or electrostatic pistol. The surfaces to be protected must be prepared by brushing, or by sand- or shot-blasting, if the best results are to be obtained.

Possible fields of application are very extensive, both for protecting new work and for making good worn-out galvanized coatings.

These high-zinc paints have also been found very economical for reconditioning welds on galvanized steel structures fabricated by arc-welding (see section below : "Studies and Research, Related Techniques).

Cathodic protection

This process makes use of zinc anodes, the potential of which is lower than that of the steel, which thus becomes the cathode. When connected electrically, the couple of the galvanic pile thus formed is utilized.

The applications of cathodic protection are very extensive, i.e. :

(a) in seawater (ships' hulls, immersed metal structures),

(b) in fresh water (sluice gates, dam equipment),

(c) buried structures (storage reservoirs, underground pipelines, etc.).

The zinc anodes are of different types, some of which fulfil the specifications of the Marine Nationale Française.

High-purity zinc with an iron content below 0.0014% is used.

Studies and research, related techniques

Faced with the wide field of utilization of steel in all its forms, and in all types of construction, it was considered essential to examine the problems raised by its use.

The Centre Technique du Zinc and the Association Technique Française de Galvanization together with other branches of industry have therefore, initiated a large programme of studies and research in connection with the protection of structural steels by zinc.

The idea of protecting steel against corrosion is rapidly gaining favour with such people as architects, engineers, builders and even property owners who would finally have to defray the costs of upkeep.

It was therefore necessary to review the various problems raised by the use of zinc-treated steel, whether hot-dip galvanized, metallized or coated with zinc-rich paints.

The hot-dip galvanizing process has received special attention, since it is being increasingly applied to the traditional materials used in metal construction : sheet, tubes and commercial sections.

Sheet and tubes are delivered already galvanized by firms equipped with galvanizing plants integrated into the production line, and this is now beginning to be done with stock sections; and steel stockists are holding galvanized structural sections to meet a constant demand.

Galvanizing of sections can be carried out entirely automatically, as in the case of sheet or steel tubes, i.e. in large batches in specialized galvanizing shops. The price per kilogram of material so treated will be lower than is possible for work, (sometimes difficult to handle) treated in galvanizing pots and at the preparatory stations (pickling vats, rinsing, fluxing) which precede the galvanizing stage.

In order to prepare for this increasing utilization of hot-dip galvanized steel and make it possible, the following problems have been studied :

Arc welding of galvanized steels

Although, as we have stated, galvanized stock sections, tubes and sheet are now regularly used in constructional steelwork, it is still necessary to enable the structural engineer to join the components together into sub-assemblies and then into assemblies, using normal welding techniques.

Arc welding with coated electrodes was the first technique examined, and the completely positive results obtained have already enabled most satisfactory results to be achieved.

Resistance spot welding of galvanized sheet

The value of this technique, now brought to an advanced state of development in U.S.A., has been confirmed in France by trials undertaken by the Institut de Soudure in a programme carried out in conjunction with A.T.F.G. and Irsid.

The rhythm of welding is well adapted to the requirements of the automobile industry, which is particularly interested in the use of galvanized sheet for body underframes.

More recent trials have also produced a significant improvement in the yield of electrodes by coating the tips or contact surfaces with gold. Contrary to preconceived ideas, the cost of this coating is very moderate, about 3 French francs per piece.

Bronze welding of galvanized steels

The metalworking industry (locksmiths, builders' hardware), constructional engineers, the heating, ventilation and air conditioning industries, etc., should be kept informed on the performance of the various techniques applied to galvanized steel. Here again a number of tests have just been concluded in co-operation with the Institut de Soudure, and much useful technical information has been placed at the disposal of the users.

Application of decorative paint direct on to the galvanized surface

Although protection by zinc, and in particular by hot-dip galvanizing, is desirable in most cases, the appearance of the galvanized product is often a disadvantage from the consumer's point of view. This is especially true when the weldedj oints have been reconditioned by applying a zinc paint which is darker in colour than the original galvanized coating.

Until recently, painting on galvanized surfaces and on zinc in general could not be carried out without first applying a ground coat (wash-primer). Although this product is not expensive, the labour costs are high when large structures have to be treated. It is therefore essential to develop paints which do not react with the zinc, and which can be applied directly without a wash-primer. Such paint qualities, put on the market in the same price ranges as other grades of paint, are already at an advanced stage of development and several large producers are able to supply them.

Experiments in progress

Influence of hot-dip galvanizing on the coefficients of friction

Although constructional steelwork is making increasing use of hot-dip galvanizing, it is clear that joining and fabricating processes must not be affected by the treatment. This problem has been resolved for arc welding.

This is not the case for bolted connections (traditional or using high-strength bolts). It appeared, according to trials (German in particular) that the drop in the coefficient of friction of two galvanized surfaces is of the order of 30% compared with the same surfaces in the as-rolled condition. But these untreated surfaces are subject to corrosion, and if they are painted their coefficient of friction again decreases.

Experiments have been conducted by the Association on test pieces of the Sofresid type (single friction surface) on which relative measurements were made of coefficierts of friction of various paints intended for the protection of metal frameworks for the iron and steelmaking works at Dunkirk.

With these test pieces the galvanized steel behaved very well compared with other coatings; but this type of test piece is not officially approved in all European countries, so that the tests will have to be repeated using specimens of the German type which is accepted by every country (double friction surface). C.T.I.C.M. is to supply the test pieces to be treated, and the Centre Expérimental du Bâtiment et des Travaux Publics will carry out the tests.

Influence of hot-dip galvanizing on high-strength bolts

After considering a systematic investigation of the problem set by the protection of these bolts, we came to the conclusion suggested by the principal manufacturers, namely :

That hot-dip galvanizing changes considerably the surface condition of the threads and hence the value of the tightening torque; the scatter is too large to be able to evaluate the prestress to be applied to the bolt on the basis of the value of the tightening torque which will have been pre-determined.

All the trials carried out by manufacturers tend to improve the uniformity of the surface condition of the threads, with the aim of reducing as far as possible the scatter in the tightening torques (zinc plating, cadmium plating, bonderizing).

Hot-dip galvanizing is nevertheless applied to high-strength bolts, but only when they are used as an ordinary grade of bolt, i.e. without pre-stressing.

This study has now been discontinued.

Influence of hot-dip galvanizing on narrow-flange sections

Steel structures are increasingly being made of lighter, thin-flanged sections which, instead of the traditional sections of 1/10 (example : U-irons, angles or sections of 40-thickness 40/10) have become 1/15, and subsequently 1/20.

For these sections it is necessary to roll steels with a higher yield strength, and hot-dip galvanizing, which does not affect the mechanical properties of the hot-rolled structural steels at present in use, can exert an influence on the properties of these new steels.

A first series of tests appears to confirm this fact, and it is essential to establish the exact limits of the resulting changes in the properties,

Influence of hot-dip galvanizing on high-strength steels

These steels are used in the pre-stressed state for concrete structures and also for the cables of suspension bridges. It is well known that some mechanical strength is lost, but that this does not preclude their use, because these applications of high-strength cables (140/160 kg./mm.^{2}) are current practice in America.

Again, it is necessary to establish the exact extent of the effect of the hot-dip galvanizing treatment of these steels.

A first series of tests has been carried out by Irsid, but the encouraging results obtained, although confirming the possibility of utilizing these steels, must be checked by at least one more series using several grades of steel. This supplementary programme should be finalized with Irsid.

Technique of glueing galvanized surfaces

This revolutionary technique has been considered for some time and certain applications are already envisaged, if not already accomplished. Certainly, tests carried out abroad have given conclusive results.

The technique consists simply in glueing sections together at the joints instead of riveting, bolting or welding.

Trials are now in progress.

Reinforcing rods

The corrosion of reinforcing rods in concrete construction especially with thin-walled structures, is a phenomenon which has sometimes had grave consequences (fractures) and frequently unpleasant effects (rust streaks).

Even with sealed concrete their quality can influence the behaviour of the zinc. The resistance to corrosion of reinforcing rods will be checked for current grades of concrete.

As far as the adhesion of zinc and concrete is concerned, trials have already been carried out in France and elsewhere, and positive results have been obtained, which indicate that adhesion is sometimes even improved when zinc is used.

Scheduled studies

Appearance of rust on recently galvanized surfaces

The Association Technique Française de Galvanisation is assembling rational criteria for drawing up the programme for this study.

Each member has been asked to bring every phenomenon of this kind to their notice.

A programme of tests will be worked out shortly.

The double-immersion technique

The programme is to consider whether this technique will enable a thicker galvanized coating to be obtained. This process is at present in use in France in the wiredrawing industry, with subsequent re-drawing.

Behaviour of a galvanized coating at low temperatures

Preliminary trials have been made at the request of a mechanical engineering firm for nests of exchanger tubes. A complete programme will be drawn up for more exhaustive trials.

Galvanized steel joints welded under a protective atmosphere (10 to 40/10)

In many constructional engineering shops structures are very efficiently fabricated by arc welding with coated electrodes under a protective atmosphere. There are many technical reasons for this, the main ones being automatic operation and speed of working.

It is obviously essential to know the behaviour of galvanized steel when fabricated by this process.

Welding under an electrically conducting flux

This programme had been considered when it appeared likely that a decision in favour of a bridge over the English Channel would be made in preference to a tunnel. The construction of two very large hot-dip galvanizing shops, one on each side of the Channel, had been envisaged. Although this project has now been put on one side, it is true that for some heavy structures, such as occur in boiler-making, constructional steelwork and shipbuilding, sheet of from 10 to 20 mm. thick is used, and this must be protected by zinc after assembly. Although metallization with the spraying pistol is widely used in this type of work, it is conceivable that sheet which has previously been hot-dip galvanized could be utilized.

It must be admitted however that:

these sheets are too large to be treated in existing galvanizing pots;

preparation of the edges to be welded, which must be bevelled into a V or X, automatically removes the zinc and thus cancels the problem raised by its presence;

measures taken to protect this work, which are quite effective when the zinc is applied by metallizing, greatly diminish the value of this welding process.

These trials have therefore been cancelled for the time being.

Jacques CAUCHETIER

Automatic Metallization — Methods of Composite Protection

(Translated from French)

Although engineer Schoop's process of metallization by spraying molten metal with a gun is already, like hot-dip or electrolytic galvanizing, half a century old, it too, has been modernized and there are now in existence entirely automatic and electronically controlled metallization systems providing a perfectly even coating of a predetermined thickness.

We propose to quote a few examples from France, pointing out however, if this has not already been done, that in England the 100 micron zinc metallization of the girders of the new Forth bridge was also done automatically by mobile, electronically controlled, double nozzle sprayheads.

One of the earliest applications in France was that of metallizing domestic and butane gas bottles; after they had passed through a blasting cabinet where the surface is cleaned by centrifugal shot-blasting using turbine wheels. The article passes in front of a metallizing table where a gun rotating about its own axis metallizes the bottom of the bottle whilst another, with a lateral motion, metallizes the sides, the bottle for this purpose rotating about its own axis.

Metallizing to a 40 micron thickness takes 26 seconds.

Some structural frame sections are also given direct protection in steelworks. After passing, as in the first case, through an automatic shot-blasting cabinet, the sections are conveyed by a transfer system to a battery of nine metallizing guns all at different angles. Depending on the shape of the section only those guns required necessary to give complete coverage are brought into operation. Switching on is simultaneous and electronically remote controlled. This system can treat 2 to 3 tons of section per hour (fig. 4, p. 230).

We would also mention the automatic metallizing of the inside of a piston of a blast furnace gas engine in Lorraine. Subsequent to a fracture inside due to internal corrosion the 6 m. long piston was metallized with zinc. The equipment, which requires a space more than 12 m. long, consists of an angled spray-head operated by an electric motor as the system moves to and fro, the travel being 6 m.

The same applies to the internal and external zinc metallizing of steel shell cases (fig. 5, p. 230). As the case turns on its own axis a gun with a sideway travel metallizes the outside and an angled spray nozzle inside the casing sprays zinc into the internal surface.

These automatic metallizing systems are becoming more and more widely used and are very profitable when large volume series production is involved, for they considerably reduce the proportional labour cost and ensure perfect regularity of coating thickness.

Although improvements in the qualities of steel has enabled the weight of metal structures to be reduced, this very fact has also meant that corrosion resistance has had to be increased. This is the reason for the research and tests that have been carried out on the value of composite metal/paint coatings; it has, in fact, been possible to increase substantially the time the protection lasts. The sprayed metal undercoating necessitates rigorous surface preparation by sand-blasting with calamine removal and, at the same time, plays its protective role by sacrifice when the paint starts to show weak spots. On average the metal coating gives the paint twice the normal life and, when the old paint is discarded, allows a fresh coat to be applied — since there is no rust — without the need for long and difficult wire-brush surface preparation. Some certain rules, however, must be observed: if a wash primer is used it is essential, because of the spongy nature of the metallization, that the wash primer should not contain too high a proportion of phosphoric acid (not over 3%). The first coat should be put on by brush or roller so that the paint penetrates the rough surface which metallization produces. If linseed oil paints are used, pigments of metals other than that of the coating should be strictly avoided (zinc oxide, for example, can be used for zinc): bituminous, glycero-phthalic or vinyl paints generally present no problems. With two-pack paints with a catalyst however (epoxy, polyurethane and isocyanate) care must be taken that the latter does not attack the coating; at the present time pre-testing is recessary. 10-year guarantees are common for composite coatings of 80 and 120 microns of zinc with a paint system of 80 microns total thickness. It is clear from this that this dual anti-corrosion system makes a not insignificant contribution in the battle which steel is waging with concrete.

DISCUSSION

P. MORISSET

(Translated from French)

Mr. Odone's extremely interesting paper gave us a picture of the progress made possible by continuous hot-dip galvanizing of steel sheet and of the enormous range of uses which this has opened up. I should like to say a few words about these uses, more particularly concerning usability, with reference where appropriate, to standards.

With regard to the corrosion-resistance of galvanized steel, Mr. Odone quoted figures, including a lifetime of 3-5 years in industrial atmospheres for a 300 g./m.^{2} coating. I feel the concept of "industrial atmosphere" is insufficiently defined and liable to mislead. A great many industrial plants do not have atmospheres specially corrosive to zinc, so that galvanized plate and sheet may be perfectly acceptable for much longer periods than these. Only in the case of specially corrosive atmospheres containing abnormally high proportions of sulphurous fumes need extra protective measures be taken, in particular, coating with appropriate paints, which very considerably lengthens the life of the metal.

As regards classification into three types of coating, light, normal and heavy, may I make one or two points concerning a somewhat different approach which has been adopted in France and other countries. The zinc coating weight for ordinary purposes is taken, for example, in the French standards system, as 400 g./m^2. Having regard to the tolerance rules for test checks, we may class this as nearer to the "heavy" than to the "normal" type which Mr. Odone mentioned. For weights below 400 g./m.^{2} no specification is given, since it is considered that in these cases the weight depends on the extent of the forming which the plate or sheet is subsequently to undergo.

Next, three details concerning usage. In the building trade hot-dip galvanized sheet is much used for cladding of all kinds. In the motor industry, not only electro-galvanized but also continuous hot-Sip galvanized sheet is now widely employed in the United States for car-bodywork. On the welding side too, electric resistance welding, known as "spot welding," is now in common use.

Finally, in regard to painting of galvanized sheet, Mr. Odone's report gives a full and detailed account of the various possibilities, emphasizing in particular surface preparation by phosphatization or similar processes, to give the paint better adherance. There would appear to be two types of situation: either the sheet is to be subjected to extensive forming after it has been painted, in which case the adhesion of the paint must fulfil special requirements necessitating appropriate surface preparation, or it is painted in the state in which it is to be used, that is, without undergoing any great degree of forming at a later stage. In the second case, cheaper, directly adhering paints, applied in one or more coats, are quite adequate, for example bituminous-type paints, paints based on zinc oxide and zinc powder, or calcium plumbate paints.

Reference to "industrial atmospheres" is always related to tests in highly noxious environments, such as Sheffield. It is risky and inaccurate to rate the atmosphere around any and every plant alongside the atmosphere in surroundings chosen specially for their degree of injuriousness.

Antonio PORTA

(Translated from Italian)

The figures quoted by Mr. Odone for the life of a 300 g./m.² coating in an industrial atmosphere are based on experimental tests or published data. The tests were carried out close to our integrated steel plant, where in consequence of the presence of blast-furnaces and coke-ovens the atmosphere is laden with the sulphurous fumes which, as Mr. Morisset correctly points out, impair the coating by converting the protective basic zinc carbonates into soluble zinc sulphates. The results are confirmed by various items of published information. Thus Hudson and Stanners (*Journal of the British Iron and Steel Institute*, December 1953) give a coating weight of 305 g./m.² a life of three years in the industrial atmosphere of Sheffield, while Hudson and Banfield (*Journal of the British Iron and Steel Institute*, December 1946) also mention, for the same atmosphere, the following formula for the life of the coating in function of the weight:

$$L = 0.0086\, W + 0.5$$

L being the lifetime and W the coating weight. For the atmosphere of London, Gilbert (*Journal of Applied Chemistry*, April 1953) mentions five years for the same coating weight of 305 g./m². So the average of 3-5 years which Mr. Odone indicates is quite accurate.

As regards the discrepancy between French coating weights and the values given in Mr. Odone's paper, it should be pointed out that the latter are in accordance with the values of the Italsider catalogue, and correspond to the types of coating used in a number of countries.

List of illustrations

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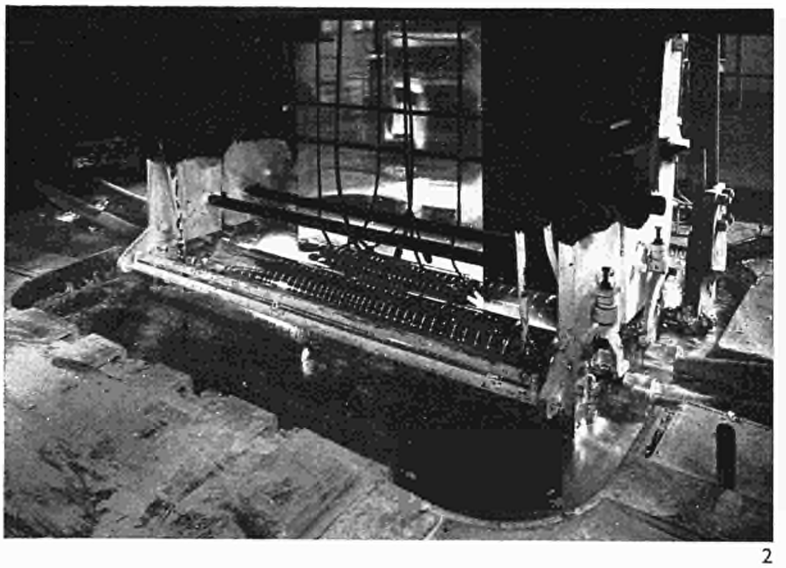

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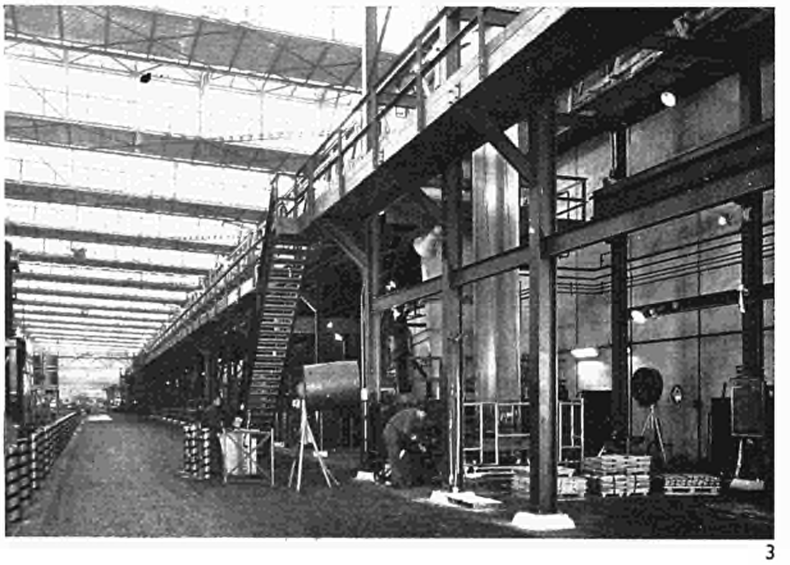

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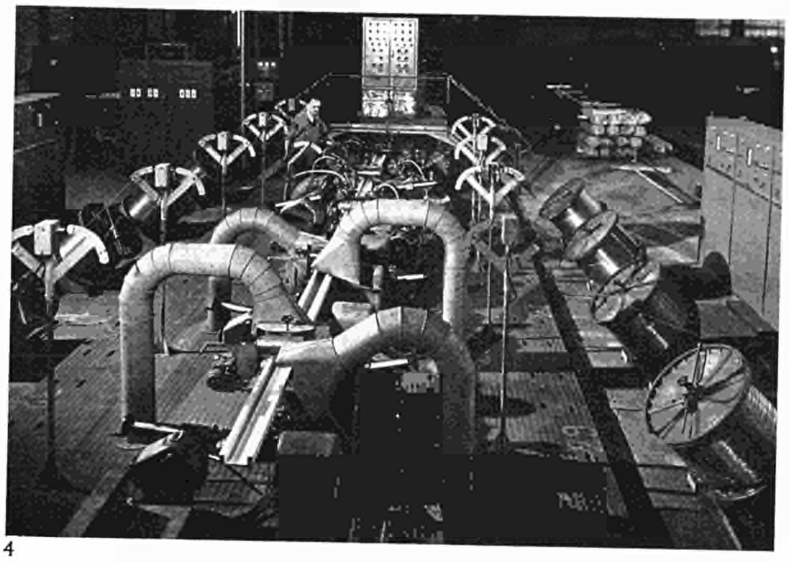

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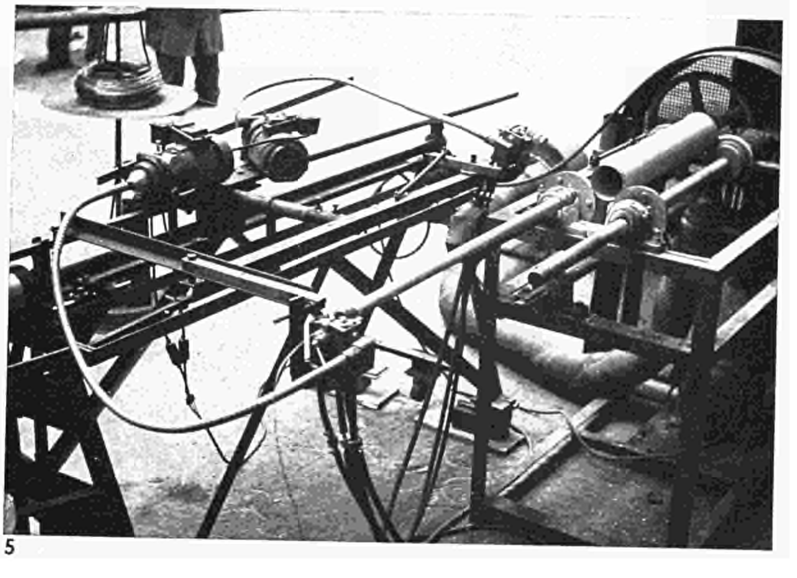


5

Pierre BAZILLE

Diffusion of Alloying Elements in Steel Surfaces — New Processes and Fields of Application — Future Prospects

(Translated from French)

Its has long been observed that structural materials rarely exhibit simultaneously both the surface properties and the internal properties which were expected of them. In practice, the bulk of the material should offer resistance to certain mechanical forces, while the surface is subjected to physical and chemical attack by the external medium.

Attempts were therefore quickly made to protect materials, chosen for their internal strength, by means of greases and paints. There followed coatings by immersion in molten metals, electrolytic deposits, plastic coatings, etc.

On the other hand, external mechanical forces are transmitted to steel products through the medium of their surface, and at points where these forces are applied wear takes place. Hence likewise the need for protection against wear.

With metals for example, and particularly with steel, it was clearly desirable to obtain this protection against corrosion or wear by modifying at the surface the characteristics of the products themselves. In a very large number of instances this has been achieved thanks to the diffusion of alloying elements into a layer of varying thickness.

Principles of diffusion

It is not within the scope of this report to set out in detail a particular theory or theories of diffusion. The phenomenon has been known for a long time in the form of carbon case-hardening.

In 1855 Fick expressed the law which bears his name, and may be expressed as follows. The quantity, dq, of the substance diffused per sq. cm. in time dt is proportional to the concentration gradient $\frac{dc}{dx}$, which is expressed by the equation:

$$\frac{dq}{dt} = -D\frac{dc}{dx}$$

The constant D, called the diffusion constant, is dependent on the elements present.

It was subsequently observed that D is not a constant, but is in reality a function of the concentration and can be represented by the equation:

$$D = D_0 e \frac{-Q}{RT}$$

in which Q is the activation energy;

R is the perfect gas constant;

T is absolute temperature; and

D_0 is a coefficient dependent on the elements present.

e is the basis of Napierian logarithms.

From the practical point of view this equation highlights the predominant role of temperature. The diffusion velocity increases in geometric progression, while the temperature increases in arithmetic progression.

On the other hand, at a given temperature the diffusion depth varies with the square root of the time.

It may thus be seen that, other things being equal, to obtain a definite depth of diffusion it is possible to vary temperature and time. In every instance there will be an optimum compromise to be found between these two variables.

So far as the mechanism of diffusion itself is concerned, it may be considered as occuring in three ways: by direct exchange between neighbouring atoms in the lattice, through the effect of lattice vacancies, and by the insertion of atoms of the diffusing element into the lattice of the base metal.

From this we understand why the rise in temperature, which increases molecular excitation, promotes diffusion.

Diffusion can occur between solids — thus at room temperature copper diffuses to a considerable extent into zinc — between a liquid and a solid — for example carbon-case-hardening in a salt bath, cyaniding, the Sulfinuz process — between a gas and a solid — chromizing, gas carburizing — or through the simultaneous effect of two of these processes, for example calorizing.

Since metals oxidize, work should be carried out in a neutral, or preferably reducing, atmosphere. The treatment material consists of the element being diffused, or of an alloy, or of one or more salts containing the element, with or without the addition of anti-agglomerants (sand, alumina) or even of a suitable reagent. Actually, as the equation showed, the diffusion rate is also dependent on the activity of the element which is deposited at the surface of the pieces being treated, and which subsequently diffuses.

It must moreover be pointed out that the alloying elements contained in the steel of the base metal can have a very great influence on the diffusion rate. In general the elements forming a-iron, chromium, silicon and aluminium, promote diffusion, while the elements forming y-iron, manganese, nickel and cobalt, retard it. Similarly carbon, sulphur and phosphorous, slow down the rate of diffusion, so that it is important to have clean steels.

We shall now look at the principal industrial applications of diffusion, passing rapidly over those which are well known, and laying a little more emphasis on the most recent and less familiar processes.

Diffusion of carbon: Carbon case-hardening

As we all know, this is carried out in a box, in salt baths, or in a gaseous phase in furnaces with a controlled and circulated atmosphere.

Working temperatures are of the order of 900°C. The steel is carburized on the surface to varying depths according to the required use of the pieces being treated. This carburized layer acquires high hardness values after quenching.

Simultaneous diffusion of nitrogen and carbon: Cyaniding and carbo-nitriding

The first is carried out in liquid cyanide baths, the second in furnaces with a controlled and circulated atmosphere. Working temperatures are of the order of 800 to 850°C, and as with carbon case-hardening, a very hard surface layer is obtained after quenching.

Diffusion of nitrogen: Nitriding

Three forms of nitriding should be distinguished:

Conventional Nitriding

This is well known; the nitriding agent is cracked ammonia.

The working temperature is of the order of 550°C. A very hard layer is obtained immediately, quenching of the body of the piece having been carried out before nitriding. Special nitriding steels are required.

So-called Accelerated Nitriding: Ion Bombardment Nitriding

This is a recent process, still little known, which at the start of its industrial career certainly promises to have a good future.

It is carried out in a vacuum furnace, cooled by air circulation within the furnace walls. This furnace represents a cathode, and the piece being worked forms the anode. Heating of the pieces is carried out by means of electric discharges. After excitation of the discharges, a controlled quantity of ammonia is introduced. This is dissociated, and the hydrogen and nitrogen atoms are ionised. This activity of the nitrogen is thus much greater than in the conventional process. Moreover, there is exposure of the surface of the metal to the mechanical, physico-chemical and chemical actions caused by the electron bombardment and the ionised hydrogen.

It is understandable that under these conditions diffusion of the nitrogen is particularly rapid. Treatment continues from 1 to 8 hours, as opposed to 40 to 100 hours during conventional nitriding.

The great importance of ion bombardment nitriding, apart from its rapidity, lies in the ability to obtain a thin layer possessing an extremely high hardness of the order of 1500 Vickers hardness units, starting with relatively cheap steels. Applications are particularly important on stainless or high-temperature steels, which can be treated without preliminary passivation, and also on high-speed steels.

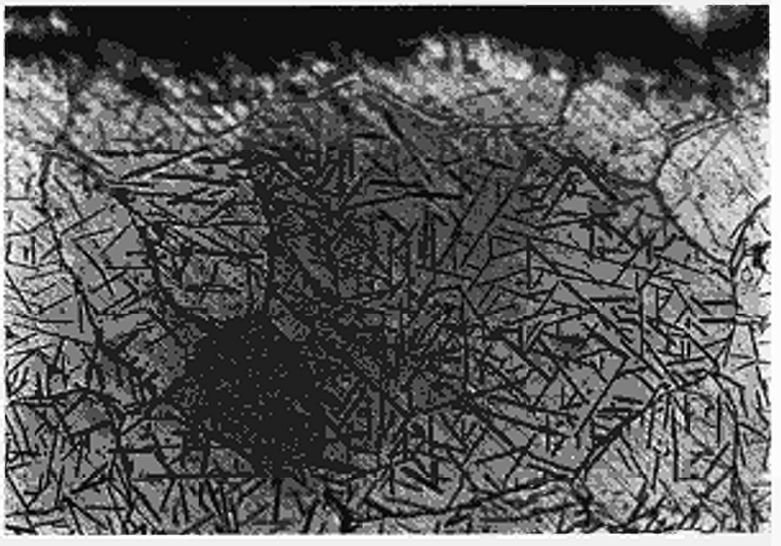
Soft Nitriding

This is carried out in cyanide or alkaline cyanate baths at 560°C. A so-called combined surface layer, about one hundredth of a millimetre in thickness, is obtained; this contains carbides and nitrides of iron which improve the abrasion properties and reduce the dangers of scuffing, and a nitrogen diffusion layer some tenths of a millimetre in thickness, which considerably improves the fatigue resistance.

It should be noted that after soft nitriding no straightening is possible, and that the treatment causes tempering at 560°C.

Diffusion of nitrogen and sulphur: the sulfinuz process

This process is similar to the preceding one, but in addition there is transfer of sulphur, which makes the treated pieces self-lubricating. Scuffing is completely suppressed, whatever the load. If the stress exceeds the elastic limit, flow of the steel takes place without seizure. Wear resistance is even beter than that of pieces subjected to soft nitriding. Running-in time is considerably decreased, and self-polishing occurs on two pieces rubbing against each other; the fatigue resistance is clearly improved.



Sulphinated Mild steel

The sulfinuz process can be carried out on practically all steels, including high-speed and stainless steels, cast irons and bronzes, not containing alloying elements with melting points below 500°C.

As with soft nitriding, no straightening is possible, and the treatment causes tempering at 570°C. Nevertheless the sub-surface layer can be hardened by high-frequency quench treatment after the Sulfinuz treatment.

This treatment, which has been used industrially for some fifteen years, is beginning to be fairly well known in France and abroad, but it has not been so widely extended as it deserves.

Diffusion of zinc

Sherardizing has been employed for some 60 years. It is carried out in a furnace, generally rotary, between 350 and 400°C, the pieces being charged into the furnace with case-hardening material consisting of powdered zinc and sand. Treatment lasts from 2 to 4 hours, and the thickness of the hardened surface is about 0.05 mm.

The consumption of zinc is less than during galvanizing, and above all only a slight dimensional increase is involved, so that the process can be used to protect bolts and nuts against wet corrosion.

Diffusion of silicon

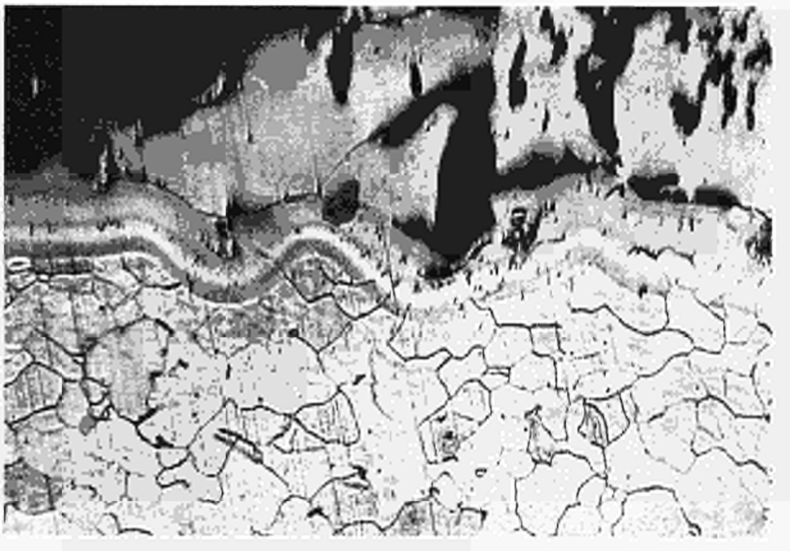
The alloy layer with a high silicon content is especially important on account of its resistance to acids. Unfortunately it is very brittle. Hence industrial applications are restricted.

It is carried out in a rotary furnace containing the pieces to be treated and silicon carbide. A stream of chlorine is circulated through the furnace. The temperature is from 950 to 1000°C.

Other processes have also been tried out, but they do not appear to have found industrial application.

Diffusion of aluminium

This has received the name "Calorizing", an American term which recalls its corrosion-resistant properties at elevated temperatures, i.e. up to about 800°C during continuous service.



Calorizing

The pieces are placed in a fixed or rotary furnace with treatment material consisting of powdered aluminium, or powdered ferro-aluminium, alumina and ammonium chloride. The latter dissociates during heating into hydrogen, nitrogen and hydrochloric acid. The hydrochloric acid reacts with the aluminium to form aluminium chloride, which is cracked at the surface of the pieces being treated, liberating the aluminium, which then diffuses into these pieces.

In the absence of ammonium chloride, diffusion still takes place, but it is considerably reduced. Working temperature is of the order of 900°C, and layers from 0·05 to 0·1 mm. in thickness are obtained.

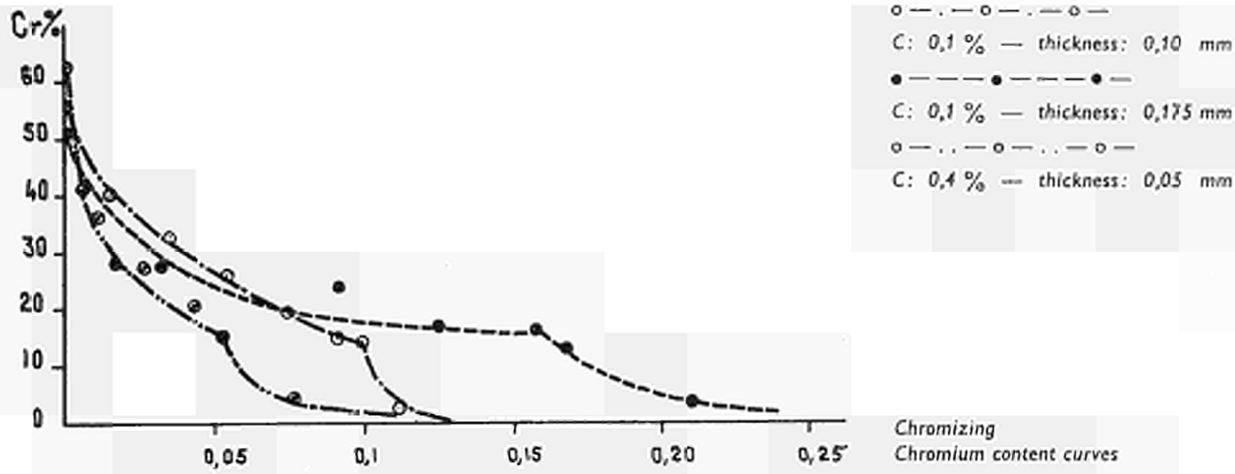
Calorized pieces, if deformed, must be hot straightened, since the layers of ferro-aluminium will not tolerate any appreciable cold deformation without crack formation.

This treatment, the industrial application of which dates from about 1910, was extensively used between the two World Wars and for several years after the Second World War. Since then its use has considerably declined, for customers often prefer high-temperature steels to calorized steels. Calorizing however is still applied to boiler tubes and components, pipes and parts of furnaces, heat recuperators, hot-air generators, pyrometer sheaths, heat treatment baskets and racks.

A start has been made in the application of calorizing to high-temperature steels themselves, to improve their behaviour in contact with sulphurous gases: sulphuric anhydride and sulphuretted hydrogen.

Diffusion of chromium: chromizing

The possibility of diffusion chromium, a supremely corrosion-resistant element, has clearly tempted many research workers. The first research papers appear to go back to the first World War. In the United States, Kelley took out a patent in 1919. He operated a process at very high temperature (1300-1400°C) by diffusion between solids in a protective atmosphere of purified hydrogen.



Chromizing
Chromium content curves

Subsequently, numerous research programmes were conducted in all the industrial countries, on diffusion between solid and solid, liquid (salt baths) and solid, and gas and solid.

At present, all these industrial processes use a chromium halogenide, prepared either in a preliminary operation, or formed in situ in the treatment furnace.

The first process was brought into operation in Germany a little before 1940. The treatment material consists of porous porcelain impregnated with chromium chloride. The working temperature is of the order of 1100°C.

During the war, in Great Britain, R.L. Samuel developed the chromium iodide process. The treatment material consists of ferro-chromium in granular form and of an additional refractory diluent in powder form containing ammonium iodide, which dissociates under the influence of heat. The hydroiodic acid reacts with the chromium to produce chromium iodide, which liberates its chromium onto the pieces being treated, and this active chromium diffuses into them. The working temperature is of the order of 900°C.

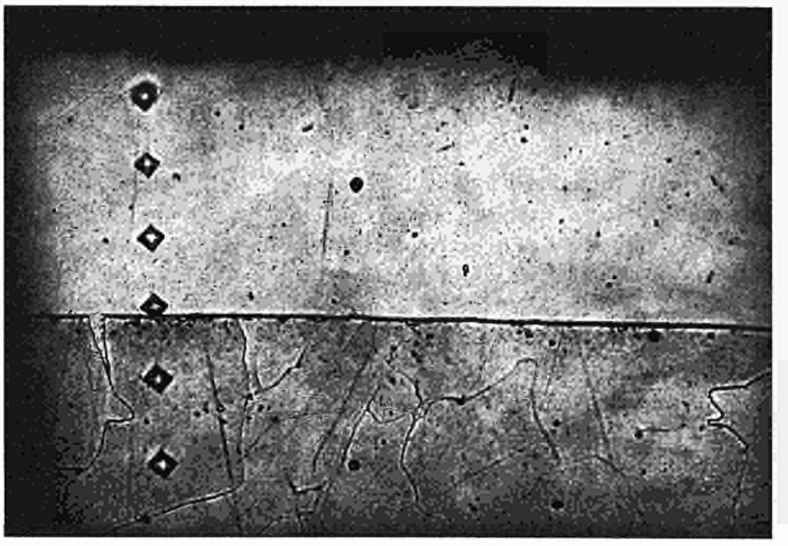
Some 15 years ago Ph. Galmiche developed the fluoride process. The treatment material consists of pure granular chromium without any addition of refractory material, and the chromizing agent is chromium fluoride. Working temperatures are in the range from 900 to 1100°C according to the nature of the pieces being treated and the desired result. It is possible to obtain a glittering surface on the treated pieces if they are of mild steel.

Finally, in quite recent years, one, or rather two, processes have appeared in the United States, employing above all chromium boride. The first is similar to the preceding processes: the pieces to be treated being heated in porous chromium or ferro-chromium, impregnated with one or more chromium halogenides. In the second process, the pieces being treated are separated from the mixture, and the atmosphere containing the chromium halogenide is forcibly circulated, and successively sweeps over the stock of chromium or ferro-chromium and the pieces to be chromized. This enables open coils of sheet metal to be treated.

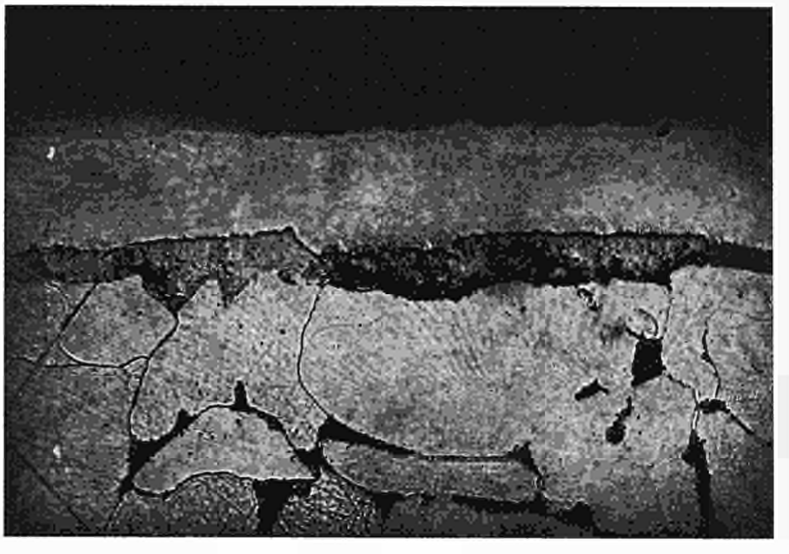
A distinction should be made between two types of chromizing .If a mild steel is treated, a surface layer is obtained, varying generally in thickness from 0·05 to 0·1 mm., according to the temperature and duration of treatment. This layer of ferro-chromium is resistant to dry and wet corrosion, and to corrosion by nitric acid. This is soft chromizing (first figure p. 237).

But if a steel with a sufficiently high carbon content is treated, a layer of chromium carbide, from 0·02 to 0·03 mm. is obtained, which is resistant to wear, to dry corrosion, and to a certain extent to wet corrosion. This is hard chromizing (second figure p. 237).

Present practice is to use soft chromizing for screws and bolts, nuts and bolts, magnetic relay components, food industry components, atomic energy components, petroleum industry components, etc.



Soft chromizing



Hard chromizing

Hard chromizing is employed for all sorts of tools for stamping and pressing, wire-drawing, extrusion, aluminium foundry moulds, working of plastic materials, various wearing parts, wire and cable guides, etc.

Unfortunately, chromizing — such a promising process a priori — finds a restricted field of application for two reasons:

The first, which applies to hard chromizing, is that, in order that the layer of chromium carbide shall withstand the forces applied to it, it is often necessary for it to be supported by a backing layer which in itself is very hard. It is then necessary to quench the treated pieces after chromizing. But this quenching inevitably involves deformations which cannot be made good by straightening, for the chromized layers are too thin. To have steels which are not subject to any deformation during quenching would be an absolute necessity.

The second limitation applies to soft or bright chromizing. Though the resistance to dry corrosion is always excellent, whatever the steel treated, the same is not true of wet corrosion, where the effect of a backing layer is paramount. Experience shows that to obtain complete resistance to wet corrosion it is necessary to use titanium stabilised steels, and these moreover must have very low contents of sulphur and phosphorus. Such steels exist, but at present they are too costly for mass production with the use of chromizing.

Research work is in progress to find a steel to give satisfactory results at a reasonable cost price. When this work is completed, the field open to chromizing will be considerable, for the treatment, when carried out in very large furnaces, will not be very costly. Moreover, the chromized layer is sufficiently plastic to be hot, and even cold-formed. Consideration might then be given to the chromizing of semi-finished products.

Even today chromized flat-rolled products exist in the United States, where they are principally used for exhaust silencers. Perhaps one day we shall see chromized rounds, flats, beams and angles at an economic price, which would in practice do away with maintenance of metal structural frameworks.

Conclusion

This short review shows that since the start of the century processes of diffusion of alloying elements into steels have multiplied, and have taken an important place in the fields of mechanical resistance, resistance to wear, and resistance to corrosion. True, so far only a small number of elements have been used for industrial diffusion processes — metalloids such as carbon, nitrogen and sulphur, or metallic substances such as chromium, aluminium and zinc. The field of action open to research is therefore enormous. It is equally true that attempts have been, and are being made to diffuse many other elements, certain of which should be particularly important, and also to bring about the diffusion of a combination of elements.

New industrial processes will certainly see the light of day, widening still further the field of application of diffusion processes.

G. CATTRO

and

L. MASSIGNAN

The Relation Between the Surface of Rolled Products and the Condition of the Initial Billets

(Translated from Italian)

Products rolled from special steels are today required to meet ever more stringent quality specifications. At the same time rolling programmes must obviously be designed with a view to maximum economy.

Since one of the most important requirements in rolled products is the necessity to provide good surface quality, we must obviously include among the problems of major concern to good rolling practice the relationship between the surface condition of the intermediate stock (usually billets) and that of the finished product.

For various reasons it is usually considered expedient to carry out surface conditioning as far upstream as possible: in the case of high-quality special steels such treatment often starts with the as-cast ingot which may be turned, milled or ground or else flame-scarfed or hot-milled. It must be remembered however, that such procedure is not without its disadvantages and the tendency to too early surface conditioning is therefore open to criticism. In fact, it in no way removes the need for surface treatment further down the production line for ingot surface defects may well occur in various forms and for various reasons in subsequent processing stages. At the same time it poses technical and economic problems that may at times be extremely awkward. The problem of bloom surface condition is nevertheless a very real one especially when one considers that as the rolling sequence proceeds, so the surface/volume ratio increases and similarly the relative wastage caused by surface treatments with consequent adverse effect on overall costs.

It is therefore necessary to find a solution to the far from easy problem of optimizing surface conditionment to achieve a certain standard of end-product quality. The wide range of steel grades which have to be catered for, their varying workability properties and oxidizing behaviour, the characteristics of the rolling mill plant, not to mention the economic considerations already referred to, all these factors compel us to divide our problem up into a number of component tasks each of which must be individually studied and solved. Important and subtile as these subjects may be, we shall however here refrain from entering into details of the various types of surface treatment and their productivity and from discussing the organization for material flow. The manufacture of high-quality special steels with the frequent need to produce small lots over a very wide range of grades introduces further complications which must vary from firm to firm so that any solution must necessarily also take account of the needs, aims and available resources of the individual manufacturer concerned.

However, the point that we particularly wish to underline as a subject for possible discussion is the relation between the defects exhibited by the billets presented to the finishing trains and the quality of the finished products.

We have found investigation of this question to be by no means straight-forward. Just what degree of billet imperfection is admissible for a given target quality of the finished bars or coils? The answers received to this question are liable to be diverse and sometimes conflicting, conditioned as they are by the rolling plant and the facilities for surface conditioning installed.

To suggest one uniform standard for billet surface conditioning is obviously out of the question. One has only to consider the differing costs and complication of the various methods of surface inspection and treatment each designed to detect progressively slighter flaws until not even the minutest imperfection can hope to remain undiscovered (blasting, pickling, blasting and pickling combined, magnetic, fluorescent or eddy-current crack-detection) to see how absurd this would be. Then, finally, there is the requirement to remove all defects more or less as soon as discovered which in turn involves the use of equipment the operating costs and productivity of which will vary very considerably.

Since, as we have been at pains to point out, the question of cost will always intrude, we are left with the basic problem of establishing the optimum degree of billet imperfection that will still give a product acceptable for the various intended uses.

This problem has long been under study by an Italian institute and has not yet been fully solved although good progress has been made and a number of constituent results achieved. The first major obstacle is the difficulty of working experimentally on the operating plant (bar mills and wire-rod mills) under conditions of perfect control. Any influence attributable to alteration of optimum plant operating conditions has to be identified and eliminated and any tests already conducted in such abnormal conditions must of course be entirely or at least partially scrapped.

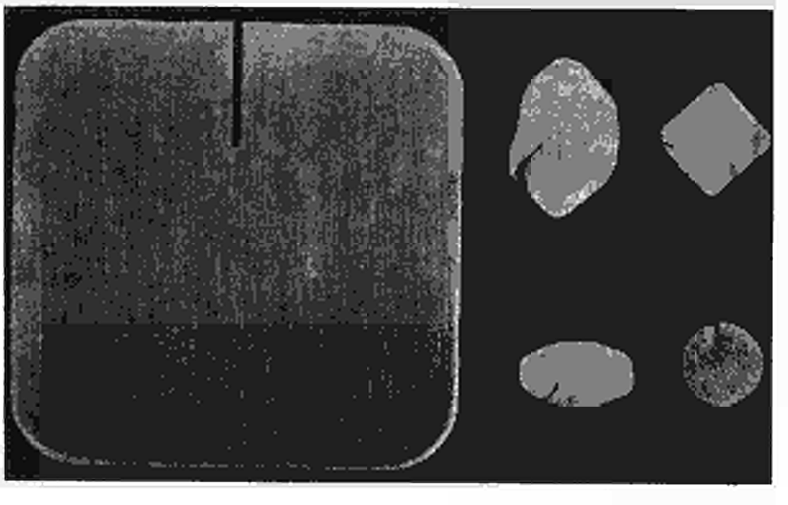
Even the choice of experimental technique experienced several false starts. The commonly used method of simulating billet defects and following up their subsequent development history (see above figures and on following pages) was abandoned, despite its undoubted advantages, for the reason that artificial defects are hardly ever quite the same, especially in shape, as real ones and such disparity may well become unacceptably significant during the course of successive stages of deformation. Nor must we forget that we are dealing with special steels the flaws in which are usually of small degree.

After numerous trials the technique of measuring the dimensions of actual billet defects and monitoring their influence on the end product was also discarded. Although it was possible to measure some flaws without removing them completely there was always the danger of their dimensions altering (especially depth) even in closely adjacent zones.

As regards other defects (of non-elongated type), it is practically impossible to determine their dimensions without eliminating them completely.

Eventually, after a great deal of experiment a suitable procedure was evolved. The billets were subjected to different surface treatments, a statistical evaluation made of the defect incidence "masked" by such treatments and the visible defects carefully removed from the variously prepared surfaces. Working for example with surfaces subjected to overall grinding and then pickled, the removal of all defects followed by continued inspection prior to further pickling if required gave a virtual certainty of complete defect elimination. We were then left with pickled surfaces free of visible defects.

In other test series the billets were blasted and it was found that in certain operating conditions this practice leaves concealed defects of definite type and size.



Section of a 68 mm.² billet showing original longitudinal crack and sections through the same billet after reduction in various shaping passes.

Thus, the defects undetected by visual inspection and hence not removed will be of a type that is reasonably well identified.

Finally, tests were conducted on surfaces that had merely been metal-brush finished and trued of all defects detected by visual inspection.

The methods employed in these tests, which were carried out some years ago, have undoubtedly been improved upon since. There have been various fairly recent studies aimed at the application of magnetic flaw detection methods for locating, indicating and recording the various types of defect. If, as seems probable, such techniques prove fully reliable in continuous operation they may well mark a notable step forward in reducing the problem to terms of almost mathematical precision and so bring about its final and satisfactory solution.

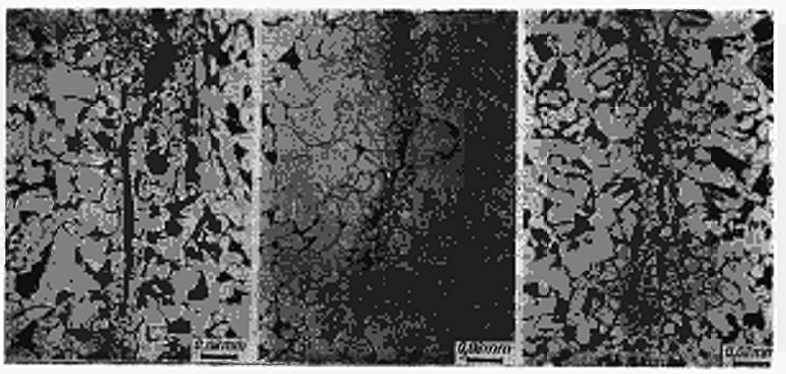
We should mention incidentally that insofar as evaluation of residual imperfections in finished rolled products is concerned, particularly rounds, there are to the best of our knowledge various effective and reliable methods of inspection already which allow the standard of surface quality to be assessed with acceptable accuracy. Our investigations were carried out, with the aforementioned precautions to ensure that the mills used for test were operating under controlled conditions, on various groups of special steels whose behaviour when hot could be accepted as reasonably similar (ballbearing steels, spring steels, Cr-Ni-Mo structural steels, austenitic and ferritic stainless steels, etc.).

The following is a concrete example:

Steel UNI 38CD4-Cogne KM1 (Cr-Mo). Two groups of 30 billets each were subjected to conditioning on surfaces that had been differently prepared:

Surface type A (with maximum flaw detection effort and all defects removed); surface type B (with visible defects removed only if greater than 0.5 mm.).

Rolling was carried out with A and B billets alternately. The quality of the coiled rod produced on an automatic train was evaluated on the basis of an index of imperfection — and which is defined as the ratio of the maximum defect incidence observed on the bar or billet to the maximum possible value



Micrographs of the billet of the preceding figure in different stages of reduction (nitric acid alc. attack). Approx 370: 1, original 500: 1.

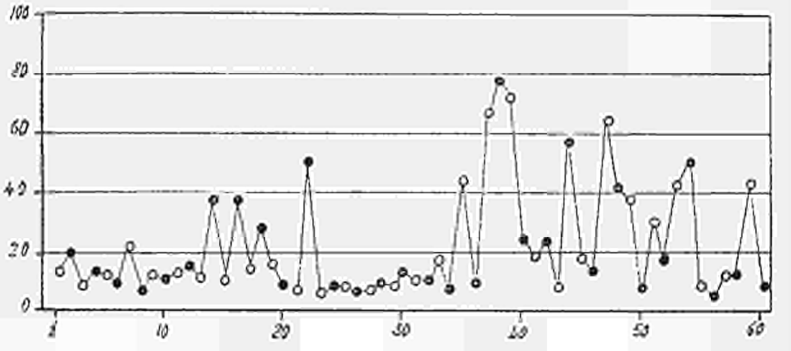
multiplied by 100 — suitably predetermined and relating to ghosts, laps and scabs and their actual sizes. In the case here considered it was found that the A billets satisfied the predetermined standards which were represented by an index value of 20 whilst the B billets proved unsuitable for such a strict specification.

During the course of this test series a defect developed on the mill machinery which was however fairly easily located and corrected so that the tests, though delayed, did not have to be cancelled.

Evaluation of the test results established that a relation existed between the defect incidence on the billets and that on the coils, though obviously no such correlation was possible for the period of rolling under uncontrolled conditions.

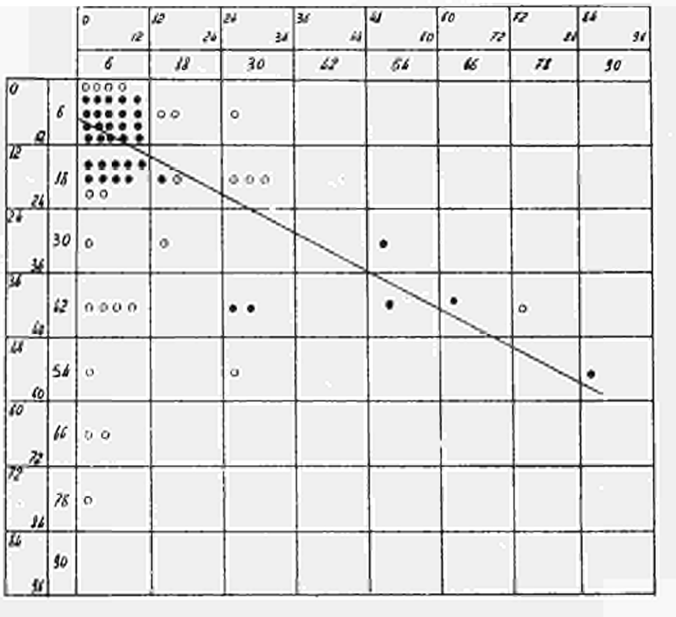
As a result of repeated trials it was confirmed that the system answered to requirements on the rolling plant used and offered tangible advantages under practical mill operating conditions, particularly in that conditioning of the billets was no longer subject to the judgment and decision of the operators. Moreover, the residual billet imperfection was with reasonable approximation divided into several definite classes, quite independently of any assessment made by those responsible for the conditioning treatments, and to every such class there corresponded equivalent degrees of imper-

○ *Batches of A billets*
● *Batches of B billets*



Index of flaws in batches KMI steel (UNI 38 CD 4)

● *Relative data on control batches*
○ *Relative data on batches not controlled*



Index of flaws in billets; Index of flaws in batches.

fection on the finished products. This also helps to reduce factory inspectorate personnel costs.

It cannot of course be denied that this system also has its weaknesses. The high degree of scatter of some parameters which cannot always be kept under sufficiently strict control introduces random elements which adversely affect precision. This mainly concerns the various billet pretreatments (variations in the time/particle-size relation of the grit and rounding off of corners in the case of blasting; variations in the nature of the scale depending on cogging or annealing finishing temperatures or the method of cooling the billets, etc.).

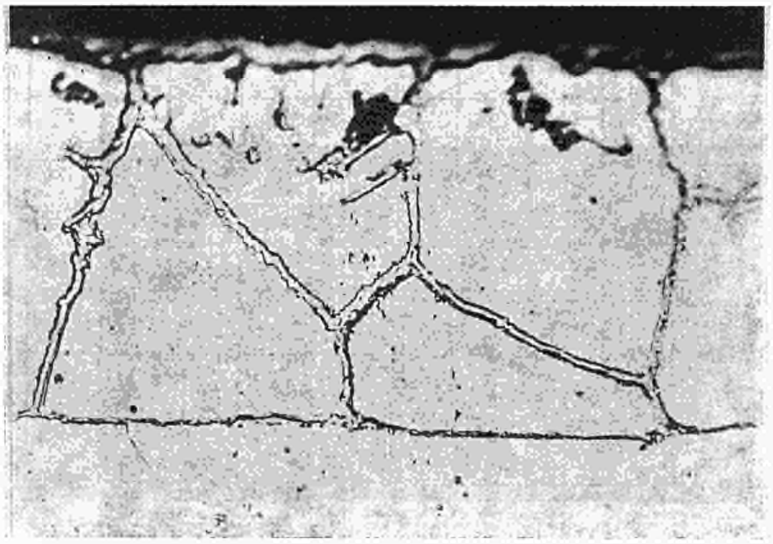
However, these drawbacks are not really very serious and certainly offer no argument against continuing on the lines described and seeking to improve the various operating techniques involved. Meanwhile it is to be hoped that work in developing automatic equipments for recording the degree of defect incidence on billet surfaces will soon reach a point where this technique can be applied to industrial practice.

Gottfried BECKER

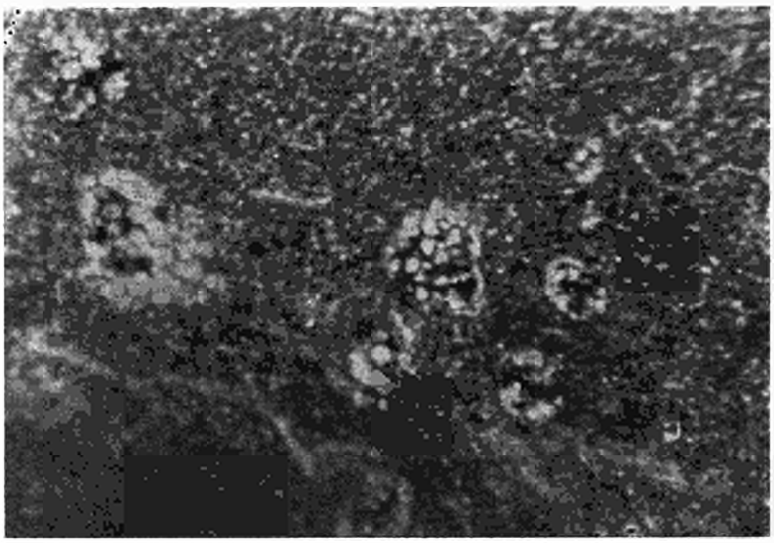
The Chromizing of Special Steels

(Translated from German)

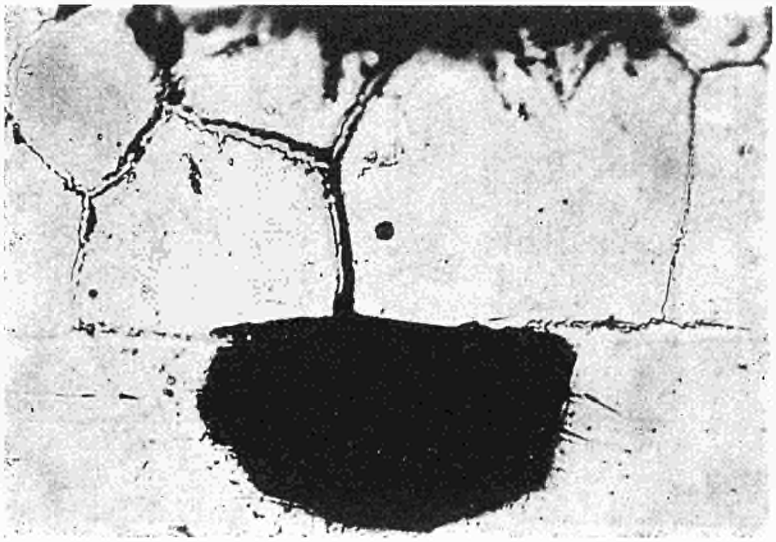
When chromium is diffused into iron for the purpose of forming corrosion-resistant coatings the carbon in the basal material can, as we know, adversely affect the coat properties. We have already shown that the carbon migrates towards the impregnating chromium whereby, even if the content be slight, it acquires a high zonal concentration in relation to that throughout the material section. This is manifested chiefly as the precipitation of intercrystalline carbide veins as illustrated in the first figure on this page. Such a structure is rust-prone under severe moisture conditions. The second figure shows a plan view of parts attacked in this way from which the rust has been carefully removed. In these parts crystals of the coating can be individually distinguished without signs of coherence. The first figure on page 243 shows a section through one such part from which it is evident that corrosion attack follows the carbide veins along the ferrite grain boundaries. The second figure on page 243 offers a more highly magnified fragmentary view from above of a zone that has been subjected to the action of very dilute sulphuric acid. In this case also the ferrite grain boundaries have obviously been heavily attacked. By this means, it was possible to isolate the carbide network as shown in the third figure on page 243 whereafter a C content of approx. 8% was established. Small wonder therefore that, with a view to obtaining good protection against corrosion, a German steel company manufactures IK steels (short for



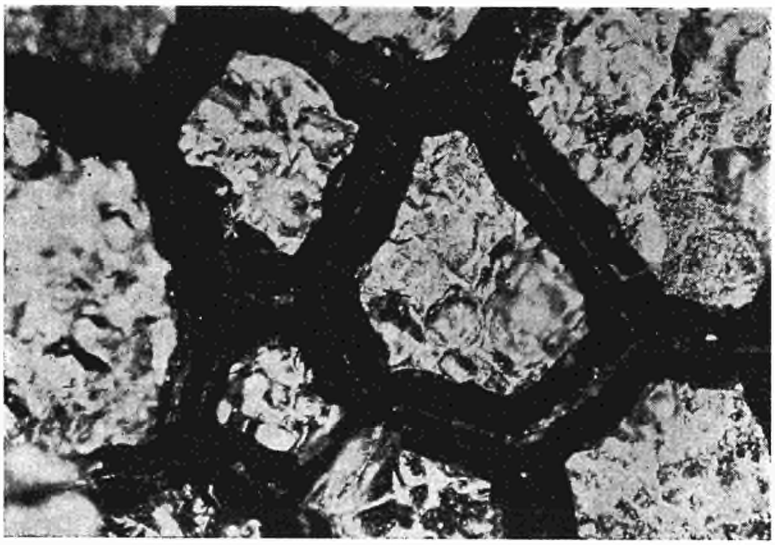
Intercrystalline veins in chromizing zone



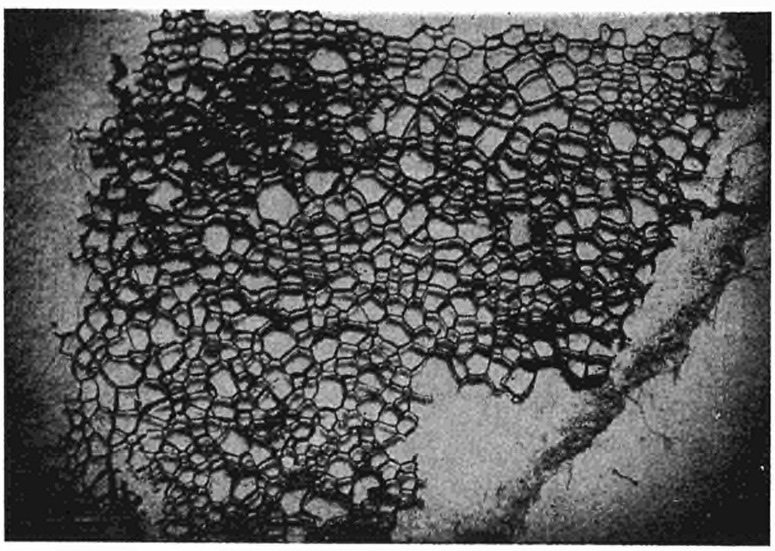
Top plan view of corroded areas



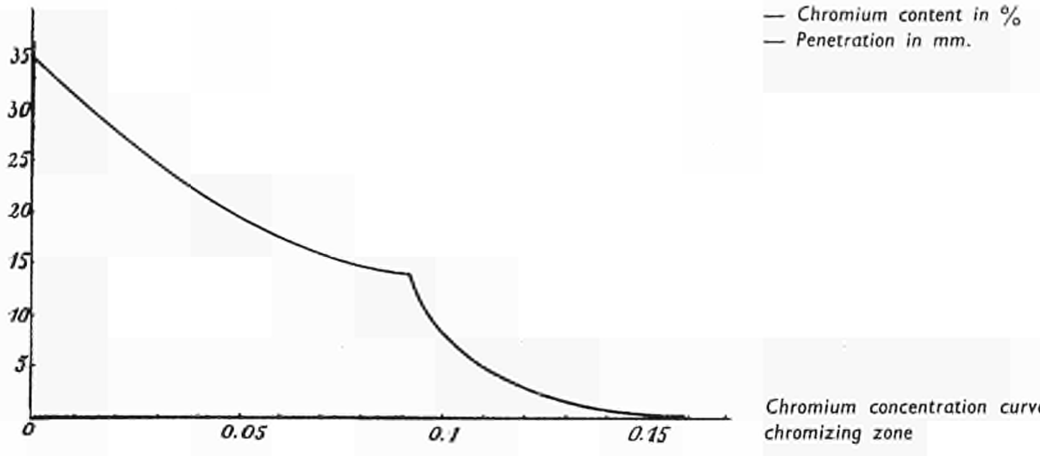
Corrosion of the granular boundaries along the intercrystalline veins



Corrosion affecting only the edges of ferrite crystals



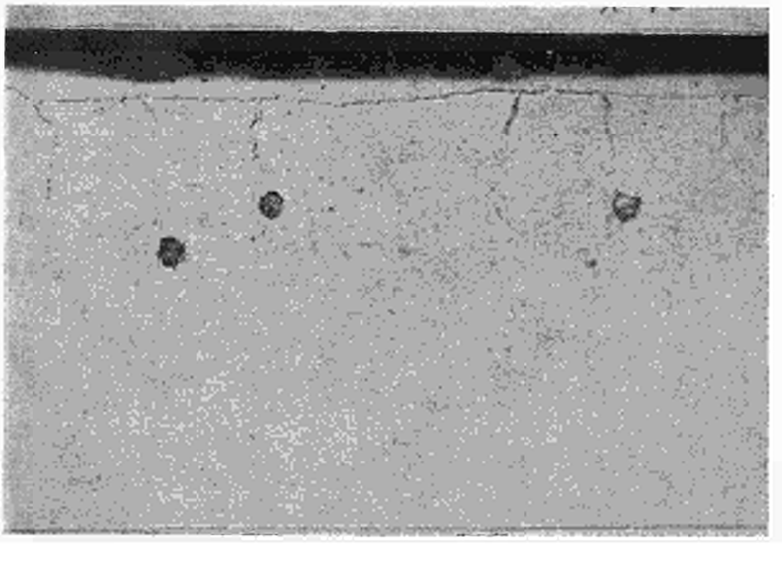
Isolated network of intercrystalline veins



Chromium concentration curve of a normal chromizing zone

InKrom steels) in which this undesirable carbon migration is suppressed by the inclusion of powerful carbide stabilizers.

In this connection we should mention another drawback to which chromized coatings may be subject. When practical development first started we published the chromium concentration curves, reproducted above, from which it can be seen that the outside Cr content for the protective layer is given as 35%. One sometimes hears the opinion expressed that higher contents of around 50% can in fact be achieved. Admittedly, this is quite possible, but such a practice should not be unconditionally subscribed to, since it can lead to a structural formation as shown in the following figure. Here we see that a hard outer layer of some 800-1000 HV has formed as a result of sigma phase genesis due to the high chromium content. The prejudicial effects of sigma phase formation on corrosion-resistant steels are of course generally recognized, but it must be remembered that they are just as inherent to its appearance in chromized coatings.



Sigma-phase formation in a chromizing zone with a very high chromium content

Effect of aliting on scaling and cracking of turbine blades made of a cobalt-base alloy

It should be clearly inferred from the foregoing arguments that the strength properties of chromized parts cannot be implicitly raised by increasing the carbon content. For this reason a German steel company produces chromizing steels, the strength increase of which is achieved through the alloying metals. This practice is conditioned *inter alia* by the need to keep the price of such steels low in comparison with that of corrosion-resistant chromium and chromium-nickel steels. In one case for example this is achieved by adding approx. 1·5% copper. This gives a strength after chromizing of about 50 kg./mm.^{2} which is subsequently raised by hardening and tempering to around 70 kg./mm.^{2} depending on the impact value required.

Heat-resisting and high-temperature steels are given compositions designed to afford certain creep rupture strengths; they are however not always proof against the oxidizing and corrosive milieus to which they are liable to be exposed and which may, in the presence of certain combustion-atmospheric impurities, be extremely aggressive. To raise the corrosion-resistance by altering the analysis does not necessarily produce the right answer since the creep rupture strength will usually thereby be lowered. Thus, protective coatings are nowadays needed for these steels and alloys as well. So for example, resistance to attack by sulphur compounds is heightened by diffusing chromium into the surface. Impregnation with aluminium and silicon is also employed where very high temperature stressing must be resisted.

The above figure shows two turbo-jet vanes after a long period of service in alternating stress conditions of rapid heating to 1100°C, followed by rapid cooling. The unprotected upper vane has developed cracks which penetrate through the scale into the material itself. The lower vane, which had been given an Al-impregnated protective zone and subjected to the same stress conditions, shows no cracks and hardly any oxidation.

Friedrich SCHMIDT

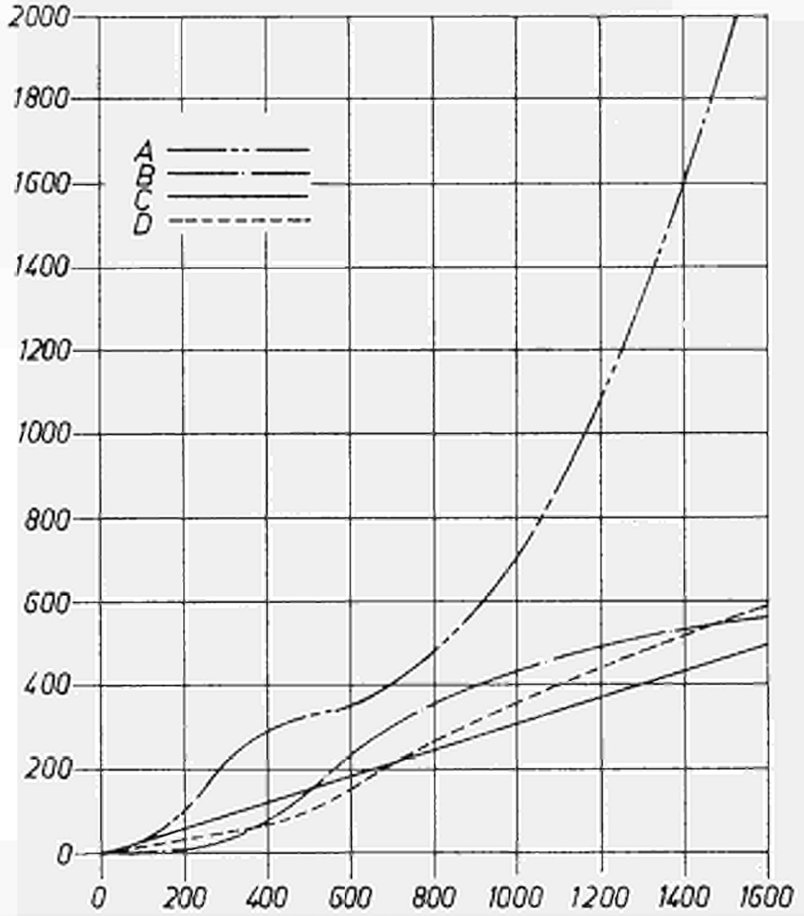
Diffusion of Alloying Elements in Steel Surfaces: New Processes and Field of Application

(Translated from German)

In his most interesting paper Mr. Bazille has given us a first-class account of the various diffusion processes used in industry to-day. Among them he mentioned chrome diffusion in metal surfaces, known as "chromization". Mr. Bazille pointed out that in the case of hard chromizing, deformation of the workpiece can be a drawback. It was also said that with soft chromizing the crucial question was the development of a base material at an attractive price.

I should now like to give you some results of the experiments we have carried out with the chromizing processes developed by two American companies and one in France.

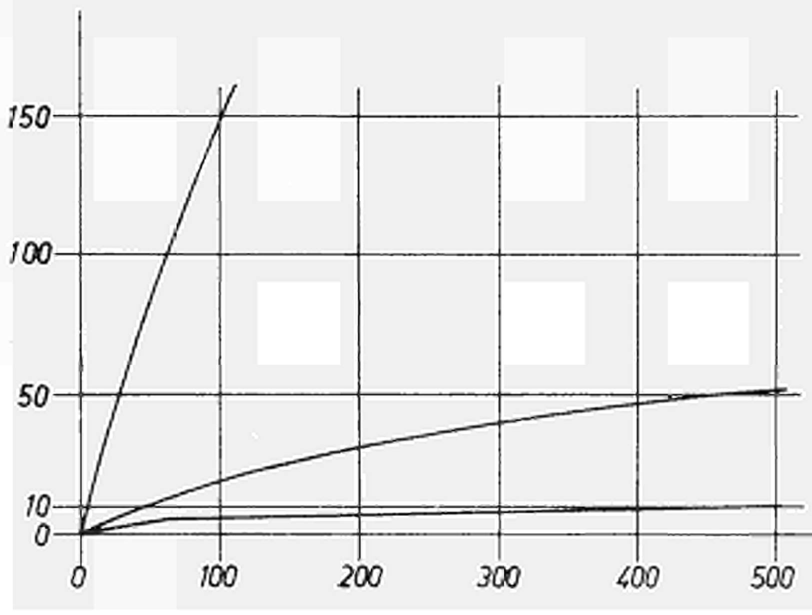
Special interest naturally attaches to the comparability of a chromized steel with chrome alloy steels. On this point we were able to establish the following facts from various series of tests in which we simultaneously exposed chromized



Weight loss in mg./dm.².
Test time in h

Corrosion of various alpatized steels of different chemical composition as a function of the storage time in hours

	Specimen taken from bundle No.			
	A	B	C	D
Mean Cr content of the surface in %	30	33	33	33
Mean Cr content of the layer in %	21	22·7	22·8	23·5
C content of the layer in %	0·35	0·06	0·05	0·05
Depth of layer in mm.	0·02	0·022	0·021	0·022



Storage temperature: 680°C
Weight increment in g./m.².

mild steel

aluminized steel

alphatized steel

Oxidation test of various steels of different chemical composition as a function of the storage time in hours steels, 12% and 17% chrome steels and aluminized steels to the ASTM salt spray test.

After a 72-hour test it was found that the chromized steel was absolutely comparable with the 17% chrome steel. It withstood the test better than the 12% chrome steel and the aluminized steel. If the chromized steel was lightly killed with chromic acid it could be further observed to rate even better than the 17% chrome steel in corrosion resistance.

To attain this level of corrosion resistance with chromized steel a minimum chromized depth of 2-3/100 mm. is generally necessary. The chrome content at the surface is somewhere between 25 and 35%. It is however, also essential that the carbon content in the chromized layer should not exceed 0.05%. If this requirement is not satisfied, the effect clearly shown in the first figure on page 246 is produced.

This figure shows loss in weight plotted against time of exposure to the ASTM salt spray test. The individual curves show the behaviour of test pieces taken from different chromized sheet coils. Whereas all the coils had a surface chrome content of 30-33%, averaging 22% for the whole depth of the layer (about 0.02 mm.), coil A, which showed considerably greater corrosion in the test than coils B, C and D, differs from the others in its carbon content in the chromized layer. The test pieces from coils B, C and D had an average carbon content of 0.05% in the chromized layer whereas coil A proved to have a carbon content of 0.35%. Mr. Bazille has already pointed out—and we can confirm this from our own investigations—that in order to avoid such effects it is advisable to use sufficiently high carbon steels or else to chromize titanium stabilized steels. The latter show even better corrosion resistance than the steel qualities shown in the graph.

A particularly interesting application of chromized steel is that of heat-resistant material, e.g. in boiler-making. The following three figures show the increase in weight plotted against exposure time at three different exposure temperatures.

In the first, weight increase is shown for unalloyed structural steel in comparison with aluminized and chromized steel at a temperature of 680° C.

It is not at all surprising that aluminized steel and chromized steel have considerably better resistance to corrosion than normal mild steel.

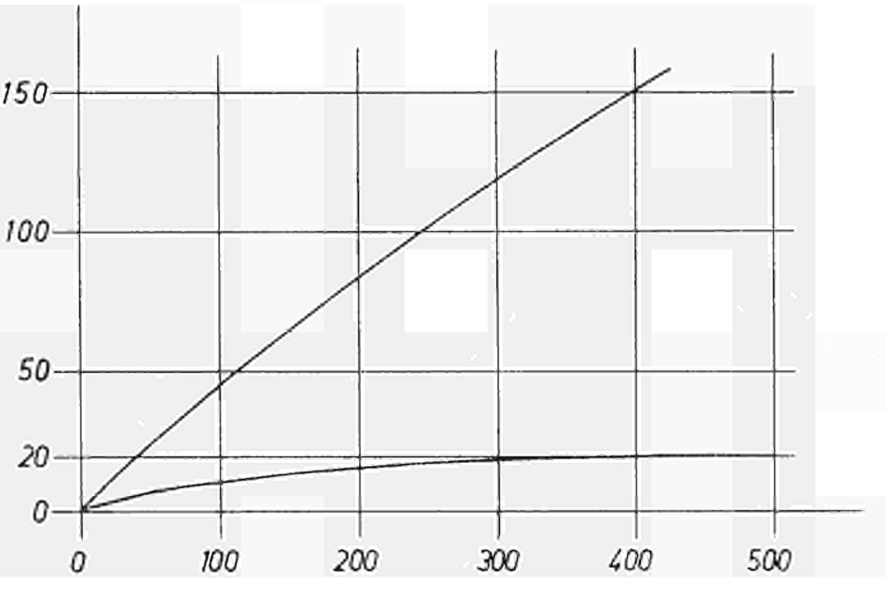
The next figure compares aluminized steel with chromized steel at an exposure temperature of 750° C. The high resistance of alphatized steel to scaling as compared with aluminized steel is clearer still at this exposure temperature.

At the exposure temperature of 830° C (see second figure on p. 246) the following are compared:

- 12% chrome steel
- 17% chrome steel or alphatized steel
- 12% chrome steel chromized, additionally, on the surface, and
- 17% chrome steel chromized, additionally, on the surface.

The figure clearly shows the effect of chromizing on the resistance of the steels to high temperature and underlines, in particular, the possibility of giving unalloyed or low-alloy

Storage temperature: 750° C
Weight increment in g./m.².
Aluminized steel
Alphatized steel



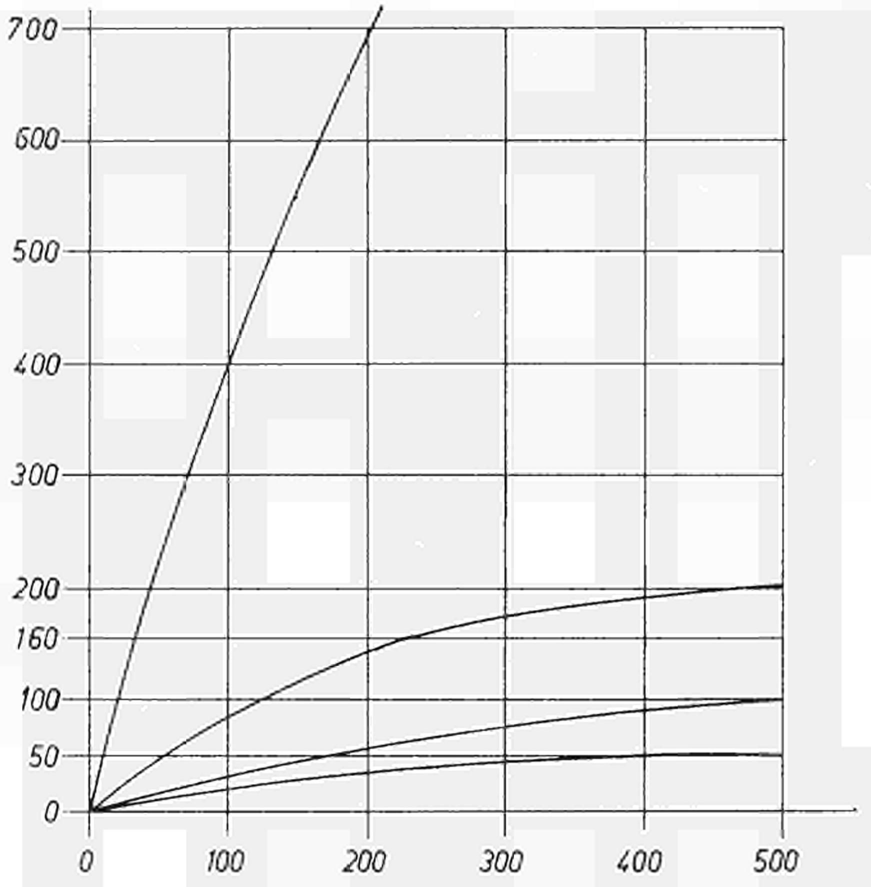
Oxidation test of aluminized and alphatized steel as a function of the storage time in h.

steels a surface with greater resistance to scaling than would otherwise be normal with the base material.

Chromized steel is comparable with 17% chrome steel.

The oxidation resistance of 17% chrome steel is further considerably increased by supplementary chromizing.

Of the many fields in which chromized steel is already being used, we would mention in particular the construction of a polyvinyl-chloride bunker built for an important French chemicals firm. This 500 m.[3] container has a diameter of 75 m. and a height of 19 m. It is made entirely of steel plate chromized on one side. The plates were welded together, after chromizing, by the electric arc process. The weight of the chromized plates used for this vessel is about 20 tons. As



Storage temperature: 830° C
Storage time in h.
Weight increment in g./m.².
Stainless steel with 12% Cr
Stainless steel with 17% Cr or alphatized steel
Alphatized steel with 12% Cr
Alphatized steel 17% Cr

Weight increment of various stainless steels of different chemical composition as a function of the storage time in h compared with alphatized steel.

regards price, in this particular case, since the fabrication of the vessel in ordinary structural steel would have called for a Hypalon lining, making it in chromized steel plate is fully competitive with the traditional method.

For about two years now a French firm which has the exclusive licence for Europe for the process I mentioned earlier, has been working in the field of soft chromizing with excellent results. Numerous chromization applications have found a market, and although the individual products are naturally more expensive than the same in ordinary structural steel, the use of chromized semi-finished products nevertheless enables unusually attractive prices to be quoted.

The numerous tests that have been made on the physical properties of the steel, e.g. corrosion resistance and oxidation resistance and also on its processing qualities such as its forming and welding properties, justify the opinion that chromized steel will replace stainless steel in many fields of application, of volume production of semi-finished goods in chromized steel. The individual parts can be offered at a price considerably below that of the same products in stainless steel.

M. GENIEYS

Chromaluminizing

(Translated from French)

Afco Chromaluminizing

The demand for more advanced mechanical properties in constructional materials for miscellaneous high-temperature equipment increases the importance of the corrosion factor at high temperatures.

During recent years, aviation, metallurgy and chemistry have made demands for increasingly noble materials combining advanced mechanical properties, usually at high temperatures with corrosion-resisting properties in increasingly aggressive environments.

In the case of numerous materials whose mechanical strength properties at high temperature are improved by various metallic and non-metallic additions (steels and refractory alloys of the precipitation-hardening type, oxide-precipitation super-refractories, and carbide-precipitation super-alloys), resistance to corrosion at very high temperatures often appears to be inadequate; also, materials of similar chemical composition frequently have very different corrosion resistance. It is therefore advantageous, and sometimes essential, to consider the protection of refractory materials against the corrosive action of high-temperature combustion gases.

The principal characteristics which protective coatings or casings must satisfy are, firstly, an excellent bond with the surface of the protected materials, and, secondly, the absence of brittleness combined with high resistance to chemical corrosion and to thermal fatigue when subject to corrosion.

In addition, the coating treatment must, as far as possible, be capable of being carried out under conditions which do not give rise to a significant alteration in the high-temperature mechanical properties of the treated materials.

Among the different solutions which can be considered for effecting such coatings, the formation of surface diffusion-alloys seems to be the only method which allows all these requirements to be reconciled.

Chromium diffusion, or chromizing, gives coatings of low brittleness, and assures effective protection for the materials up to temperatures of about 1000°.

Aluminium diffusion, or calorizing, assures a protection suitable for temperatures up to 1100° C, but the coatings obtained are brittle. They can crack or become detached under the influence of mechanical or thermal shock.

In 1949, Mr. Galmiche, a doctor of engineering developed a process for the simultaneous diffusion of chromium and aluminium which brought together and even improved most of the respective advantages of chromizing and calorizing.

The process used has a number of points in common with chromizing treatment. It is, in effect, a cementation in which the elements chromium and aluminium are brought into contact with the workpiece in the form of a gaseous halogenous compound which, at high temperature, decomposes; in doing so, it deposits atoms of chromium and aluminium which diffuse through the surface of the workpiece.

These coatings are therefore not platings but rather a transformation of the base metal for a certain thickness at its surface.

The cementation charge consists of a mixture of chromium in powdered aluminium and alumina. It is possible, in part, to substitute silicon for the aluminium content of the treatment medium. A CrAlSi surface diffusion alloy is thus formed, or, in the extreme case, a CrSi one.

Results obtained by chromaluminizing

Surface Conditions

Chromaluminized and silicon/chromaluminized workpieces have a surface which exactly reproduces the original micro-relief of the piece treated, irrespective of the temperatures used. In each case, however, the coating treatment gives an extra thickness equal to about half the thickness of the diffusion layer proper, and amounting to some tens of microns in the case of refractory alloys and super-alloys. The appearance of the treated pieces is bright or semi-bright, similar to that of metal-rich paint coatings, according to the nature of the materials treated.

Iron, stainless steels and refractory alloys present a bright light-grey surface appearance similar to that of polished stainless steel.

Nickel, and nickel-based refractory materials, show a very homogeneous semi-bright sky-blue surface.

Cobalt, and cobalt-based refractory materials, present a very homogeneous orange-beige surface appearance.

A preliminary nickel-plating treatment of articles submitted to diffusion coating produces articles coated with a nickel-based protective layer which have the usual surface appearance of refractory nickel/chrome alloys protected by chromaluminizing or by chromsiliconizing.

Structure and Hardness Distribution of the Diffusion Alloys Resulting from the Treatment

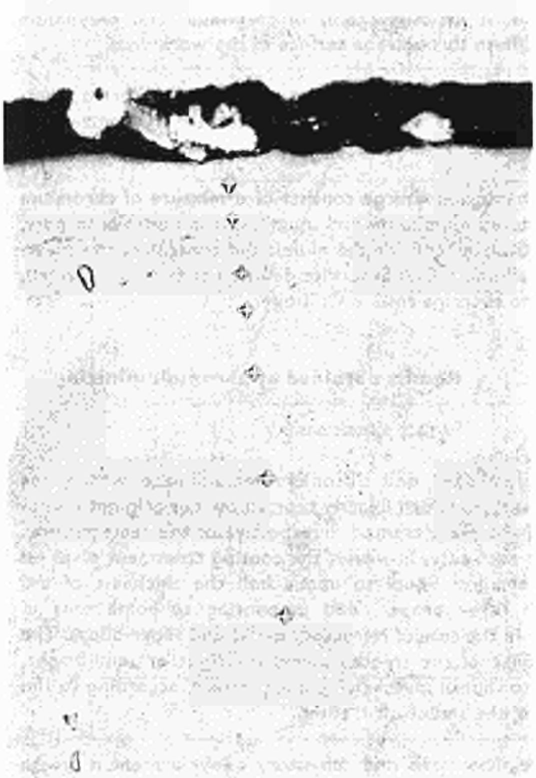
The coatings formed are closely bonded by diffusion, to the surfaces of the workpieces. They have no porosity or breaks in continuity, and their hardness changes very gradually with distance from the surface.

For chrome alloys, the hardness is relatively high in chromaluminized zones (800 to 900 Vickers microhardness); it is lower in aluminized superficial zones (400 to 500 Vickers micro-hardness).

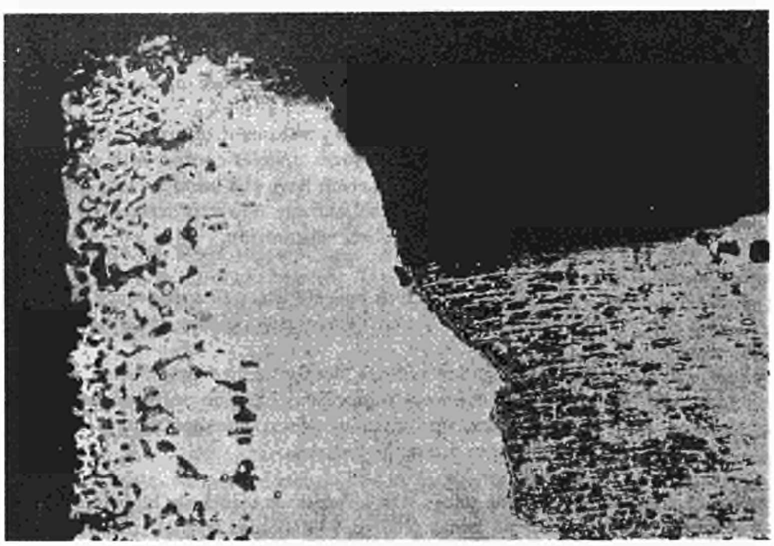
The thickness of the diffusion layers formed is a function both of the nature of the protected material and of the conditions of treatment (temperature and duration). In the case of refractory alloys and superalloys, the total thickness of the diffusion coating is usually between 30 and 100 microns for treatments lasting some hours and carried out in a single operation, or in two consecutive operations, in the 1000° to 1100° C temperature range.

The thickness is much greater, for equivalent treatment conditions, in the case of non-alloy ferrous metals; it reaches several tenths of a millimetre.

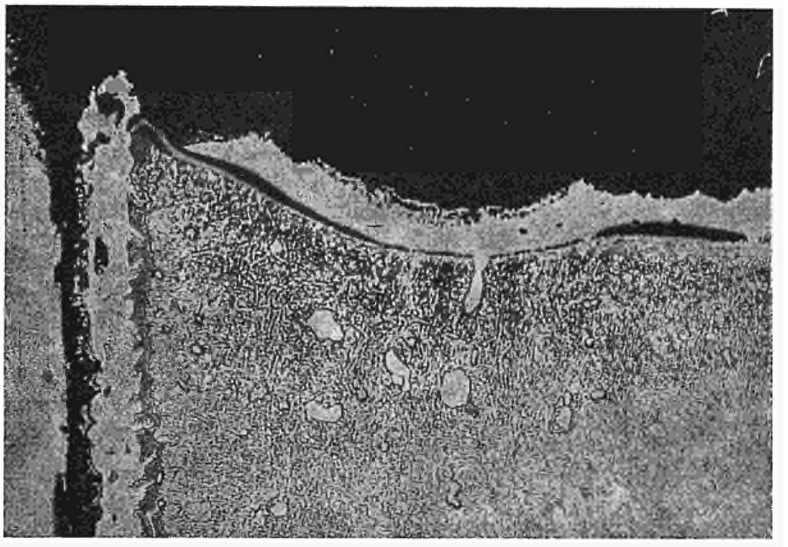
Coatings formed on steels and on refractory alloys and superalloys are proof against the most severe mechanical or thermal shocks; they can in general be cold-formed without risk of cracking. For example, Nimonic 75 sheet (a nickel-base refractory alloy) can, after chrom-aluminizing or chrom-siliconizing, be bent or formed without any cracking of the protective coating; the same applies to HS 25 sheet (a cobalt-base refractory alloy).



Structure of the surface zones of Udimet 700 protected by chromium-aluminizing (500)

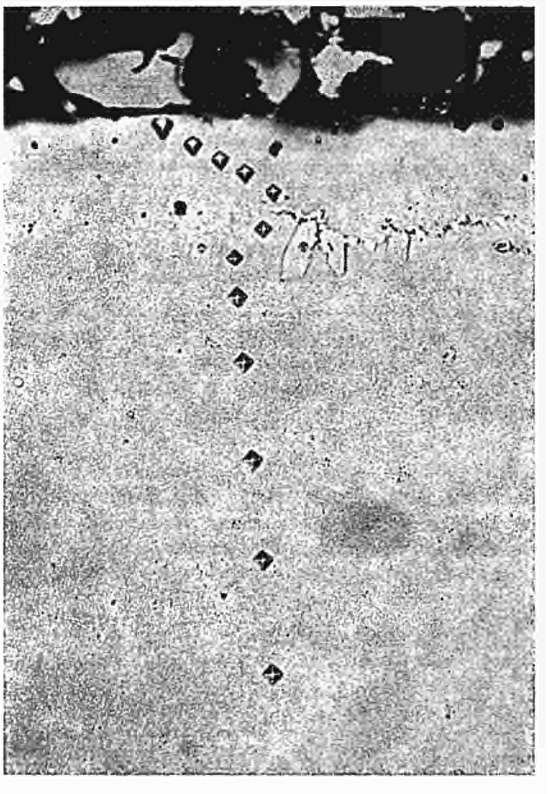


Structure of the surface zones of T.D. nickel after a corrosion test at 1,100°: left, vertical, chromium-aluminized zone; horizontal, unprotected zone (note the deep scoring along this zone) (500)



Structure of the surface zones of IN 100 *after a corrosion test at* 1,100°: *left, vertical, chromium-aluminized zone; horizontal, unprotected zone (note the deep scoring along this zone)* (200)

Structure of the surface zones of SM 200 *after a corrosion test at* 1,100°: *left, vertical, chromium-aluminized zone; horizontal, unprotected zone (note the deep scoring along this zone)*



Structure of the surface zones of A.T.G.W. 1*A protected by chromium-aluminization* (500)

Resistance to High-Temperature Corrosion

Comparative tests of the high-temperature corrosion behaviour of different materials, with and without protection by chrom-aluminizing, have been carried out by heating specimens in air and in paraffin combustion-gases; the gases were alternately "oxidizing" complete combustion and addition of secondary air) and "reducing" (gases of incomplete combustion without addition of dilution air).

Corrosion tests in the combustion gases were made at 1100° C, interrupted by 20 rapid forced-air coolings intended to increase scaling effects. The total duration of each test was 100 hours, consisting of 10 hours of subjection to corrosion in the "reducing" gases and 90 hours in the "oxidizing" gases. Tests for oxidation behaviour in air were made at 1100° C and 1200° C, again interrupted by rapid forced-air coolings.

The first table below gives the compositions of the main types of materials tested. The second and third tables below show comparisons between the rates of scaling measured, respectively, in the 100-hour tests at 1100° C in combustion gases and in the 100-hour tests at 1200° C in air.

The scaling rates are expressed as loss of metal per unit of surface area; they were determined by weighing the specimens after a sandblasting which eliminated quantitatively the oxidized layer.

The complete results can be summarized thus: in every case, irrespective of the initial corrosion susceptibility of the material tested, chrom-aluminizing gave very effective protection to the materials at a temperature of 1100° in air and in combustion gases aver the 100-hour periods arbitrarily chosen for the tests.

In complementary tests for oxidation behaviour in air at 1100° C, over periods exceeding 500 hours, there was no failure among the different materials tested, which had initially been protected by chrom-aluminizing; these were 18/8, HS 25, Hastelloy X, Nimonic 75, Multimet, Nimonic 100, and even mild steel sheet.

When submitted to the action of dry corrosion at high temperatures, chrom-aluminized surfaces present a light grey appearance changing gradually towards green; the layers of protective oxides are perfectly adherent and show no pitting in the surfaces subjected to the action of corrosive gases.

The rates of scaling measured are, in all cases, very low and roughly the same, irrespective of the type of material treated.

On the other hand, the various materials submitted to the action of dry corrosion without preliminary protection showed significant, and sometimes very considerable, scaling and pitting.

In the 100-hour tests at 1100° C in combustion gases, certain materials such as 18/8, HS 25 and Z 24 were destroyed or severely corroded; other materials such as Nimonic 75, Hastelloy X or Nimonic 100 showed greater resistance but the scaling rates were nevertheless considerable.

At 1200° C, these latter materials, not protected beforehand, were themselves destroyed or seriously damaged, whereas the same materials, with diffusion coating, still displayed only low rates of scaling.

The presence of silicon in the diffusion layers does not appear to have any marked beneficial effect, at least not under the test conditions employed. Its effect is mainly seen in an increase in the hardness of the coatings. The scaling rates measured for the different materials tested in the protected condition are in any case, too low to permit the precise determination of values outside the normal mean scatter of the results; for the same reason, any benefit derived from the addition of thorium and zirconium to the coatings could not be clearly shown.

The results obtained in the ONERA laboratory were completed by a comparative study of the behaviour, in air, at 1300°, of specimens of the refractory alloys NS 30 and Kanthal A 1, some chrom-alumii ized and the others not so protected. This investigation, carried out at the C.N.R.S. micro-calorimetry laboratory under the direction of Professor E. Calvet, showed excellent behaviour in pieces protected by the ONERA technique. The method was later used for making new calorimeters for very high temperature service.

Effects of the Treatment on High-Temperature Mechanical Properties

In the case of precipitation-hardening refractory alloys requiring heat treatment at very high temperatures, the operation of diffusion coating can usually be combined with a basic heat-treatment operation. By this means, the creep resistance characteristics of the treated materials do not become modified.

In the case of refractory materials normally cast without further thermal treatment, chrom-aluminizing in the more usual range of temperature (1000° to 1100° C) can lead to a more or less marked lowering of creep resistance in the treated materials.

In such cases, it is generally possible to carry out the protective treatment at temperatures approaching those which the parts would be likely to encounter in service; the duration of the treatment can consequently be increased.

On the other hand, there are usually specific thermal treatments for maintaining or improving the high-temperature mechanical properties of these materials (in general, solution treatment in the 1150° C to 1200° C range, followed by complementary treatment in the 900° to 950° C range). Such treatments can generally be included in the chrom-aluminizing operations, and may be preliminary treatment at very high temperature or complementary hardening treatment.

Coating by chrom-aluminizing does not, in itself, give rise to any unfavourable effect in respect of elongation properties in the fracture of test-pieces submitted to creep tests. Because of its plasticity, the coating follows the deformations produced when creep occurs, and abnormal cracks and fissures do not ensue.

The absence of brittleness in chrom-aluminized coatings, their proof against thermal shock, and their very high resistance to corrosion justify the opinion that the ONERA chrom-aluminizing treatment is not likely to have an unfavourable effect on the behaviour of materials in respect of mechanical or thermal fatigue.

In the first tests carried out on experimental wheels by Pratt & Whitney in the U.S.A., no fracture or abnormal behaviour of the protected parts was observed, despite the very severe test conditions.

Applications for Chromaluminizing Treatment - General

Apart from its use in the protection of aircraft gas-turbine components, chrom-aluminizing coating treatment can be envisaged for a number of applications: components for marine and land gas-turbines, internal-combustion engine components, electrical heating elements, parts used in refining and cracking hydrocarbons, and metal components for service inside furnaces used in the iron and steel industry.

One can also envisage such special applications as protection combined with the formation of an electrically-insulating covering, for magnet components or those used in induction heating. A simple oxidation treatment in air or wet hydrogen, carried out at about 1000° or 1100° C, allows the formation of an insulating and perfectly adherent film of alumina on the surface of the chrom-aluminized parts.

Composition of the main types of refractory alloys submitted to comparative tests for resistance against dry corrosion. (Compositions expressed as %).

Nimonic 75	Nickel base Chromium : 20 Aluminium : 0·2 Titanium : 0·6	carbon : 0·1
Multimet	Iron base Chromium : 20-22 Nickel : 17-21 Cobalt : 18-21 Molybdenum : 2·5 - 3·5 Tungsten : 2-3 Niobium plus Tantalum : 0·75-1·25	carbon : 0·1
Hastelloy X	Nickel base Chromium : 22 Molybdenum : 9 Iron : 14-16	carbon : 0·15
HS 25	Cobalt base Chromium : 19-21 Nickel : 9-11 Tungsten : 14-16 Iron : 3	carbon : 0·1
Nimonic 100	Nickel base Chromium : 10-12 Aluminium : 4-6 Titanium : 1-2 Molybdenum : 4·5-5·5 Cobalt : 18-22	carbon : 0·3
Z 24	Experimental super-alloy, cobalt/chrome base, carbide-precipitation type.	

Resistance to scaling of different materials with and without prior protection by chrom-aluminizing. Weight losses expressed in mg./sq. cm., after sandblasting.

Material	Unprotected	Chromaluminized (4 hr. 1080, A.F.C.O.)
10/8	58	2·5
Nimonic 75	12·5	1·5
Nimonic 100	40	4
Hastelloy X	10	1·5
HS 25	65	8·5
Multimet	78	4·5
Z 24	totally destroyed	11

100-hour test at 1100° in paraffin combustion gases, alternately oxidizing and reducing, interrupted by 20 rapid coolings. The specimens were formed from sections of 1-mm. sheet, except those in Nimonic 100 and Z 24, which were in the form of small cubes.

Resistance to scaling of different materials with and without protection by chrom-aluminizing.
Weight lossos expressed in mg./sq. cm.

Material	Unprotected	Cromaluminized Condition ([1]) 4 hours, 1080°, A.F.C.O. ([2]) 2 × (4 hr, 1080°, A.F.C.O.)
18/8	Totally destroyed after 20 hr	([1]) Destroyed after 45 hr ([2]) Destroyed after 15 hr
Nimonic 75	Totally destroyed after 59 hr	([1]) Destroyed after 6 hr ([2]) Destroyed after 4·5 hr
Nimonic 100	Totally destroyed after 30 hr	([1]) Destroyed after 10 hr ([2]) Destroyed after 8 hr
Hastelloy X	Totally destroyed after 50 hr	([1]) Destroyed after 4·5 hr ([2]) Destroyed after 5 hr
HS 25	Totally destroyed after 20 hr	([1]) Destroyed at about 60 hr ([2]) Local pitting after 14 hr
Multimet	Totally destroyed after 20 hr	([1]) Destroyed at about 50 hr ([2]) Onset of pitting after 11 hr
100 hour test at 1200° in air, interrupted by 20 rapid coolings.		

Maurice GENOT

PVC - Coated Steel Strip and Sheet: Their Resistance to Corrosion and their Forming

(Translated from French)

Cladding of the metal

The idea quickly occurred of bonding plastic to metal sheets, in order to benefit by the advantages afforded by the association of metal with plastic. The use of a film of polyvinyl chloride was clearly indicated on account of its tensile strength combined with good elongation, its resistance to chemical attack, and its weatherproofing properties.

PVC-clad steel sheet is probably used for two principal reasons; the first is that it is in itself a material requiring no complex finishing technique, and the second that it produces a surface capable of being corrugated, printed or coloured, and at the same time it is resistant to corrosion.

The metallic sheet forming the base is cold rolled steel strip or sheet suitable for deep drawing, galvanized sheet, or aluminium or magnesium sheet. This base is covered on one face, or on both faces, by the film of polyvinyl chloride.

The film is formed by calendering. It is a partly plasticized composition with a high molecular weight. Particular care must be exercised over the proportion of plasticizing additions, in order to avoid subsequent migration phenomena. It must also be arranged that the chocks exert the correct pressure on the film during the course of the operation of bonding to the metal base.

The principle of the manufacture of laminated PVC-metal sheets can be summarized as follows: the strip or sheet is first subjected to a preliminary chemical treatment, which principally consists of depositing on the metal a very fine film of a phosphoric or chromic composition, capable of reacting chemically with the metal base, and on the other hand of keying the adhesive which ensures the bonding of the PVC-film, with the subsidiary purpose of improving the resistance to oxidation.

The strip or sheet is then treated with adhesive, which is activated by heating in a continuous furnace. The final operation is the bonding of the film to its base by rolling under pressure.

The material from the aspect of adhesion in aggressive atmospheres

Since in the course of time the product will age, the PVC-metal laminated sheets have been tested from the point of view of loss of adhesion. Numerous accelerated ageing experiments have been carried out. The official report on the industrial type, accelerated ageing experiments ends with these words: "The plastic-clad sheets proved entirely satisfactory during the experiments."

In parallel, natural ageing tests have been conducted. The clad sheet was exposed in Katanga, at Kolwezi, for five weeks during the rainy season and five weeks during the dry season. In Belgium, in one case on the coast, and in another in an industrial atmosphere, the clad sheet has been exposed for seven years, inclined at an angle of 45° towards the South. No substantial change, such as delamination, wrinkling, blistering or flaking, was observed on any of the specimens exposed. The bahaviour of the material therefore proves very good, from the aspect of adhesion in aggressive atmospheres.

Possibilities of improving the corrosion resistance of clad sheet

It is a fact that plastic materials in general, and polyvinyl chloride in particular, are practically insensitive to all forms of corrosion. Since cladding of only one face of the metal by means of PVC is the normal production practice, corrosion resistance is dependent on protection of the reverse face. For steel sheet, the bonderizing carried out on the production line only affords a protection capable of maintaining the sheets in good condition for 8 to 10 weeks against the effects of humidity while in storage. In general, the products applied to cover the reverse face are paints for ironmongery, pigmented primers with a high zinc chromate content, providing a key for paint application, and permitting spot welding and bonding to various supports. The corrosion resistance of this type of coating is, for a given medium, essentially a function of the thickness and uniformity of the film deposited, but in general, these paints afford protection for 15 to 20 months in a dry atmosphere and 2 to 3 months in a wet atmosphere. Clearly it is possible to obtain vastly superior forms of protection, which will also allow for forming of the material, by using stove enamel varnishes. The cost of this protection, however, is some fifteen times that of primer. Finally, material on a base of galvanized or aluminium sheet is protected by the very nature of the base sheet.

Such protection nevertheless has a time limit. One so called perfect solution, from the aspect of corrosion, consists in cladding both faces of the base sheet with PVC-film. As very often only one face is visible, the films applied are generally different in appearance, the object being to make the price more reasonable.

The film applied to the face side is clearly the same as that used when the material is clad on one side only, while on the reverse side, in principle not visible, the film is of industrial quality, having a smooth surface but with possible slight defects in appearance, defects having no effect on corrosion resistance. It is understood that for applications where it is necessary, the same film or two different decorative films can be applied to both faces of the base sheet.

The unclad edge can create a serious problem for the application of plastic clad sheet at a site where the relative humidity is considerable. The problem of protection of sheared edges however, arises only with a steel base sheet, since with a galvanized base sheet the sheared edges remain protected against corrosion by the hammering of a thin bead of zinc over the sheared edge, with consequent electrochemical protection of the steel by the zinc.

Where a shaped product is required, it is always possible to apply decorative profiles, or to bend over the edges of the sheet to mask the edges. Aluminium profiles are extensively used; sometimes, however, a joint can be covered with plastic strip and then with a plastic profile. This method is advantageous where the degree of humidity is high; so called sealed joints are thus obtained, and the danger of corrosion by capillary action is considerably reduced. The same result can likewise be expected from the use of an acid-resisting paint based on chlorinated rubber.

Finally to resist the most arduous conditions of humidity, it is possible, by electrolysis, to coat with cadmium not only the edges, but also holes and cutout sections.

Welding

Flame welding and brazing destroy the surface of the PVC. Welding by means of PVC rods and a hot-air welding torch can be used for sealing the angles between two sheets. For example, the edge of each piece to be joined can be bent over through 90°, and the pieces can then be joined with the PVC films against each other. Under the action of the heat the PVC settles into the joint and unites with the film.

It is a simple matter to resistance-weld cleats, stiffening ribs or ties to the metal face without destroying the PVC film. Since the film is an excellent electrical insulator, to establish the electrical circuit recourse must be had two electrodes mounted side by side, on the side of the metal face. The electrodes should clearly be in contact with the sheet over a sufficiently wide area, thus limiting the current density, and avoiding the formation of excessively hot areas, which would mark the plastic film. Use of the projection welding method is, moreover, indispensable.

It is possible to convert an ordinary spot welding machine. An auxiliary system of electrodes can be installed, while the secondary current characteristics should be altered. After adaptation in this way, the machine will use very short welding times and high secondary current densities. It should be equipped with electronic timing devices for forging pressure application and current-flow, and control of the primary current should be carried out by means of ignitrons, since mechanical contactors are not sufficiently fast to control welding times of a half-cycle. In this way satisfactory welds can be made within the limits of the capacity of the welding machine. It is possible, therefore, by conventional methods to spot weld the material by means of a welding machine having a special head equipped with electronic timing devices.

Forming of the material

The material is formed by applying the normal techniques for working metals; the methods and procedures are the same. The tools must naturally be in good condition and very well adjusted.

Shearing is carried out on a machine with a blade which must always be correctly ground and set, while the bearing face of the sheet hold-down plate should be covered with rubber or an elastic material, in order not to mark the PVC film. As the shearing action must not be allowed to loosen the edge of the film under tension, the raw edges must be less marked than those tolerated for unclad metal, and operations must be arranged so that these raw edges occur on the side of the metal.

A certain amount of care must also be taken in handling operations with the finished product. Stains and scratches must be avoided, and this implies that all traces of filings which might become embedded in the plastic must be removed from the tools; if necessary, provision must be made for placing felt on the tables, and the wearing of gloves by operators.

During drawing, the film follows very closely the deformation of the steel, and if a clad sheet is formed in an area where drawing is by nature directional, this deformation can be very marked in the film of PVC, and can modify more or less intensively the surface appearance. An example of such distortion is that arising from deformation caused by elongation. Folds and rounded sections must have as large radii as possible in order as far as possible to avoid cracking of the film under pressure. A point not to be forgotten, so far as working with plastic clad sheet is concerned, is that the cladding is thermoplastic, and that during the winter period the thermometer can fall to about zero. At this temperature care must be exercised over mechanical working, for a reduction in ductility can occur, and the result can be cracking of the PVC surface during forming.

Dies are lubricated with warm soapy water. For exceptionally deep drawing soluble oil is used. In most instances it will be necessary to increase the pressure of the sheet hold-down plate, in order to overcome the wrinkling effect caused by the lubricating action of the polyvinyl chloride, and moreover the pressure of the hold-down plate must be varied, depending on whether the PVC film is on the inside or outside of the die.

Finally, wherever possible, blanking should be carried out on the press. If the sheet is machined with a milling cutter, the cutting angle of this tool must be studied and the cutting rate will have to be reduced.

In short, this material, if handled and worked with all the care which a finished material normally requires, makes it possible to impart increased life to the objects produced and at the same time a new aesthetic interest.

Heinz BECKER

The Welding of Plastic-Coated Steel Strip and Sheet

(Translated from German)

During the last decade, plastic-coated sheet has been introduced in the European market to an ever-increasing extent. As the use of this new composite material becomes more general, the question of its weldability increases in importance. In this sense weldability implies that the plastic layer undergoes no change of any kind in its appearance. The solution of this problem is difficult when it is considered that, on the one hand, the welding process necessitates temperatures from about 1000° C up to a maximum of about 1600° C while, on the other hand (depending on its composition) the plastic will be altered or disturbed above about 150° C. Furthermore it should be noted that, in current coating procedures, and in order to obtain a better adhesive strength, the plastic is not usually glued to the sheet but rolled on, so that the heat of welding is slightly deflected from the plastic coating; the plastic lies on a good heat conductor of only about 0·5-1·5 mm. thick sheet. Hence, it is clear that this welding problem cannot be solved by conventional processes but only with special welding plant which — it must be emphasised explicitly — is already available in many forms and varieties.

Welding Procedure

Sheet coated on one or on both sides can be welded without damage to the plastic coating.

Sheet coated on one side

With sheet coated on one side only, attachments such as splice bolts, screws, nuts, studs, etc. are welded to the uncoated reverse side i.e. the joint surfaces are steel to steel. The most efficient weld joints will then be achieved when the maximum strength in the weld is reached without any change in the plastic coating. The basis of this is that — in contrast to conventional welding with welding times of measurable duration — in welding plastic coated sheet the welding time amounts only to a few milliseconds. Therefore the appearance of the plastic layer and the strength of the welded joint are influenced by welding heat in opposite senses. With an increase in welding heat-input on the one hand, higher strength is achieved but also, on the other hand, the good appearance of the plastic layer suffers. The weldability of sheet coated on one side only facilitates the employment of several welding processes.

Resistance welding with phase synchronisation

In resistance-welding with phase synchronisation, both electrodes are placed on the uncoated side of the sheet. The welding time lies between 3 and 10 milliseconds. This short welding time necessitates an increase in the welding current and voltage since in order to heat a definite volume of material to a plastic state, a fixed quantity of heat is essential; with a shortened welding time, the heat must be introduced by means of a high electrical energy input. Certainly, it is necessary to minimize the welding pressure to the maximum extent — in contrast to conventional resistance welding — in order to avoid damage to the plastic coating. An associated increase in the transfer resistance from the electrodes and an increase in the specific power loading of the contact face results in the preponderant heat centre originating at the electrode and not between the welded sheet components. The weld zone therefore lies further away from the plastic layer than it would normally do and therefore so does not endanger the coating so much. Finally, it should be noted that the compaction pressure has already been released when the heat of welding reaches the plastic layer. Furthermore, the welding of screws, nuts, studs and similar component attachments on the reverse side is facilitated.

As on the reverse side of coated sheet, the applied electrically non-conducting corrosion protection is not so thick, there is the possibility that with certain set-ups, the contact faces will be mechanically penetrated. It is therefore necessary to remove the corrosion protection before welding.

In resistance spot welding it is found that the welded zone in the coated sheet has only been directly fused on the reverse side, as shown in the left side of the figure on the top of the next page. The shear stress required to tear this type of spot weld out of the sheet amounts to 100-300 kp.

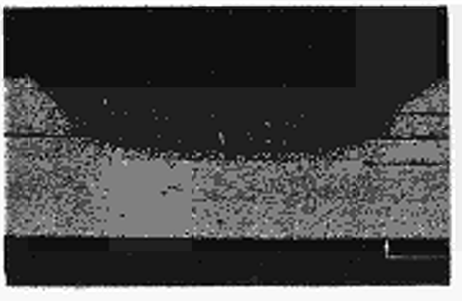
Capacitor-discharge welding

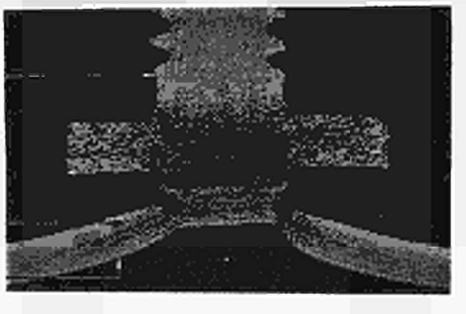
Apart from the use of the well-established process of resistance welding with phase synchronisation, capacitor-discharge welding can generally be used to weld screws, nuts, studs and other components, by using coaxially arranged electrodes on the reverse side of coated sheet. The welding times lie between 1-10 milliseconds. In order to compensate for the short welding time, the initial contact face of the screw or similar part is reduced in order to avoid a large heating zone and to attain a high specific current load.

The right-hand side of the figure shows clearly that, in spite of the intentional attaiment of a small welded zone in the sheet, the strength of the joint is still greater than that of the sheet. The oscillographic trace of welding current and voltage illustrated in the next figure and furthermore, the measurement of the electrical power in watt-seconds with an analogue computer, facilitates good control of the welding process. Thus, for example, in this experiment, it can be inferred from the clearly variable course of the oscillogram that the material in the weld spot location has been in the intended plastic state; measurement of the electrical work enables the operation of a control in practice to ensure that welding proceeds within the prescribed conditions.

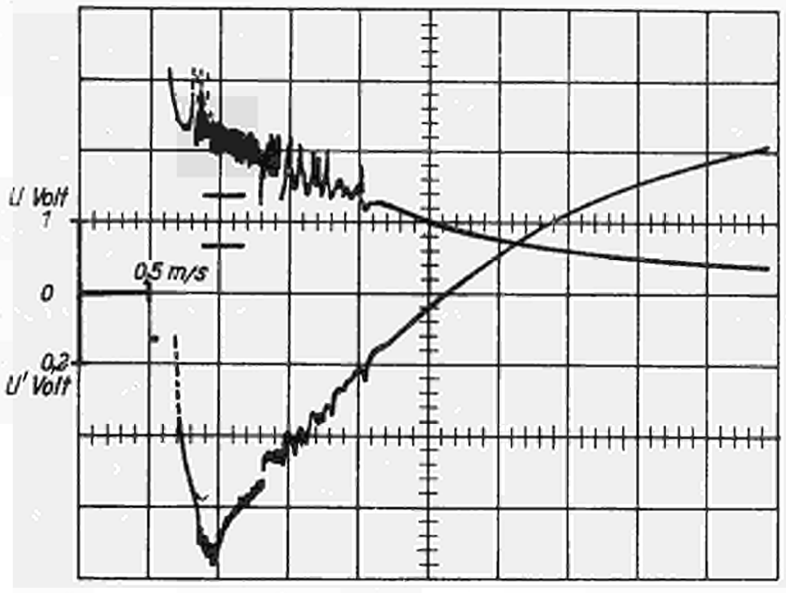
Obviously such basic experimental measurements may be carried out for all the welding procedures employed in these studies in which steel is welded to steel.

Capacitor-Discharge Welding

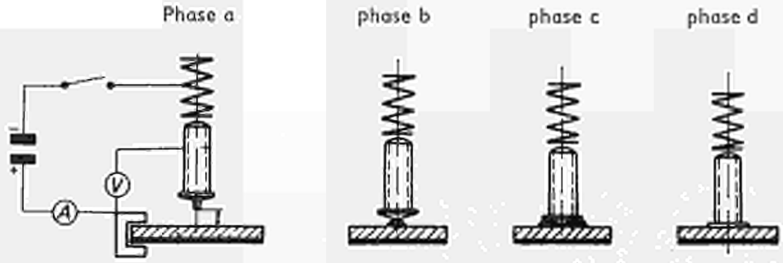




Welded joints in composite sheet



Oscillogram of discharges in Capacitor-Discharge welding plant in the welding of composite sheet.



Schematic of the Graham system of arc pressure welding

Flash-Butt Welding

With plastic-coated sheet, not only may welding be carried out in which the steel is transformed only to the plastic state, but also, fusion welding is possible without damage to the plastic coating.

At the present time, only screws and studs can be welded on by flash-butt welding; in the execution of this work, the handy pistol-type of welding gun facilitates welding on to large awkward parts such as is often required in the fabrication of constructional parts in plastic-coated sheet.

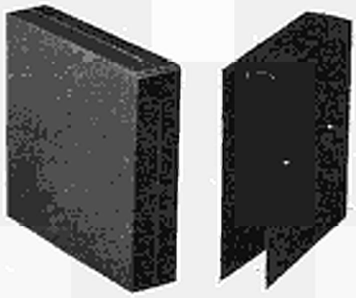
As may be seen from the last figure on the preceding page, in flash-butt welding the welded faces are completely melted by the arc. This involves the stipulation that the welding time is even shorter than in the processes previously described in which only a plastic condition of the weld zone is necessary. The welding time in the present case amounts only to about 1-3 milli-seconds. The correct setting-up of the clearances between the igniting stud and the sheet is of paramount importance for the soundness of the joint.

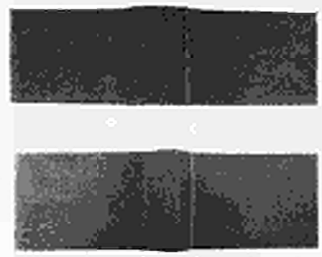
Sheet coated on both sides.

The welding procedures described so far have been concerned with sheet coated on one side only and where the weld was made between two steel surfaces. For sheet coated on both sides however, after overlapping the two sheets to be joined one upon the other, the plastic coatings only are welded together by means of a high-frequency current. The resulting coating thickness on each side amounts to less than 100 μ so it is useless to lay a plastic film between the sheets with a view to increasing the strength of the joint. High-frequency welding presents no difficulties. Joints of this type always accept a shear stress of 100 kp in shear tests, in which the separation always occurs between the welded plastic coating and the steel sheet core.

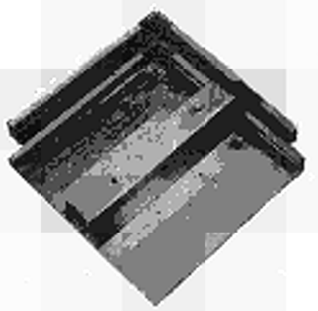
Welding Design Standards

In our last figure accepted design standards for "Steel to steel" welded joints vis-a-vis "Plastic to plastic" joints have been reproduced.





HF plastic-to-plastic lap weld



Steel-to-steel and plastic-to-plastic sheet welds

Resistance weld on a steel-to-steel door angle

Bernd MEUTHEN

Plastic Coating and Lacquering of Wide Steel Strip

(Translated from German)

The "composite material," plastic coated steel has come into increasing use in many countries during the last decade. It is estimated that about 100 coating and lacquering plants are in existence at the present day. Experience in the construction and operation of modern rolling and finishing lines for wide steel strip could be utilized for developing suitable lines for plastic coating and lacquering.

The intimate bonding of the organic coating with the metallic base makes it possible to carry out many deformation and processing operations without damage. Whereas the steel determines strength and workability, and under certain assumptions the welding characteristics, the plastic provides adequate resistance to corrosion. The single or multi-coloured and attractively designed surface, the high wear resistance and elasticity, together with added heat and sound insulating properties must be stressed.

This pre-processed material saves the user from having subsequently to protect the finished part against corrosion, and also serves the purpose of rationalization in many branches of industry. In addition, the continuous coating of the semi-product is kept very much more uniform. The steel industry has thus been offered the possibility of opening up new fields of application or of extending existing ones. Examples include the building industry, especially the finishing end, the metal and sheet goods industries, and vehicle construction.

Using as an example a wide strip coating plant for the manufacture of this composite material which went into production in 1960, a number of important points will be discussed. These relate to the selection of the steel and of the organic coating, as well as to the chemical processes which take place during coating.

Steelworks materials

The material coated is cold-rolled wide steel strip with a thickness of 0·20 to 1·50 mm., the maximum width is 1250 mm. The pay-off installation can take coils up to 10 metric/tons in weight. According to the technological requirements, during further processing, strip is charged in commercial. drawing, deep-drawing or special deep-drawing qualities.

If additional corrosion resistance is required from the material, for instance for outside use or under corrosive conditions, the wide strip is previously galvanized electrolytically, or by the Sendzimir hot-dip galvanizing process. With electrolytic galvanizing a zinc coating is provided which is usually 2·5 µm on each side, occasionally 10 µm or with different thicknesses on each side (differential galvanizing). The advantage of this process is that the properties of the steel are not changed by the treatment; above all the flatness of larger sheet is ensured. It is known that the electrolytically deposited zinc layer, normally post-treated, forms a particularly good undercoat for organic top-coat systems.

Outline of the plastics used in the continuous coating of wide steel strip

Plastic	Type of coating	Thickness of deposit	Colour	Surface finish
Polyvinyl chloride (PVC) soft	*plastisol*	*100 to 400 (one or both sides)*	*single colour*	*not printed printed decorative printing*
	sheet	*100 to 400 one side*	*single colour multicoloured printing*	*not printed printed decorative printing*
Polyvinyl chloride (PVC) rigid	*sheet*	*50 to 200 (one side)*	*single colour multicoloured printing*	*not printed*
Polyvinyl fluoride (PVF) rigid	*sheet*	*25 to 50 (one side)*	*single colour multicoloured printing*	*not printed*
Vinyl chloride copolymers (for example PVC/PVAC)	*lacquer*	*25 to 30 (one side)*	*single colour*	*not printed*
Polyacryl resin modified	*lacquer*	*25 to 30 (one side)*	*single colour*	*not printed*

Hot-dip galvanized wide strip has zinc coatings of 20 to 25 µm mm on average on each side, so that the corrosion protection as such is greater. In the case of non-ageing deep-drawing qualities, the material is tempered after galvanizing.

Plastics

The table below shows the types of plastics which have so far been used, and the form, thickness, colour and type of surface provided for the coating. In making this selection the criterion has been the intended application; the most favourable must be used, taking economic factors into account.

Of all the plastics PVC plays the greatest part, because it is relatively good value, and because many favourable properties are combined in the calibrated material. It is used mainly in the softened (plasticized) state, either as a highly viscous paste (plastisol) or indirectly through sheet preformed in the calendar. The processing as plastisol is done by a special method which is essentially known only with PVC, and which works very well when used with rolls in the coating process. A very fine dispersion of PVC particles is employed (proportion by weight 70 to 80%) in a mixture of fluid plasticizers, consisting mainly of the esters of phthalic, adipic, sebacic and phosphoric acids.

Occasionally secondary softeners (extenders) such as chlorinated paraffin are added to regulate the viscosity of the plastisol. A certain part is also played by polymarizable platicizers on a polyester basis, and epoxide ester. Organic and inorganic colouring pigments are also mixed with the plastisol. In order to make the PVC resistant to the influence of light and heat during the subsequent gelling process and in later use, stabilizers are introduced. Tin, barium and cadmium compounds have been found particularly satisfactory as heat stabilizers; derivatives of benzo-phenone and benzo-triazole have become known as UV absorbers.

All the constituents should be mutually compatible, and should as far as possible be difficult to volatilize, resistant to creep, cold, water and chemicals, colourless, light- and heat-resistant and as non-flammable as possible. In addition, the joint with the steel should not be disturbed. The plastisol process has certain advantages insofar as the PVC film is first produced on the strip; individual colour tones then being obtained by the addition of pigments to the same initial paste.

During gelling, which is a heat treatment lasting 2 to 3 min. at at emperature a little higher than 160° C, a homogeneous coating is formed from the disperse phases; the hardness, stability and strength of the product depend on careful blending in accordance with the intended application, the mixing and the gelling conditions. The furnace used is divided into several zones, and operates with hot air circulation.

Recently, rigid PVC, which contains little or no plasticizers, has become of importance. As a hard, scratch-resistant coating which also resists attack by chemicals, it can be deformed without adhesion difficulties. It can also be stabilized with physiologically satisfactory results, if it is intendep to be used as a packaging material. The coating of steel strip with rigid PVC sheet had already been developed in Germany during the last war as a substitute for tin plate, because of the shortage of tin.

Both soft and rigid PVC sheet can be imprinted with multicoloured designs, which also make the composite material suitable for decorative purposes.

In special cases, when the product is to be used outside under difficult conditions, a sheet of polyvinyl fluoride (PVF) is selected. This unplasticized plastic is dearer than PVC; but its high resistance to light and heat, combined with considerable hardness and good resistance to chemical attack, makes its use appropriate. Problems of the adhesion of PVF to the steel or zinc surface are solved by means of suitable adhesives.

While the plastic layers, over 100 µm thick, are characterized by excellent wear resistance and insulating properties, and can be provided with an attractive surface in many cases by imprinting, the coatings produced by lacquering with a single-layer deposit are only about 25 µm thick. The solvent is driven off by stoving, and further cross-linking reactions take place. Among the systems offered by the lacquer industry the vinyl chloride copolymers have proved particularly satisfactory because of their good deformation characteristics and elasticity, and the modified acrylate resins due to their hardness, resistance to scratching, heat and weathering.

As lacquering, with its thinner deposits, is cheaper than plastic coating, lacquered wide strip and sheet have already been assured of a large share of the market in the USA, and are likely to arouse increasing interest among consumers in other countries.

Coating

The figure on page 264 shows diagrammatically the essential operations in continuous coating with plastics or lacquers. The mechanical entry side of such a plant, consisting of coil receiver, uncoiler, shears, welding machine, looping pit and tension roll, corresponds to the usual layout of strip processing lines. The coating process begins with surface pretreatment and deposition of the adhesive.

The quality of the composite material depends essentially on the adhesion. This is achieved by a satisfactory interface between metal surface and organic coating. The chemical pre-treatment consists of a conversion of the metal surface into a complex layer of phosphates, chromates and oxides. Suitable phosphate, chromate or alkaline passivating solutions are introduced, according to whether the supporting surface is iron or zinc; the weight of the layer is usually less than 1 g/m². The actual adhesive preparation however is carried out by roll coating and stoving a thin layer of an organic deposit.

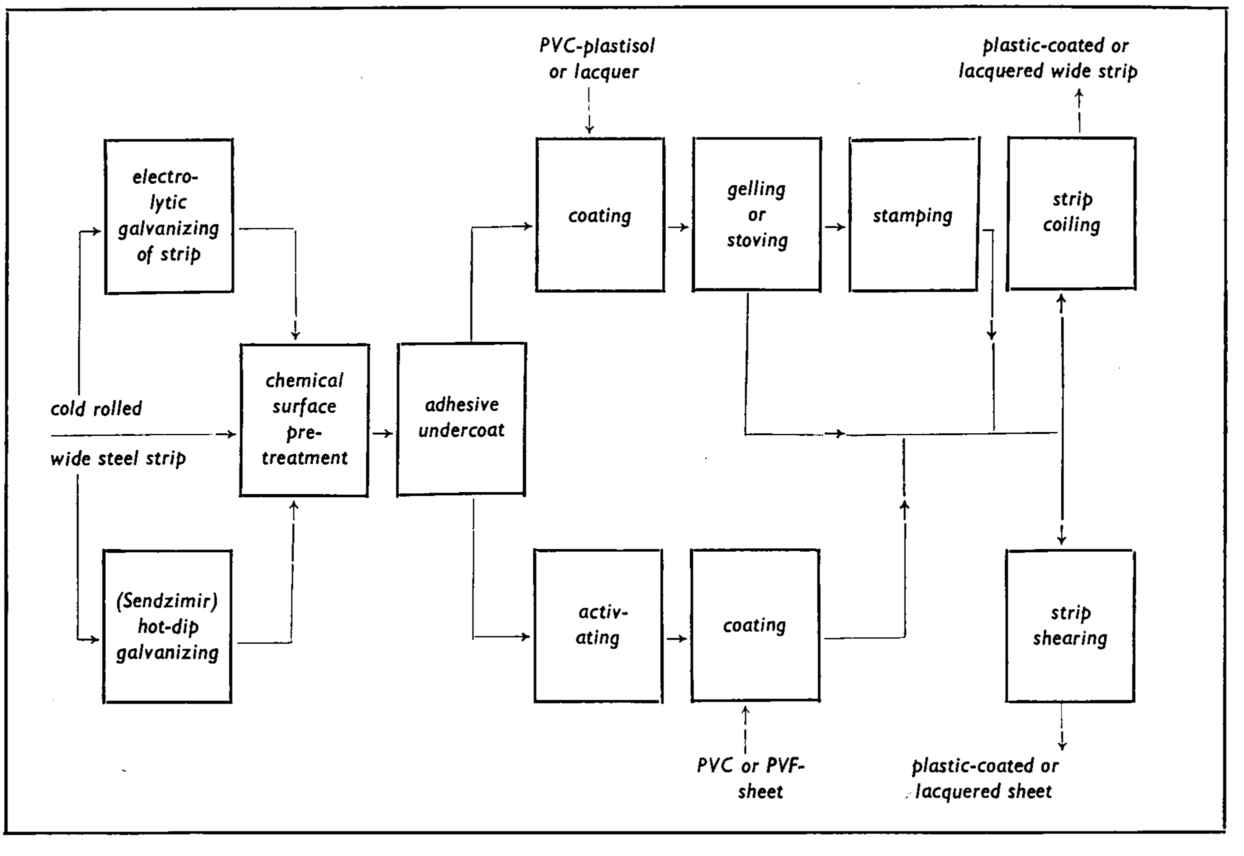
The adhesive is also applied by rolls. It consists in general of a solution of mixed polymers of vinyl, acryl, phenol and epoxide resins, the composition of which is specially adjusted to the individual types of plastic. After stoving at temperatures between 130 and 230° C a layer a few µm in thickness remains.

The adhesive film must be uniform and dense, and must have a favourable thickness, as determined by experience. Induction heating has proved satisfactory for stoving the two organic layers; this is followed by water spraying, to cool the pre-treated strip down to normal temperatures.

When applying the plastisol the thickness of the coating is regulated and maintained by the roll gap. The strip emerging from the gelling furnace can be directly processed with a stamping roll which transfers the desired pattern. Directly afterwards the state of the surface is preserved by cooling with water. The PVC plastisol can be applied to one or both sides; in the first case, as with all sheets and lacquers applied to one side, the reverse side of the strip is provided with a colourless or pigmented protective lacquer.

In coating with sheet (soft or rigid PVC and PVF) the sheet is rolled in the pre-stamped state on the adhesive, which has been thermally activated in the gelling furnace, after which the strip is cooled rapidly. It is possible to convert the coating plant immediately to lacquering, because the individual stages of pre-treating and applying the lacquer are similar.

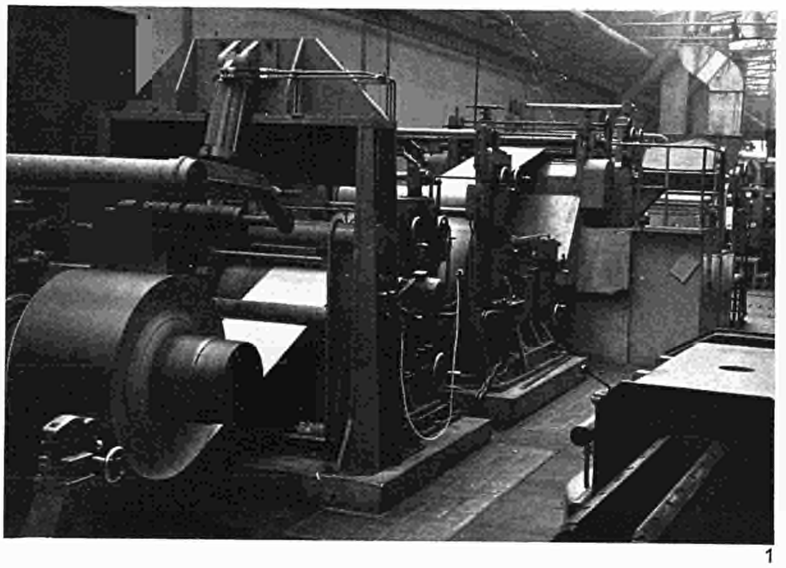
Diagrammatic representation of the operating processes in the continuous coating of wide steel strip with plastic or lacquer



The mechanical exit side of the plant consists of the usual centring and tension rolls, the cropping and side cut shears, a coller (figure 1, p. 267) or alternatively the shearing line (figure 2, p. 267) with straightening machine and piling. The sheets can be 800 to 4000 mm. long.

To comply with the increasing demand for plastic-coated strip, and in order to be in a position to supply certain special types of product, a second wide strip coating plant is at present being constructed. This is intended for wide strip of up to 1800 mm.

List of illustrations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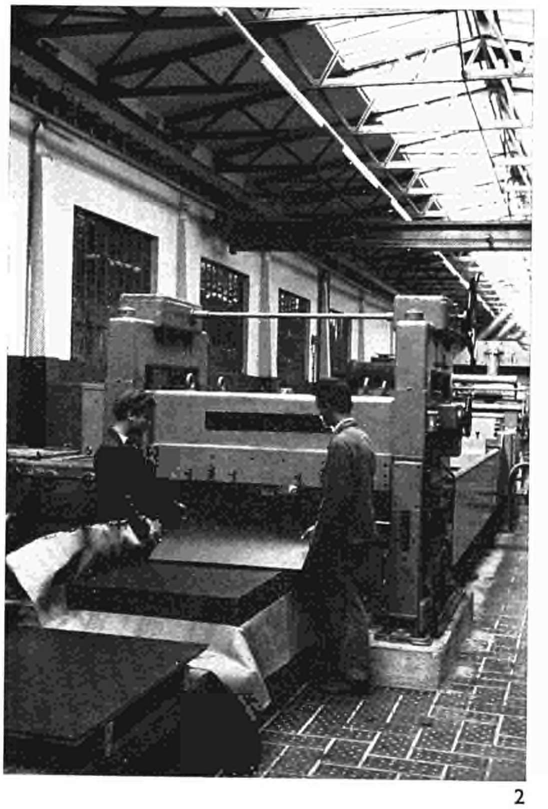
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A. DIETZEL

and

H. O. MULFINGER

Steel for Enamelling and the Single-Coat Enamelling of Steel

(Translated from German)

The following paper will consider which problems, and more particularly which defects result from the combination of two alien materials, steel and enamel, by enamelling. It is obvious that for an audience which consists of people connected with the steel industry, the subject in question must be dealt with so that the emphasis is on those defects and on that part of their cause which are related to the production, chemical composition and properties of the steels. In other words: how should the steel be processed for the enameller's needs, so that optimum enamelling characteristics are provided. Although an exhaustive answer to this question is not possible with the knowledge at present available, an attempt will be made here to provide the steel producer with some indications. Thus, in the first part of this paper the important features of enamelling with a ground and a top coat are considered, especial mention being made of the metallurgical aspects. In the second part single-coat enamelling and its fundamental differences from enamelling with a ground and a top coat, viz, the special properties required of steels for use in single-coat enamelling, are discussed.

Enamelling with a ground and a top coat

In this kind of enamelling, a ground coat of enamel is first applied to produce adhesion between the two materials enamel and metal. The sheet articles to be enamelled are previously cleaned, i.e. oils and other impurities of an organic nature are removed by chemical pretreatment and partly also by annealing. Scale is removed from the sheet surface by acid pickling followed by coating, by spraying or dipping in the slurry containing the enamel "frit", which must then be dried. The sheets or parts pretreated in this way are then fired between 800°C and 950°C so that the enamel is melted to a firmly adherent vitreous state. The ground enamel always has the disadvantage of a most unsightly discoloration caused by the adhesive oxides it contains and the dissolved iron oxides. Further it is usually unsatisfactory from the aesthetic point of view since it has a blistered and uneven surface.

One or more layers of top coat are therefore applied over the ground coat. The top coat applied by dipping, spraying or dusting, is dried and fired at somewhat lower temperatures than that which is necessary for the base coat. These temperatures generally lie in the range 800-850°C. During firing of the top coat there are no further chemical reactions with the sheet. The top enamel coat must satisfy aesthetic requirements as well as the chemical, mechanical and thermal requirements dictated by the final application.

Types of steels sheet and the important mechanical properties

Steel sheets for enamelling fall generally into the groups:

1. Normal enamelling sheet.
2. Armco enamelling sheet or subsequently decarburized or surface decarburized sheet.
3. Alloyed sheets, containing Cr, Ni, Nb, Ta, Zr or V and
4. Titanium alloyed steel sheet which are known by the trade name Tinamel.

For enamelling with a ground and top coat, the normal enamelling sheet is most frequently used. The low-carbon Armco-sheet is rarely used although it is excellent for enamelling. Alloyed steel sheet has as yet not acquired any great importance in enamelling. Titanium alloyed sheet occupies a special position, since it is outstandingly good for enamelling. This sheet is however much less used for "conventional" enamelling than for single coat enamelling. Describle mechanical properties for enamelling steels have been listed in the technical literature and are given below. Surface decarburized sheet will be dealt with later.

Mechanical properties

Enamelling is generally preceded by deep drawing the sheet material. Enamelling sheets must therefore have a good deep drawability. In Germany, minimum cupping values are laid down in DIN 50 101 and are determined manually by the Erichsen deep drawing test. Good enamelling properties and good drawability usually go together. This can be explained as follows: inhomogeneities, caused by pronounced phosphorus and sulphur segregation and also by slag or oxide inclusions, piping and other sheet defects, lead to an embrittling of the material and consequently to difficulties in deep drawing. The same defects are, however, as Leon and Slattenschek (Biblio. 1) have shown, one of the possible causes for blister formation during firing of the enamel. Difficulties during forming also occur if, as a consequence of annealing at too low a temperature, recrystallization of ferrite and precipitation of cementite takes place. Petzold (Biblio. 2) has given the following technical characteristics for enamelling sheet; Brinell hardness 95-120; yield point 20-30 kg./mm.^{2}, tensile strength 30-35 kg./mm.^{2}, and an elongation of 32-35%. Another important mechanical property from the point of view of enamelling is the thermal expansion of the sheet. Because of the different coefficients of expansion of sheet and enamel, but especially because of the very changed expansion in the region of the A_3 transformation, flaking off or straining after enamelling is frequently observed. Since scale does not show the mentioned variations in expansion, flaking is then specially observed according to Dietzel and Wegner (Biblio. 3), if the reverse side of an article enamelled on one side is covered with scale, or if the ground coat enamel present is heavily enriched with scale, flaking or straining only occurs very lightly when the A_3 point is not reached during firing the enamel. By addition of certain alloy constituents, such as titanium for example, the A_3 point is raised considerably and is not reached during enamelling. Because of this titanium alloyed sheets do not flake. The same effect is obtained, but to a lesser degree, if the very low carbon containing Armco sheet is used, for which the A_3 transformation temperature is higher than for sheets with a higher C-Content.

Cleaning of sheets before enamelling

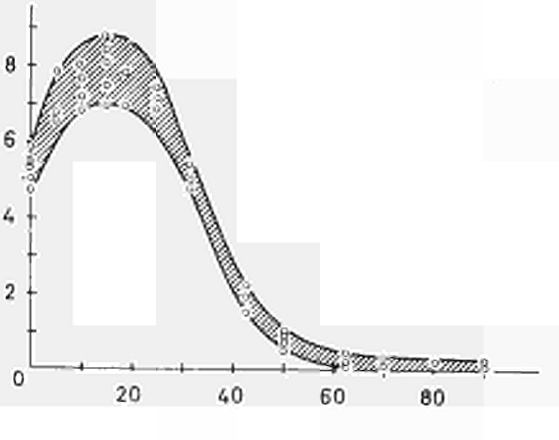
During processing, sheets come into contact with oils which must be removed prior to enamelling, because they will decompose or burn during firing and the evolved gases subsequently form blisters, causing poorer wetting by the enamel and leading to a deterioration of the adhesion. Cleaning is effected either using solvents, or with alkaline liquids, which saponify the oils. In many cases the sheets are also annealed in an oxidizing atmosphere. Annealing removes stresses which have occurred during forming, impurities are burnt and the surface cleaned by formation of a scale, which is later removed by pickling.

Pickling: For enamelling with a ground and top coat, pickling, which is carried out with HCL, H_2SO_4 or mixtures of H_2SO_4 and H_3PO_4, serves above all to remove sticking scale or rust and not, as in single-coat enamelling, to cause a considerable roughening of the surface. In this case the least possible removal of iron is aimed at and for this reason, so-called inhibitors (e.g. aldehydes, phenol, pyridine, amine, sugar, etc.) are added to limit the pickling action essentially to one of scale removal. This also has the effect of reducing hydrogen evolution during pickling. Hydrogen is not evolved during pickling as long as active Fe^{III}-oxide is available, which uses up hydrogen for transformation to Fe^{II}-oxide. If the scale is removed, further acid attack is on the metal, which is then dissolved with the evolution of hydrogen. The hydrogen evolved during the dissolving of the iron does not escape completely, but remains partly in the metal. Hydrogen dissolved in the metal causes the sheet properties to deteriorate and leads to embrittlement of the iron. Further, the hydrogen atoms can recombine to form molecules at inhomogeneities such as piping, slag inclusions etc, resulting in gas-filled cavities which lead subsequently to defects in the enamel.

Hydrogen pick-up: The capacity of steel sheets to absorb hydrogen and to give it up again, is of great importance to enamelling technology, because the metal comes into contact with the gas, both during pickling and during enamel firing when hydrogen is formed by reduction of steam by iron. The hydrogen picked up by the metal can be given up again later and causes the formation of blisters or boiling in the enamel as well as "fish-scaling". Hydrogen pick-up during pickling is increased, according to Körber (Biblio. 4), Baukloh (Biblio. 5) and Bablik (Biblio. 6), by phosphorus, selenium and arsenic and especially by sulphur, because these elements can form compounds with hydrogen.

It is well known that metals absorb hydrogen at high temperatures. The solubility of hydrogen in pure iron increases with temperature, but not constantly, showing a considerable increase in the region of the ferrite-austenite transformation, because H_2 solubility is significantly greater in the face centred cubic than in the body centred cubic structure. For enamelling it is important that the H_2 solubility should remain as small as possible, or if the solubility in a particular sheet is high then the diffusion of the hydrogen should be as low as possible, so that hydrogen pick-up during pickling or firing is very small. Solubility and diffusion of hydrogen are significantly influenced by the alloy content of the sheet. Schwarz and Zitter (Biblio. 7), who have recently investigated the solubility and diffusion of H_2, found an increase in solubility with increasing temperature and with increasing content of C, Si, Cr, Ni, and Mn. Solubility is raised most by manganese, which makes itself especially felt in the austenitic range. Hydrogen diffusion increases uniformly temperature in the α-region and is reduced by transformation in the γ-structure. At room temperature hydrogen diffusion, with exception of the Fe-Si system, is steadily reduced by increasing alloy constituent content whilst it is not significantly influenced at higher temperatures in the standard concentration range for enamelling sheets of less than 0·5%. From this viewpoint a good enamelling sheet should have as little as possible P, Se, As and S avoid a large H_2 pick-up during pickling, and further to avoid a large hydrogen pick-up during firing there should only be very small C, Si, Cr, Ni and Mn contents.

Oxygen disperaal (ref. values)
Forming by cold-rolling



Oxygen dispersal as a function of the degree of cold rolling

Apart from the alloy constituents, hydrogen pick-up and diffusion are dependent also on changes in structure. The figure above which is taken from work by Schumann and Erdmann-Jesnitzer (Biblio. 8), shows that the diffusion rate of hydrogen through heavily cold worked structures decreases considerably, particularly when the cold reduction is 30% or greater. This important fact for enamelling becomes even more significant if Naeser's work (Biblio. 9) is related to it, since he has shown that hydrogen pick-up in cold rolled sheet increases quickly from a cold reduction of 40% onwards, and not by an increased solubility but by adsorption at the newly formed "internal surfaces" such as interstices and micro-cracks. This adsorption does not decrease with decreasing temperature in the same way as the solubility does, but increases, so that hydrogen evolution is prevented during cooling of the enamelled sheet.

The table below shows the results of some work by Klärding (Biblio. 10), who investigated the relationship between degree of cold reduction deformation and occurrence of fish-scale.

Relationship between amount of fish-scale and cold reduction, according to Klärding

% Cold reduction	Fish-scale count
20	90
30	60
40	25
50	5
60	2
65	0

Fish-scale, which often makes its first appearance long after finishing of the parts, is caused by the liberation of hydrogen dissolved during the firing of the sheet, owing to considerable reduction in the equilibrium solubility. The solubility at room temperature is only about 1/1000 that at 900°. In cold rolled sheets which have had a reduction of more than 30-40% diffusion is very much reduced i.e. the sheet picks up less hydrogen during firing. During cooling the dissolved hydrogen is not liberated, but is fixed by adsorption and thus fish-scale formation is prevented. The fact that according to Klärding the fish-scale count decreases greatly with increasing cold reduction, confirms the accuracy of this theory. The titanium content is also of considerable importance in determining the reaction of a steel with hydrogen.

According to private information from Chu and Davies (Biblio. 11), H_2 solubility is higher in titanium steels than in any others, but H_2 diffusion is appreciably lower. They further state that H_2 solubility in titanium steels is very little dependent on temperature. Consequently, owing to the extremely low H_2 diffusion, titanium steel absorbs less H_2 in pickling and enamel firing (other things being equal) than does a normal steel, and in the cooling of an enamelled sample very little H_2 is released, owing to the steel's non-dependence on temperature factors and low diffusion constant, so that there is hardly any tendency for fish-scale to form. An important point in the case of tinamel is that the carbon is bound as a stable titanium carbide, and the "conversion" takes place at higher temperatures.

Blister formation: The formation of blisters is frequently observed in enamelling. In most cases the root cause is in the metal. As already mentioned, Leon and Slattenschek (Biblio. 1) were able to show that defective sheets with pipe, slag inclusions and laminations especially favour blister formation because gas can collect at these points. Since carbon is able to react with oxides in the enamel or in the sheet, or with O_2 or H_2O by formation of CO, CO_2 or H_2, higher carbon content leads to considerable amounts of gas which can cause defects in the enamel coating. Such reactions mainly occur at the metal/enamel interface. Thus the carbon content of the surface layer of the sheet is more important than the overall carbon content. Whilst for example in killed steel the carbon is sistributed evenly throughout the cross-section of the sheet, rimming steel sheets have a certain degree of surface decarburization which is favourable for enamelling. According to Aldinger (Biblio. 12), the liquid remaining trapped at the edges, and seams, and also cracked weld seams can cause blister formation. Finally in this connection, mention must again be made of the behaviour of hydrogen dissolved in the sheet. Blister formation can be avoided by use of a low carbon sheet, by stabilizing the carbon as TiC, such as in Tinamel, as well as by the avoidance of inhomogeneities in the sheet.

Adhesion: An intermediate layer between the top coat and the metal, such as the ground coat, gives the adhesion. Adhesion is attained by the addition of so-called adhesion oxides such as NiO and CoO to the ground coat. Their action results from the fact that metallic iron reduces the bivalent Co^{2+} or Ni^{2+} ions dissolved in the enamel, oxidizing itself to Fe^{2+} and as such is dissolved in the enamel. Co and Ni are finer than iron and are precipitated by Fe from the enamel melt.

The reduced metals (Co and Ni) cause the formation of local electrochemical cells, as Dietzel (Biblio. 13) has shown, with the metallic iron, so that the less refined iron goes anodically into solution. This dissolution preferentially follows the grain boundaries, so that the iron surface is cracked and undergoes a fine roughening with surface enlargement and hollowing out, as is normally unobtainable by sand blasting alone. In the hollows the enamel is keyed and anchored and adhesion takes place. With regard to the alloy constituents of the steel it is well known that with Si-contents greater than 0·06% only partial adhesion is achieved, although the reasons for this are still not completely clear. Apart from this poor adhesion will occur if satisfactory wetting of the sheet by the enamel is prevented by strong gas evolution, e.g. by insufficiently degreased sheets.

Chemical composition and structure of sheets for enamelling: from what has been said, it follows that the usual elements associated with steel sheet, especially C, S, P, Si and Mn are of importance. Columns 1 and 2 in the following table indicate specified analyses for enamelling sheets recorded by Dietzel and Stegmaier (Biblio. 14).

Chemical Composition of Enamelling Sheets (in % of weight)

	Enamelling sheet		Armco sheet
	(1)	(2)	(3)
	Maximum value	Suitable value	
C	0·1	0·06	0·013
Mn	0·5	0·4	0·017
P	0·08	0·05	0·005
S	0·04	0·03	0·025
Si	0·08	0·06	Trace
Cu	0·5	0·3	—
Ni	0·2	0·2	—
Cr	0·2	0·04	—
Mo	0·1	0·1	—

The exceptionally good enamelling Armco-sheet, of composition set out in column 3 in this table has C, Mn, P, S and Si contents substantially lower than those of conventional enamelling sheets. The composition of titanium alloyed steels will be discussed under single-coat enamelling, for which these steels are mainly used.

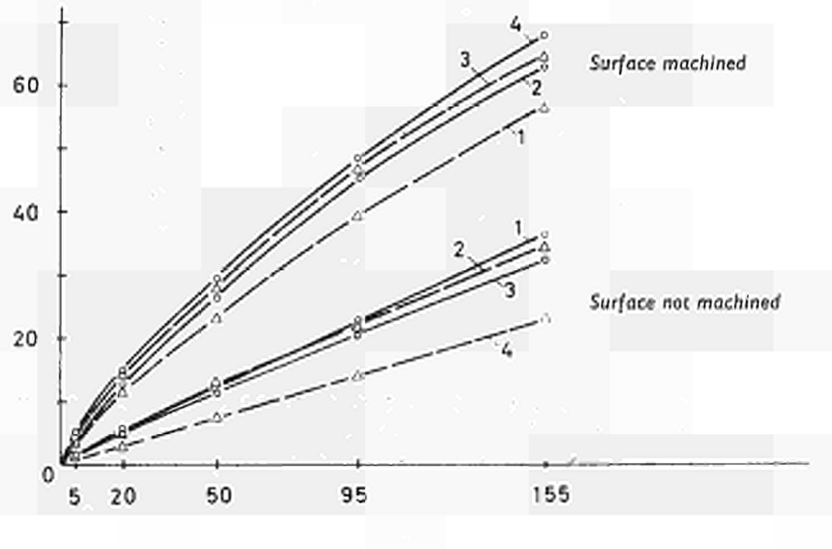
With regard to the structure of enamelling sheets it is required that it should be as uniform as possible. Grain boundary cementite, which originates by segregation of pearlite, is undesirable in large quantities, because at the enamel firing temperature it dissociates as well as suffering oxidation of the carbon, thus leading to blister formation. A completely homogeneous ferritic structure with minimum pearlite is the best perequisite for successful fire enamelling.

Single-coat enamelling

By single-coat enamelling is understood a vitreous coating on steel sheet, which consists of only *one* layer of enamel produced by firing. Single-coat enamelling was developed in order to be able to enamel economically as well as on account of the benefits which a thinner enamel coating has in relation to important physical properties such as bending strength, torsional strength, and resistance to thermal shock. Originally this development (single-coat enamelling) was towards direct enamelling i.e. it was done with no ground coat but with several top coats. By making improvements with regard to opacity or covering power of the enamel success was achieved with a single layer. The development of single coat enamelling has been carried on for about four decades. In a wider context it has been applied since the early 1950's. A single-coat enamelling must fulfil the same requirements that conventional enamelling has up to now fulfilled. Thus not only must there be good adhesion but also aesthetic requirements, such as the properties previously described, as needed in the final application must be complied with. The problem is easily solved by a special ground coat enamel, if no limitations exist as to colour. The goal however was above all to be able to produce a single-coated *white* enamel.

Adhesion: Production of good adhesion was the most important problem in single-coat enamelling. Several processes have been suggested in relation to this, e.g. the addition of colourless adhesives to the milling or melting stage, or the application of adhesive layers using nickel or various cobalt compounds in a cold pre-treatment of the sheet. In general the processes and their variants which are successful are those which utilize a deep etching treatment followed by a nickel coating. For these processes the higher alloyed interference layer on the surface of the sheet, which reacts less quickly with the nickel salt during nickel coating in a nickel bath than the base metal, must largely be removed by a penetrating etch with acid. This produces a rough, large surface, on which it is possible to deposit more nickel but in a thinner layer than on smooth surface. The nickel layer causes galvanic corrosion during the firing of the enamel, by formation of local electrochemical cells, and consequently a fine roughening of the surface takes place, which is a prerequisite for good adhesion. According to Rahn, Mayer and Frame (Biblio. 15) a relationship exists between chemical composition of the higher alloyed surface layers and adhesion. Adhesion improves if the Mn-content of the

10% HCl pickle (30° C)



Acid corrosion of various sheets as a function of time surface is lowered to that of the centre layers of the steel. Further, an improvement in adhesion was observed by a reduction in the Cu-content of the surface. According to Ryder (Biblio. 17) and others (Biblio. 16) carbon has no direct influence on adhesion.

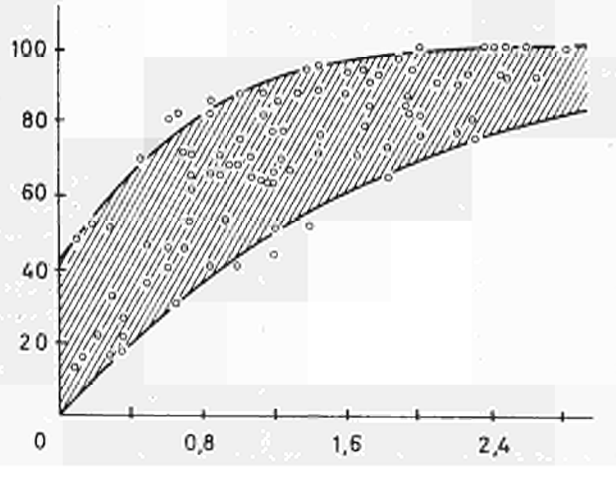
Mechanical properties: With regard to the mechanical properties required of sheets which are going to be used for enamelling by the single-coat process, those outlined in the first part are still valid. Flaking and straining of the sheet occur less frequently, because of the lower firing temperatures (about 800-850°C) and because of the fact that the titanium-alloyed and low carbon sheets used mainly for single coat enamelling do not reach the $\alpha - \gamma$ transformation point.

Cleaning the sheets for enamelling: thorough degreasing is of the greatest importance for single-coat enamelling, because gas evolution, which may occur as a result of inadequate degreasing, leads to blisters in the enamel and thus to rejection. The degreasing process does not differ basically however from that used for conventional enamelling steels.

Pickling: In contrast to enamelling with a ground and a top coat which removes only the scale, and ought not to dissolve the base metal, the process for single coat enamelling requires a removal of about 20-30 g. Fe/m.² of metal surface. This deep etching can be carried out not only with dilute solutions of HCl, H_2SO_4, HNO_3, H_3PO_4, citric acid, but also with mixtures of H_2SO_4 and HNO_3. The pickling characteristics of the sheet depend on the chemical composition of the steel and above all on that of the surface. This has recently been demonstrated at the author's Institute by pickle tests on sheets with un-pretreated surfaces and on sheets which have had their surfaces ground. The above figure shows the results of these pickle tests, which were carried out with HCl on four different sheets. It appears that what was previously the worst pickling grade of sheet shows the best pickling characteristics after removing the surface layer. Rahn, Mayer and Frame (Biblio. 15) have shown from pickle tests with H_2SO_4 that a steel containing 0·26% Cu pickles significantly less well than one with only 0·07 - 0·1%. This agrees with Lang's (Biblio. 18) investigations and with our own (Biblio. 16) findings. Rahn, Mayer and Frame further showed, by X-ray fluorescence analysis, that with increasing pickle removal the Mn-content decreases whereas the Cu-content of the surface layer increases. One reason for the different behaviour of Mn and Cu is to be found in their relative position in the electrochemical series. According to Eisenkolb (Biblio. 19) higher silicon content also leads to increased difficulties in pickling. The significance of the pickle removal for adhesion has also been shown by Rahn, Mayer and Frame. The following figure shows the relation between adhesion and pickle removal for 10 differ-

Adhesion (in %)

Corrosion (g./sq. ft)



Relation between acid corrosion and adhesion (after Rahn and M.)

ent low carbon sheets. A significant increase in adhesion with rising pickle removal can be detected. Unlike ground coats, since single-coat enamels may have a blistery structure which can pick up the hydrogen coming from the sheet, the avoidance of large collections of hydrogen in the sheet is even more important in this case. In order to prevent evolution of hydrogen during pickling, additions are made, e.g. in the case of sulphuric acid pickling of about 4·5% ferric sulphate, which by reaction with ferrous sulphate dissolves iron without hydrogen evolution. For the avoidance of considerable hydrogen pick-up in sheets during pickling, those factors mentioned earlier are valid.

Nickel coating: There are various methods of application of a nickel coating. One very frequently used is the nickel-dip process, in which the sheet is immersed in a nickel salt solution. The larger the surface area produced by pickling, the more nickel is deposited under similar conditions. Nickel deposition rate is reduced by the presence near the surface of the sheet of large amounts of elements which are finer than Fe. Since these elements are also those which cause pickling difficulties, nickel deposition is closely related to the pickling characteristics of a sheet. The amount of nickel applied depends on the particular process. The technical literature specifies nickel deposits between 0·5-2·5 g/m^2.

Blister formation: The formation of blisters, which can be tolerated to some extent in a ground coat which will later be cover-coated, must obviously not occur in single-coat enamelling. Thus everything which has been said in regard to conventional enamelling concerning the avoidance of blister formation applies even more to single-coat enamelling. An important requirement for steels for single-coat enamelling is thus a reduction in hydrogen pick-up. That this can be attained by reduction in the P, S, Si, Cr, Ni and Mn content, as well as by increasing the α- phase range, has already been explained. Thus by a reduction in the C-content, H_2 pick-up is reduced; as also are the reactions leading to gas evolution, and therefore blister formation, caused by interaction of carbon with O_2, H_2O and oxides is kept within tolerable limits. In the development of single-coat vitreous enamelling processes particular emphasis was therefore placed on the development of special steel qualities which would satisfy these requirements. Progress was made possible by the use of cold reduced sheets for the reasons already discussed above. A considerable improvement was gained from titanium stabilized steel, which picks up little hydrogen, and in which the carbon is fixed as the stable titanium carbide. At the end of 1959 a number of special kinds of steels became commercially available, the so-called "Zero-Carbon" steels; the carbon content of these is only 0·001-0·003%. Such low carbon steels cannot, as is known, be produced directly, but must be additionally decarburized. This is carried out by the "open-coil" process for these steels. These low carbon steels have given outstanding results in single-coat enamelling. They have become most widely used in America, where according to Spencer-Strong (Biblio. 20) eleven major factories are already using them in single-coat enamelling processes.

Chemical composition of enamelling steels for single-coat enamelling: the chemical composition of the titanium steels usually used for single-coat enamelling and shown in column 1 of the following table are taken from work by Petzold (Biblio. 21).

Composition of Titanium Alloyed and Low Carbon Enamelling Steels (in % of weight)

	Titanium alloyed steel (1)	Bethnamel (2)
C	0·04 — 0·08	0·001 — 0·003
Mn	0·31 — 0·42	0·23 — 0·39
P	0·008 — 0·01	0·01 —
S	0·01 — 0·03	0·02 — 0·036
Si	0·01 — 0·08	0·01 —
Ti	0·26 — 0·44	—
Al	0·01 — 0·09	—
Cu	0·04 — 0·07	0·07 — 0·12
Ni	—	0·02 — 0·06
Cr	—	0·02 — 0·07

Irrespective of fluctuations the titanium content must always be at least four times the carbon content, The Ti/C ratio of a good enamelling titanium sheet is usually between 4·2 and 9 (Biblio. 21). The composition of a typical low carbon steel, see Rahn, Mayer and Frame (Biblio. 15) and also Blickwede (Biblio. 22), is given in column 2 of the table. The relatively low content of accompanying elements (with the the exception of Ti) is common for both types of steel. A comparison with the table on page 273 shows that steels for use in single-coat enamelling not only have a lower carbon content, but, as is required, also less P, Cu, Ni and Cr. This is not only a good thing from the point of view of reducing blister formation, but above all from the point of view of pickling characteristics.

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This paper has relied on Petzold's book "Email" (Biblio. 2) except where more recent original work and literature has been used.

G. de WITTE

The Use of Decarburized Sheet Steel in the Enamelling Industry

(Translated from French)

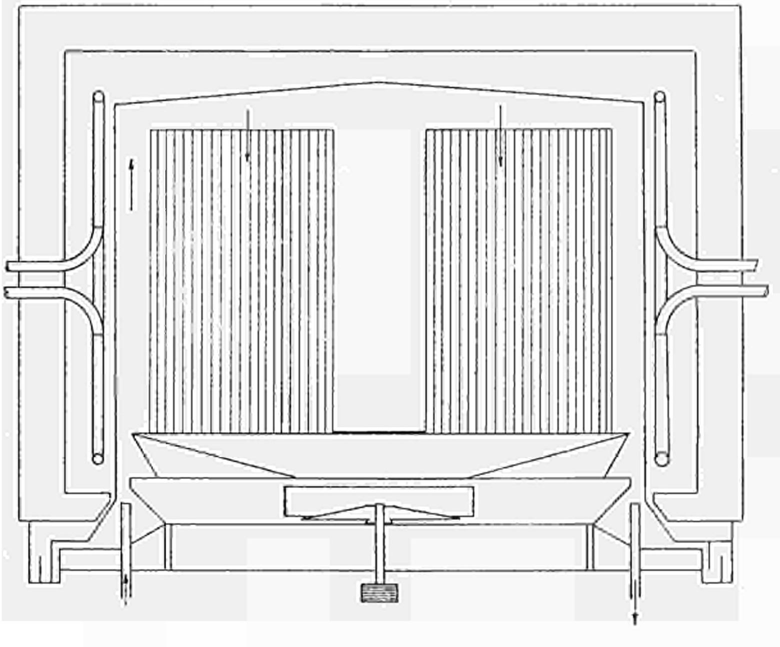
During the last few years, several steel producers in the E.C.S.C. have made decarburized sheet steel available to the enameller. In so doing the producers have not intended to replace existing grades, but to extend the range of qualities available. There were three reasons for this extension of the range.

(a) The need for a sheet with a greatly reduced tendency to deform during firing. This refers to the non-sagging and the non-warping enamelling qualities;

(b) the need for additional improvement in the quality of the finished enamelled product, with particular reference to greater resistance to blistering of the enamel (white single-coat enamelling);

(c) the need for sheet grades which more effectively combine good " drawability " with suitability for enamelling.

Some years ago, in the U.S.A., the open-coil plant was developed. This plant makes possible almost complete decarburization of cold-rolled strip so that the carbon content throughout the sheet is reduced to a very low level. This decarburization is achieved during annealing as a result of reaction between the surface of the strip and the humid gas atmosphere, the chemical composition of which is carefully chosen (see figure below). Certain producers, equipped with such an open-coil plant were not slow in investigating the new properties of the decarburized product and, by adopting new metallurgical cycles, in discovering the special merits of such products for the user.



Open-coil furnace

Non-sagging and non-warping properties

During the firing of the enamel, a workpiece may be deformed for various reasons. One of these can be the base steel in which, as experience has taught us, the (partial) transformation of ferrite into austenite (during firing) plays an important part.

It is for this reason that enamelling iron was developed some decades ago in the United States; this grade of steel does not form austenite in the usual annealing temperature range, because of its special composition (fairly low carbon and manganese content).

Such a steel is obtained by special steelmaking practice which has certain disadvantages for the producer as well as the user.

The open-coil plant enables the producer to decarburize the steel in the rolled condition and eliminates transformation into austenite during firing of the enamel. This obviates the disadvantages mentioned above. It should be noted however that enamelling iron has a carbon content of about 0·02% which is in itself insufficient to eliminate the transformation zone and necessitates in addition, the reduction in other elements, such as manganese. On the other hand, open-coil decarburization enables a carbon content of about 0·005% maximum to be attained.

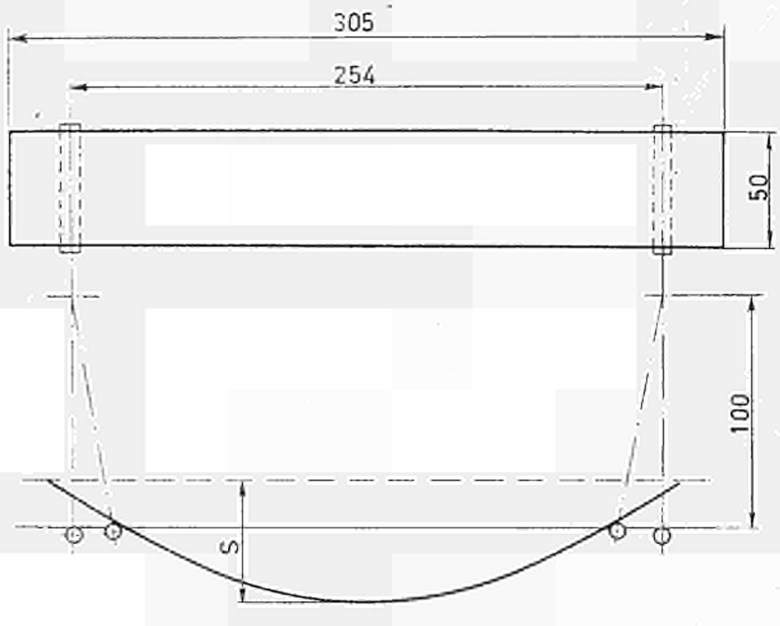
Non-sagging and non-warping qualities enable the enameller to produce a finished product which meets more exacting requirements as to rigidity and flatness. To improve flatness, enamels with lower firing temperatures may be used, but these do not necessarily improve the enamelled product to the best advantage. It is thus preferable to use decarburized steel if improved flatness is desired. Where flatness is the determining factor for sheet thickness, a non-sagging grade makes it possible to use a thinner sheet. For the fabrication of flat articles with exacting requirements as to flatness it is not enough to choose a grade of sheet possessing good non-sagging properties, because the sheet in the as-delivered condition must be as flat as possible and also free from stress.

For this reason it is essential in the fabrication of wall cladding to use decarburized sheet with very close tolerances as regards flatness. These tolerances can only be obtained by flattening or by hydraulic stretching after rolling.

The following figure gives, more quantitatively a comparison between a conventional steel and a well-known Dutch decarburized steel, Vitrostaal, as far as sagging properties are concerned. The figures represent the sag (expressed in millimetres) after firing eight minutes at two temperatures commonly used in practice. Users of the Vitrostaal grade, specially developed for wall cladding, usually specify hydraulic stretching of the sheet.

Subsidence after 8 min. at

	820° C	840° C
Conventional steel	12·8 mm.	19·0 mm.
"Vitrostaal"	4·1 mm.	4·3 mm.



Subsidence test
(S = subsidence)

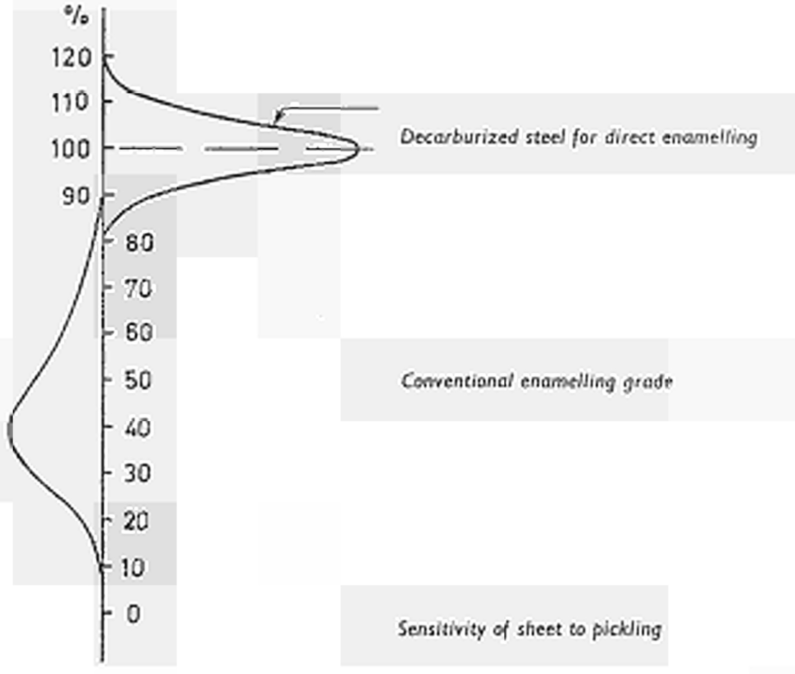
White single-coat enamelling

Efforts have long been made to produce an enamelling process which would eliminate the need for a ground coat and reduce the total enamel thickness. This would ensure greater resistance to blistering and an improved appearance of the enamel coating. These objectives have become more and more important as competition from other materials or other types of surface coatings has become more severe.

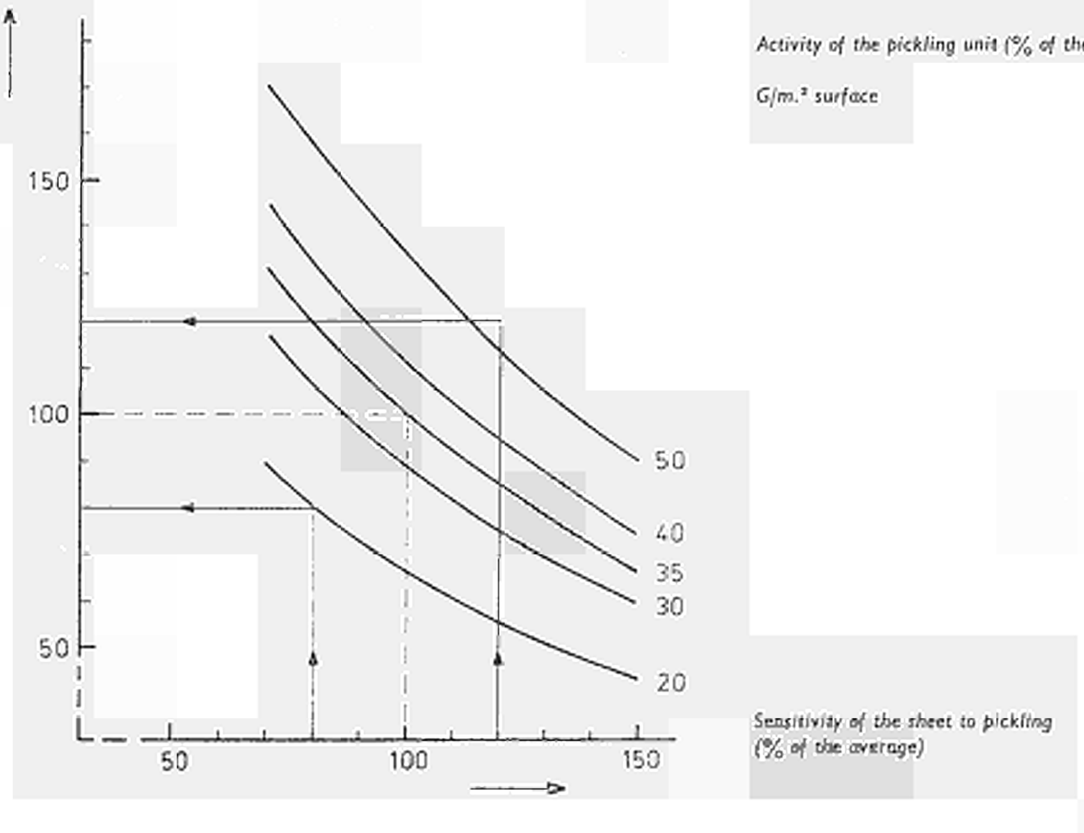
Resistance to blistering is very important for the reputation of finished enamelled products, but in addition it plays an important role in the enamellers' production and fabrication methods. It has long been known that it should in principle be possible to obtain good direct adhesion of a high-quality enamel coating on the steel without a ground coat, provided the surface of the steel is given appropriate initial preparation. This preparation consists (after degreasing) of a fairly thorough treatment of the surface with an appropriate pickling agent, followed by a carefully measured nickel deposit. This treatment however involved an apparently insurmountable difficulty: severe acid attack, a condition for good adhesion, resulted in such a heavy carbon deposit on the surface of conventional steel that the appearance after enamelling left much to be desired. In the United States this was overcome by binding the free carbon with a suitable titanium content in the steel (Ti-namel grade). In spite of its technical merits, this grade of steel has never come to be used on any scale, on account of its cost. The open-coil process has provided the answer: the free carbon is not bound, but eliminated.

The enameller however would not be satisfied with an ordinary grade of steel which had simply been decarburized. To guarantee good adhesion of the enamel coating, the steel must meet other requirements. Furthermore, the enameller should keep the loss of metal through pickling within certain fixed limits with a suitable acid and also must take care to deposit nickel on the pickled sheet, also kept within fixed limits, using a controlled nickel-coating process. In order to satisfy all these demands, not only should the enameller be able to carry out the pickling and nickel coating processes within fixed limits, but the steel producer too should supply a sheet of uniformly high suitability to pickling and nickel coating. To enable him to do so in such a way as to ensure perfect adhesion of the enamel to the steel, which is the primary consideration, the sheet producer must now acquire a new and highly specialized "know-how".

As for the pickling rate, a variant of the decarburized steel Vitrostaal specially developed for direct enamelling is compared with a conventional steel in the figure below. Thanks to a steel composition suitably and carefully reproduced, the pickling rate is greatly increased and much less variable.



The following figure shows the basic principles for co-operation between sheet producer (pickle rate) and enameller (pickling process), assuming that iron loss in pickling has been kept between 20 and 50 g./m.², for both sides. The figure suggests to what degree the metal and pickling variations should be reproduced in order to guarantee good adhesion of the enamel in normal production.



What has been said applies mainly to the quality of the directly enamelled finished product. Incidentally, the choice between single-coat enamelling and conventional enamelling is a fairly easy one. I am not concerned here with the cost aspect of single-coat enamelling since this cannot be dealt with briefly and depends on local conditions. Apart from the complications in connection with changes needed in the preparation methods, I would merely mention that the productivity of the enamelling lines and furnaces is considerably increased.

Combination of mechanical properties with suitability for enamelling

It is not necessary to go into detail here concerning the mechanical properties. It is sufficient to say that with open-coil decarburized steel treated in a particular way, an improvement in the steel's mechanical properties is obtained. This, combined with suitability for enamelling, gives decarburized sheet overall properties which are most valuable to the user.

Conclusion

As we have seen, decarburized steel is the answer to such questions as deformation during firing, enamelling with a white coating, and improvement in mechanical properties. These different uses however require suppliers to produce selected and specially treated steel.

The user also, in the case of single-coat enamelling for example, has to accept certain new conditions. Thus, close co-operation between producer and user is absolutely essential if the quality of the finished product is to be fully up to users' requirements. Such co-operation already exists in quite a number of cases.

H.-E. BÜHLER

and

L. LEONTARITIS

Investigation of the Interface Zone Metal/Enamel on Direct-on White Enamelled Samples of Decarburized Steel Sheet

(Translated from German)

Various technical publications have recently dealt with several projects concerning the technique of direct-on white enamelling (Biblio. 1 to 5). Some of these investigations provide useful information on the influence of various factors relating to the materials and processes employed, on the adhesive strength of enamels and the serviceability of the enamel surface.

The processes which occur during the firing of titanium top-coat enamels at the metal/enamel interface have been thoroughly investigated by Douglas and Zander (Biblio. 6,7). Their findings appear to be of some importance when considered in the light of the theories on enamel adhesion developed in recent years by King, Tripp and Duckworth (Biblio. 8) and also by Heimsoeth and Lang (Biblio. 9).

According to King, Tripp and Duckworth (Biblio. 8) good adhesion can only be assured if the enamel at the metal/enamel boundary layer is saturated with an oxide of the enamelled metal. The oxide formed at the boundary, e.g. FeO, must not be reduced by the base metal, e.g. iron. If these conditions are fulfilled, metal ions from the metal oxides dissolved in the metal/enamel boundary surfaces in saturated solution and metal ions from the metal form a metallic bond, in such a way that the metal ions from the oxide share the electron gas.

King, Tripp and Duckworth (Biblio. 8) were able to show that an enamel saturated with iron-oxide can be firmly fired on a polished iron surface.

These tests, carried out under ideal conditions, cannot, as shown by results published in technical literature (Biblio. 4 to 7), be applied as they stand to enamelling with titanium top-coat enamels. Crystallization processes in the metal/enamel boundary zone (Biblio. 6,7), and the need for a nickel coating if satisfactory adhesion (Biblio. 4 to 7) is to be obtained, induced Heimsoeth and Lang (Biblio. 9) to expand Kings' adhesion theory (Biblio. 8).

Heimsoeth and Lang (Biblio. 9) assume that a completely homogeneous bond distributed over the metal/enamel boundary layer is not formed during enamelling, but that adhesion occurs only at points distributed in varying degrees of density over the surface (the key point of the mechanical adhesion theory) (Biblio. 16). Compared with King's experiment (Biblio. 8), this means reduced adhesion which is offset during enamelling by the increase in iron surface (and hence an increase in the number of bonding points), which occurs during firing the enamel on an sheet surface nickel-coated after pickling.

At the research centre of a German steel enterprise extensive investigations are now being carried out in an attempt to throw light on the processes occurring at the metal/enamel interface during direct-on white enamelling.

I now propose to describe some of the results of this work, which were obtained mainly by electron-beam micro-analysis (Biblio. 15).

Test Procedure

Decarburized steel sheet of the chemical composition shown in the following table was direct-on white enamelled according to the method used by an important chemical factory in Western Germany (Biblio. 10).

All samples were pickled for 12 minutes in 9% sulphuric acid at 70° C and then coated with nickel for different periods in an acidified nickel-sulphate solution (12 g/l $NiSO_4 \times 7\,H_2O$, pH = 3.5; 0, 12, 40, 60, 80, 120, 180 and 300 minutes). The usual nickel-coating period in pratice is about 12 minutes.

Chemical composition of the samples studied in % of weight.

C	Mn	Si	P	S	Cr	Ni	Al	Cu	N	Pb
0·002	0·29	0·01	0·037	0·022	0·028	0·017	< 0·001	0·03	0·0021	< 0·0005

The firing temperature for enamelling was 810° C and the firing period 5 minutes.

After this treatment the following adhesion characteristics were determined by the Erichsen tests for the individual sheets:

(a) not nickel-coated — no adhesion

(b) nickel-coated from 12 to 120 minutes — very good adhesion

(c) nickel-coated 180 minutes — good adhesion

(d) nickel-coated 300 minutes — moderate adhesion

For determining the chemical composition and structure of the metal/enamel interface the following possibilities of metallographic analysis exist: optical microscopy, electron microscopy, electron and X-ray diffraction and electron-beam micro-analysis.

For metallographic analysis the samples were ground and polished in the usual way. To enhance contrast a zinc-selenium layer (Zn-Se) was then vapour-deposited (Biblio. 11 to 14). The electron-beam micro-analysis investigations were carried out with an AEI electron-beam "SEM 2" after vapour-depositing the samples with Al. From the analysis of the frits used for enamelling the table below gives typical values and it can be seen that in addition to silicon, the elements titanium, potassium and phosphorus are present in quantities above the limits of electron-beam micro-analysis. The additional elements present in the frit, boron and sodium, could not be determined with the electron-beam microscope available because of their low atomic numbers (Biblio. 5 and 11). In the experiments it was decided to use linear scanning which it was felt would be more informative than point analysis. A quantitative determination of individual elements would have been too time-consuming from the viewpoint of the experimental effort. The following test results therefore provide only a qualitative picture of the distribution of the different elements in the metal/enamel interface zone.

Chemical composition of the frits in % of weight.

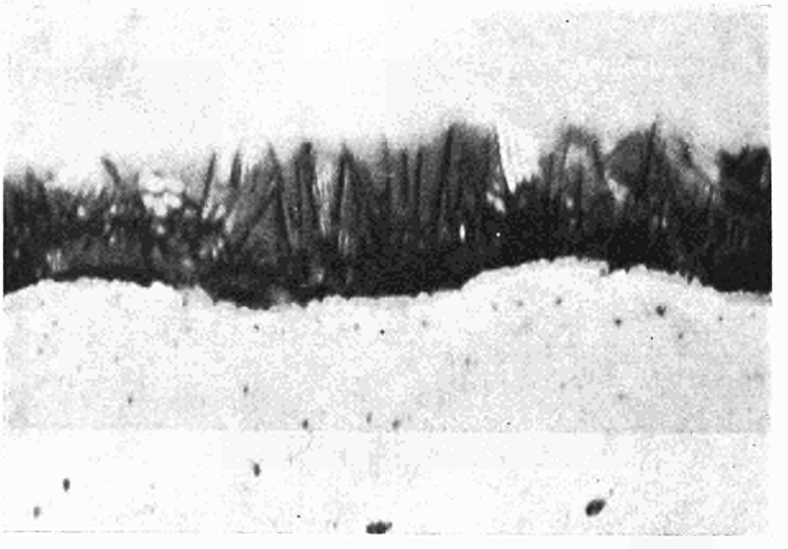
Designation	Chemical analysis in % of weight									
	B	SiO_2	Al_2O_3	TiO_2	CaO	MgO	Fe_2O_3	K_2O	Na_2O	P
A	5·4	40·6	0·98	18·4	< 0·10	1·20	0·80	3·5	9·8	0·95
B	5·3	41·8	2·40	15·1	< 0·10	1·80	0·71	3·1	10·1	0·98

For X-ray investigations, which were carried out with filtered cobalt Kα radiation, a counter tube goniometer with amplifier and recording device was used.

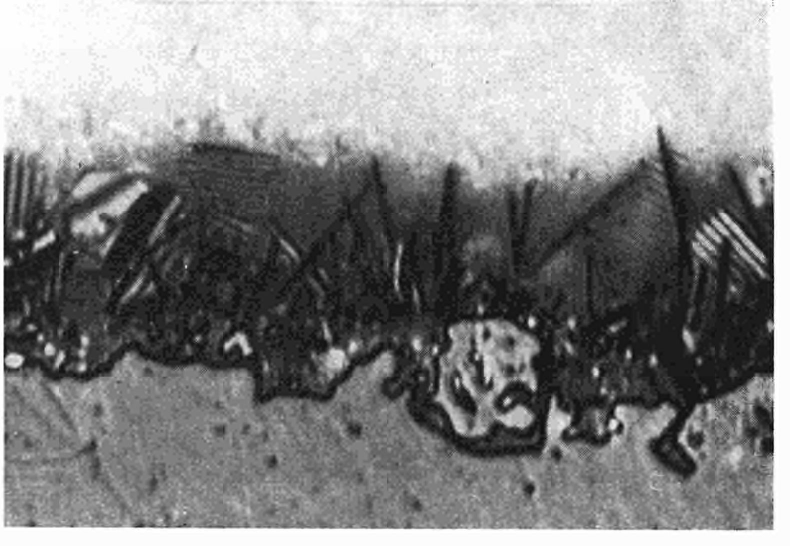
Test results

The micrograph in the eight following figures show a 10-20/μ thick layer of heterogeneous composition between the base metal and the enamel. In this intermediate layer the development of narrow, lamella crystallites is observed in all the samples investigated. In many cases these crystallites have a structure resembling twinned structure, arranged in parallel, alternate light and dark stripes. Optical microscope study shows that this is not due to a genuine twinning, but to interference phenomena, caused by refraction of the light by lamella crystallites obliquely oriented to the polished plane in the vitreous intermediate layer.

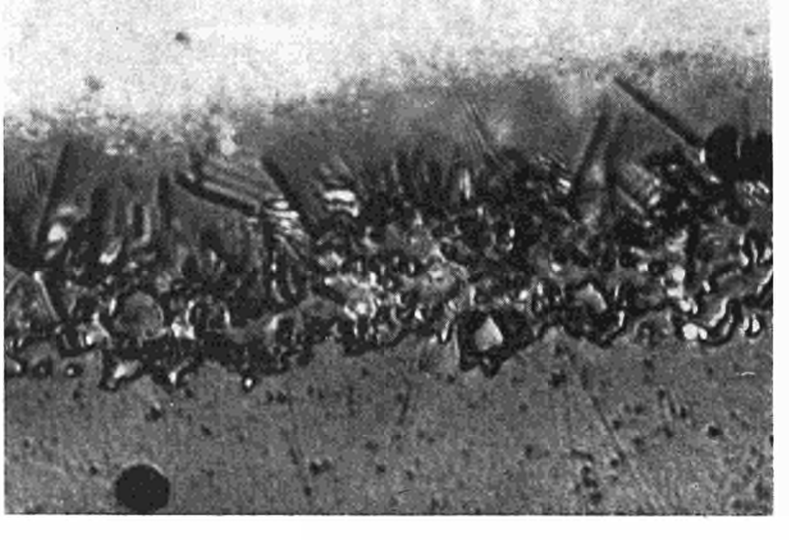
Formation of metal-enamel interface in direct white-enamelled test-pieces of decarburized sheet. Test-pieces vapour treated with ZnSe, m = 2,000 : 1 (second magnification). Original magnification m = 1,000 : 1.



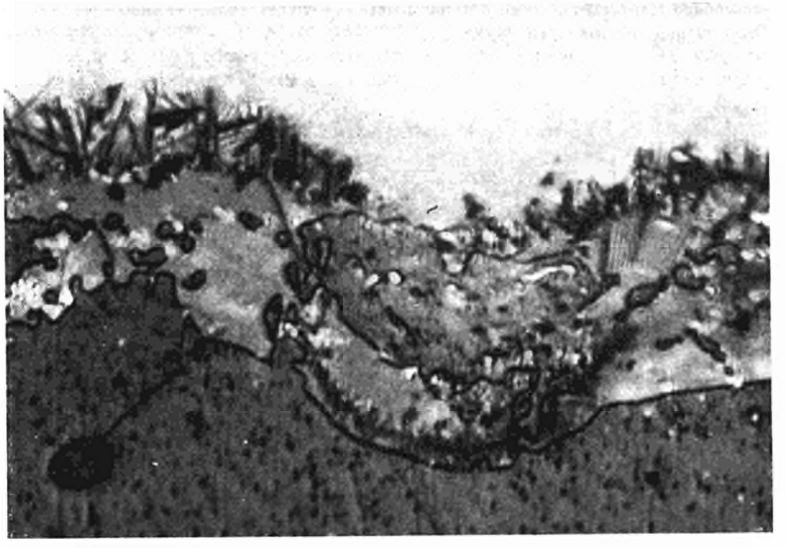
A — Pickled for 8 mins., not nickel-plated



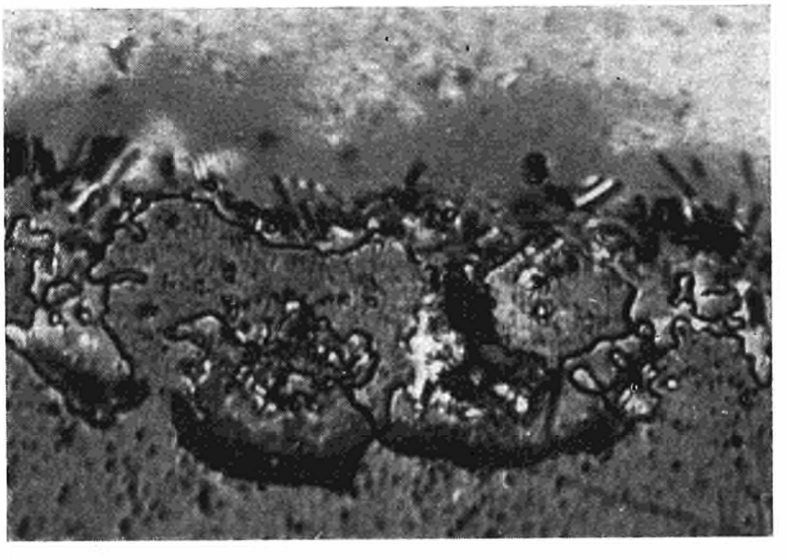
B — Pickled for 8 mins., nickel-plated for 12 mins.



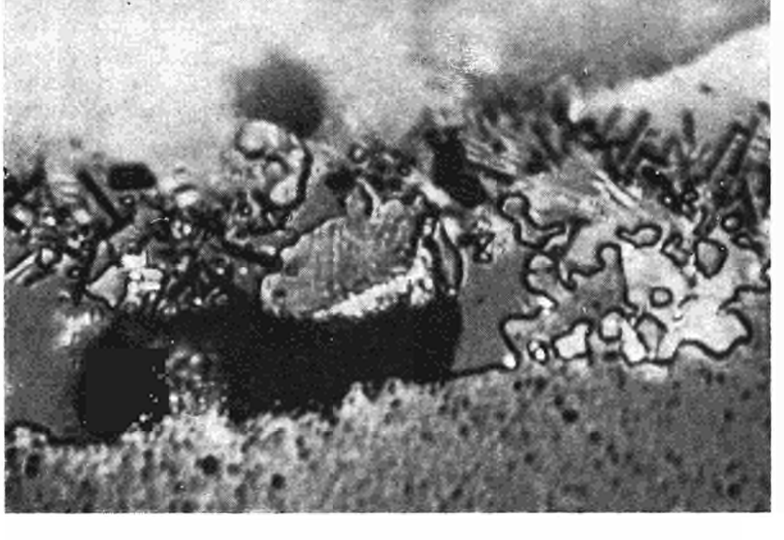
C — Pickled for 8 mins., nickel-plated for 40 mins.



D — Pickled for 8 mins., nickel-plated for 120 mins.

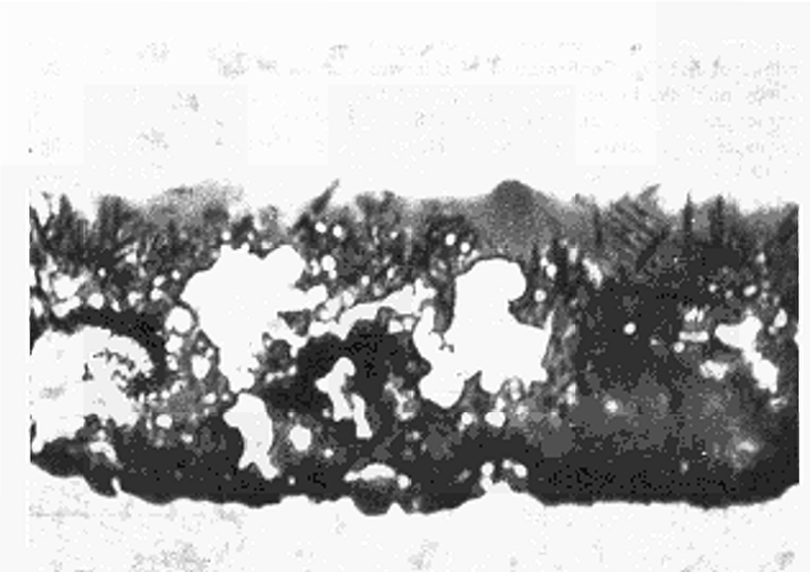


E — Pickled for 8 mins., nickel-plated for 180 mins.



F — Pickled for 8 mins., nickel-plated for 180 mins.

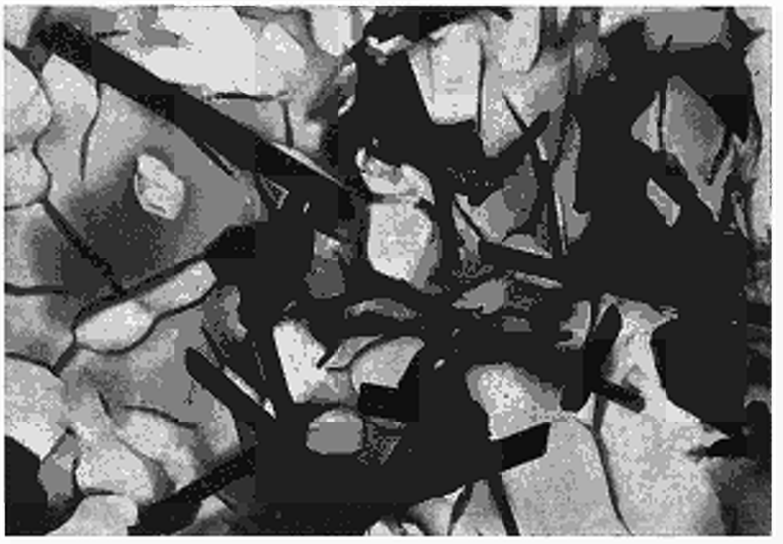
G — Pickled for 8 mins., nickel-plated for 300 mins.



H — Pickled for 8 mins., nickel-plated for 300 mins.

If the sample is enamelled immediately after pickling without coating with nickel (A), the steel surface is little roughened, the crystallites of the intermediate layer mostly appearing acicular and tending to grow perpendicular to the metal surface. Even with short nickel-coating times (B, C) greater roughening of the steel surface is observed, as in Dietzel's theory of galvanic corrosion, by the simultaneous action of nickel and atmospheric oxygen (Biblio. 16). Peninsula-shaped constrictions and small metal particles of increasing size dissolved up from the base metal (D to H) indicate the condition after progressively increasing nickel-coating periods. The crystallites now appear more frequently in a flat form. By their being frequently separated from the metal surface, they reflect the original shape of the steel surface at their positions before commencement of the firing process. The preferred direction of growth characteristic in the case of short term nickel dip coating is no longer observed. After very long nickel-coating times (e.g. 180 and 300 minutes) darkish seams of oxide are observed directly on the steel surface at the point of greatest selective oxidation.

The crystallites of the intermediate layer are also revealed by electron microscopy. In this case the enamel on non-nickelled samples (A), which had a very poor enamel adhesion, was removed by slight bending of the metal sheet. The fracture process takes place in such a way that the intermediate layer crystals adhere to the enamel. After a subsequent brief etching of the separated surface in dilute solution of hydrofluoric and nitric acid, it was possible to prepare slides suitable for electron microscope work by means of the well-known replica technique.

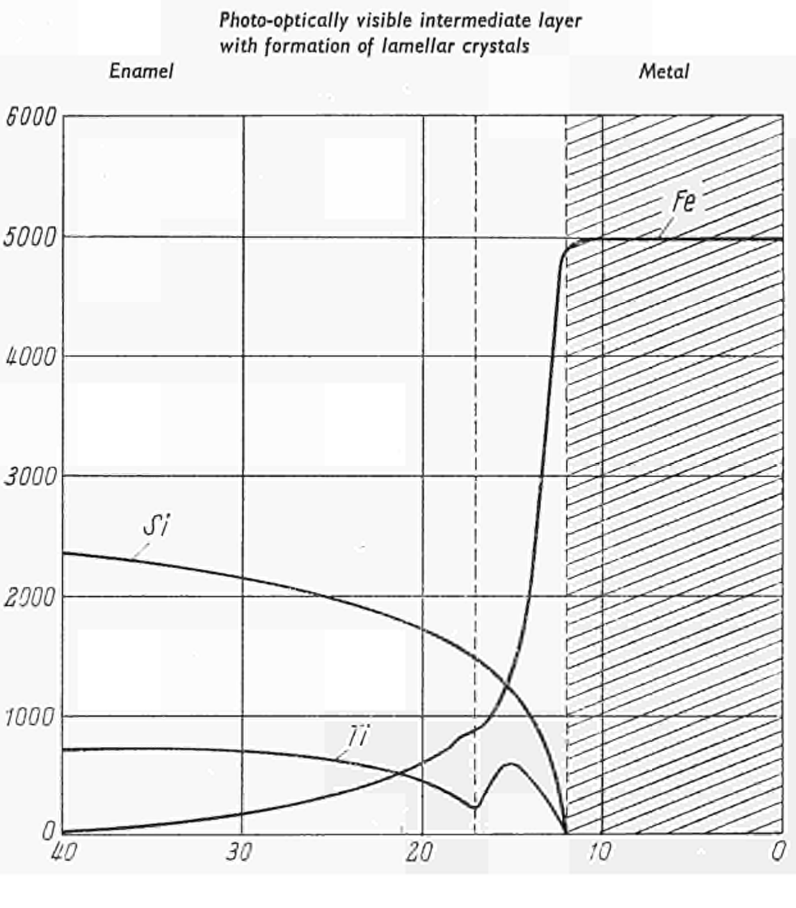


Electron microscope image of $FeTiO_3$
m = 16,000 : 1

Thin crystals both of the narrow and acicular and of the flat type can be seen in the above figure. Structure analyses by electron diffraction show that in both cases there is rhombohedral $FeTiO_3$. Confirmation of this was obtained from X-ray analysis. In addition the study of the counter tube goniometer curves showed weak reflections of the two forms of TiO_2, anatase and rutile. No iron oxide (FeO or Fe_3O_4) was detected.

In order to obtain further information on the chemical composition of the intermediate layer, variously pretreated samples, (non nickelled, nickel-coated 12 minutes and nickel-coated 300 minutes), were examined with the aid of the electron probe.

The first figure on page 283 shows the concentration pattern in non-nickelled samples for iron, silicon and titanium over a



Pretreatment: 8 mins. pickling, no nickel plating. Enamel fired at 810 °C (firing time 5 mins.)

Impulse rates (impulses/sec)
Range of measurement in μ

Distribution of elements at the metal/enamel interface of phases in directly white-enamelled test-pieces of decarbonized steel sheet distance of 40 µ in the transition zone metal/intermediate layer/enamel. Included in the diagram is the zone in which, according to the figures on pages 283 to 285, the formation of $FeTiO_3$ crystals is observed. Whilst the pulse rates of the iron decrease continuously, (apart from one slight levelling-out), with increasing distance from the edge of the sheet, the silicon concentration rises constantly. The zone of $FeTiO_3$-formation is, predictably, characterized by a pronounced maximum of titanium concentration. Adjacent, in the direction of the enamel layer, is a zone of marked titanium impoverishment. A pulse rate pattern similar to that of the silicon, with proportionate increase from the metal surface right into the enamel layer itself was observed for phosphorus. Potassium, on the other hand, has in many cases a definite maximum as regards the iron titanate-forming zone.

In contrast to the samples not coated with nickel, in which the intermediate layer is formed exclusively from the vitreous base material and precipitated $FeTiO_3$, the transition zone metal/enamel appears after the dip nickel coating in the form of a non-homogeneous zone consisting of base material, $FeTiO_3$ crystallites and metal particles partially or completely separated from the steel surface.

The distribution of the elements in the transition zone was determined at two characteristics points:

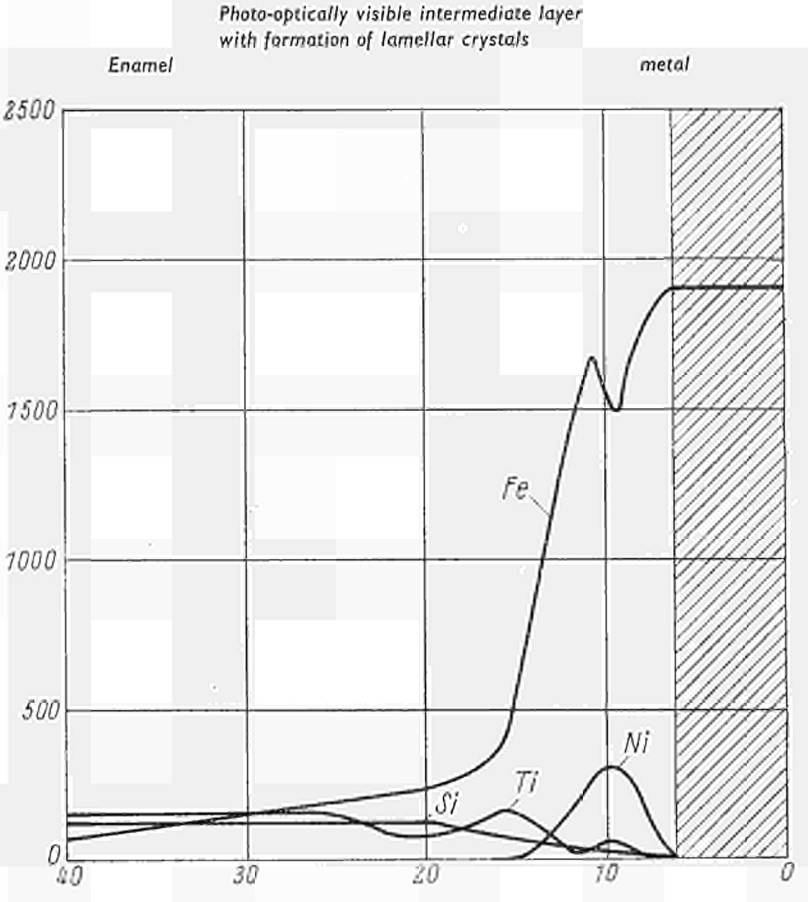
(a) in a zone with a phase sequence steel-$FeTiO_3$-enamel, as in the case of the non-nickelled samples;

(b) in a zone, with a phase sequence steel/metal particles/$FeTiO_3$/enamel.

Pretreatment: 8 mins. pickling, 12 mins. nickel plating. Enamel fired at 810 °C (firing time 5 mins.)

Impulse rates (impulses/sec)

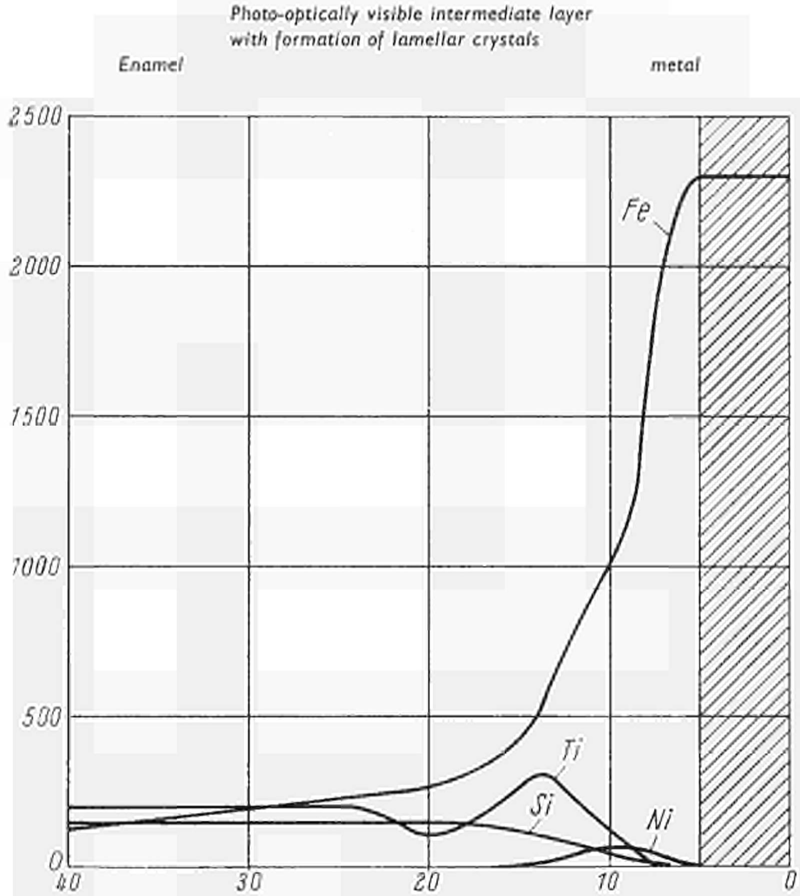
Range of measurements in µ



Distribution of elements at the metal/enamel interface of phases in directly white-enamelled test-pieces of decarbonized steel sheet

The distribution of the elements for A) (nickel coating time 12 minutes) is shown in the figure above. As can be seen, iron, silicon and titanium have concentration patterns similar to that of the non-nickelled samples. A slight sag in the pulse rates of the iron is here again observable in the same zone as that of maximum titanium concentration. In the immediate neighbourhood of the sheet surface there is a slight nickel enrichment.

The following figure shows the distribution of the elements for the phase sequence steel/metal particles/$FeTiO_3$/enamel.



Pretreatment: 8 mins. pcikling, 12 mins. nickel plating. Enamel fired at 810 °C (firing time 5 mins.)

Impulse rates (impulses/sec)
Range of measurements in μ

Distribution of elements at the metal/enamel interface of phases in directly white-enamelled test-pieces of decarbonnized steel sheet

In the zone of the metal particles measured by electron beam a pulse maximum for nickel coincides with a pulse minimum for iron. The concentration pattern for titanium and silicon is similar to that indicated for the characteristic titanium maximum in the zone of $FeTiO_3$ formation.

During firing of the enamel frits in the interface zone both for non-nickelled and for nickel-coated samples include the following:

(a) precipitation of the TiO_2 from supersaturated solution in the form of anatase and rutile (Biblio. 6, 7, 17);

(b) oxidation of the metal surface (Biblio. 8, 9, 16);

(c) formation of $FeTiO_3$ according to equation (1)

$$FeO + TiO_2 \rightarrow FeTiO_3$$

and precipitation of the iron titanates after attaining the saturation concentration in the molten enamel (Biblio. 6, 7).

We do not propose to describe in detail here the sequence of reactions occurring during the firing of the enamel, or to interpret the results of the trials in the light of the theories on enamel adhesion referred to in our introduction. These aspects will shortly be dealt with elsewhere (Biblio. 15), when we shall, *inter alia*, describe in greater detail how reactions (a), (b) and (c) are affected by variations in firing temperature and firing time.

We would however like to mention two results to which we have referred in our comments on the figures on pages 283 to 285 and pages 287 and 288.

In the case of nickel-coated samples, nickel oxide, formed as Dietzel suggests (Biblio. 16), is substantially reduced according to equations (2) and (3)

$$Fe + NiO \rightleftarrows FeO + Ni \quad (2)$$
$$\text{or} \quad 3\,FeO + NiO \rightleftarrows Fe_3O_4 + Ni \quad (3)$$

The equilibrium constants of the reactions according to (2) and (3) have a value of about 5.10^{-3} at the temperature used, 810° C, so that at approximately equilibrium conditions the nickel content of the oxide phase formed during firing should be below 1%.

The Fe/Ni ratio in the small metal particles partially or wholly separated from the steel surface, and in the enamel zones surrouding them, was determined by means of the electron beam microscope.

The investigations produced the following results:

(a) the metal particles consist for the most part of iron-nickel alloys with widely varying Fe/Ni-ratio (see also figure above);

(b) the oxide phase is practically free from Ni, but richer in Fe than the metal phase.

As has already been mentioned in dealing with figure A (p. 283) $FeTiO_3$ crystals tend to grow perpendicularly to the metal surface.

The following figure shows an electron microscope micrograph of the structure in the interface zone metal-enamel. The dark acicular $FeTiO_3$ crystals grow from the metallic base into the enamel layer. Unfortunately, because of the almost equally strong electron absorption, the two phases metal and $FeTiO_3$ appear in this picture in equally marked light and dark zones contrasting with the white enamel layer. It must be assumed that as a result of the foreign body nucleation process the precipitation of $FeTiO_3$, always begins at the roughened steel surface.

Electron image of the metal/enamel interface (4,000 : 1)

Summary

This paper describes research of the interface metal/enamel zone in direct-on-white enamelled steel sheet. With the aid of optical and electron microscopy and electron beam micro-analysis it was possible to determine the chemical composition and structure of a 10-20 μ thick intermediate layer between metal and enamel.

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DISCUSSION

Antoine POURBAIX

(Translated from French)

Are there at present any proved methods of expelling hydrogen from such materials as enamelling steels, or at any rate from those with an excessive hydrogen content?

Jean DAUBERSY

(Translated from French)

I should like to reply to Professor Pourbaix' question about the possibility of expelling hydrogen contained in enamelling steels.

The hydrogen content of liquid steel is quite harmless and is liberated naturally during the various stages of steel-sheet manufacture. Thus we have been able to produce first-class enamelling sheet from steel blown with an oxygen-steam mixture that introduces vast amounts of hydrogen into the liquid steel. The only hydrogen occuring in the enamelling process is in the atomic form; it penetrates into the sheet during the process, either as a result of pickling, decomposition of the hydrates in the enamel, or of the furnace atmosphere.

In the case of decarburized steel however, hydrogen hardly presents any problem, at any rate after cold rolling. Steel of the right composition and manufacture contains microscopic or sub-microscopic porosities (no doubt due to carbon extraction) in which diffused hydrogen may accumulate. Consequently, the static pressure of the accumulated hydrogen remains at a low level and cannot cause the enamel to chip off. This at least is the explanation currently accepted by most experts.

John DINKELOO

The New Face of Architectural Steel

The only limitation for creating better buildings is the development of new materials and building techniques. Progress is never served by gimmicks and trends. Unfortunately even though the construction industry is one of the biggest factors in our economy and affects everyone directly, it has never been aided by a basic building research program. Its products are primarily the stepchildren of some other need.

Man discovered a metal which he called iron many centuries ago. The Greeks, and later the Romans, were building great buildings approximately 2000 years ago and were very familiar with iron. However, because of its weathering characteristics it was seldom used, and bronze became the popular metal. The use of iron was relegated to a fastening material in unexposed places. It is interesting that Michaelangelo used iron chains to hold the cupola of St. Peter's together but never thought of it as a structural material. This situation continued until the industrial revolution of the 18th century when the break through that created the present industry started. Even in the building trade, the oldest craft known to mankind, the thinking changed to mass production.

The first successful venture was a cast-iron bridge over the Severn river in England in 1775. It had a span of 100 ft. and was a 45 ft. high semi-circular arch. Its structural details were stones but the "stones" were now iron castings. This was all made possible by the development of the first iron furnaces in the first half of the 18th century. This did not seep into building construction until someone thought this might eliminate the many roof fires that were occurring. One of the first examples was the reconstruction of the roof of the Théatre Français in Paris in 1786. This was an arch form constructed by instinct and not by engineering formula. This use continued as roof trussing and auxiliary type of structure until the first significant completely structural iron building in 1818. This was a Royal Pavilion in England by John Nash. The illusion of fireproofing, however, did not last very long before it was realised that even though iron did not burn, it did collapse under the stress of load and heat. Amazingly enough, even today, some 150 years later, most codes recognise timber wood construction as a better fire rating than exposed steel.

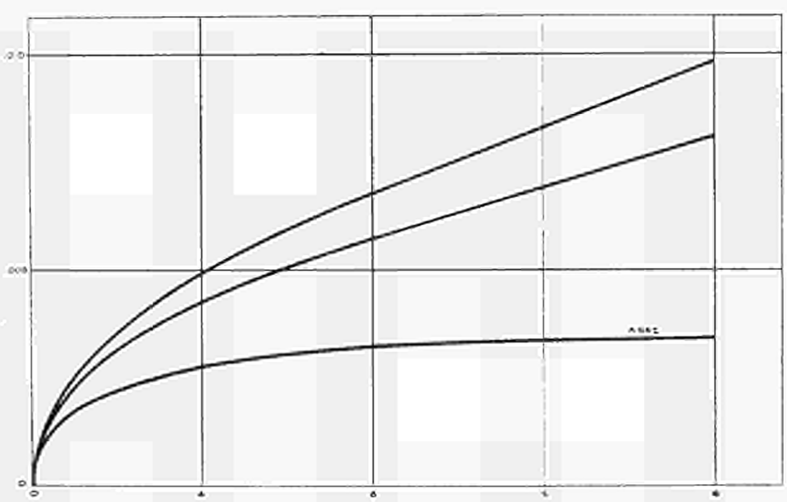
Development continued and the next point was the development of the rolled section in 1830.

Again not a development for buildings but for the railroad industry, for track rails. Although rolled section was ideal for the building industry because of factory mass production rather than field craft construction, good economy, good structural qualities with better ones to be developed, it still had the two basic problems of corrosion and fireproofing. It became a largely used, but concealed structural product. As better alloys were developed and concurrently the elevator evolved, the two factors led to the skeleton structure called "sky-scrapers", so much needed and misused in the development of our major cities. This can be credited to the mind of John Bogardus in New York City in 1848, when building was on its way to its busiest, although not its greatest, architectural period.

Amazingly enough except for a continued development in alloys producing better strength and manufacturing methods producing a more consistent and more economical product, there have been no major breakthroughs. The question has not been what the industry is doing, but why is reinforced concrete making inroads into our percentage of the building volume.

In architecture there is one constant fact, namely, that in the periods of great architecture, the buildings expressed the material and systems of which it was composed and fulfilled the needs of the people. In our present civilization, the leading exponent of bringing steel into this category of great buildings is Mies van der Rohe. Although he made great progress, his efforts were always hampered by the two original shortcomings of steel-corrosion and fireproofing. In the great majority of his buildings it was necessary to cover the structural steel with fireproofing and then cover the fireproofing with another layer of steel to express the structural steel. Not a very clean-cut solution. It was also necessary to protect the steel against corrosion by painting, paint being probably the most unsatisfactory exterior material available, but the only available answer.

In 1956 we received the commission to design a new headquarters group for the John Deere Company in Moline, Illinois, U.S.A. This company is one of the oldest and largest manufacturers of farm equipment. After a careful study of the site, the owner's requirements, and character, it was decided the type of building which would best fulfil the analysis was exposed structural frame with glass infills. However, if we were to do a building of this character, it must overcome all of the existing defects of this construction. Fortunately, the fireproofing problem was solved by not requiring it. The building is situated in the country and is therefore not in a fire zone. It is situated so that fire equipment can be used on all four sides and fire-fighting equipment is close enough to permit the erection of this seven-story, over 250,000 sq. ft. building with exposed structural metal. The more difficult problem was corrosion. The preliminary review led to the easily recognizable answers of stainless steel or aluminium, both of which eliminated themselves as being too expensive, and the undesirable appearance of a shiny silver building. Having eliminated these, there was a feeling that the problem was unanswerable, and design proceeded on an exposed concrete building. Not being satisfied, the metal search continued and found focus on a corrosion graph published by an American steel company. (See following figure.) This graph showed an interesting corrosion pattern: That carbon steel started to corrode rapidly and then decreases but continues at a perceptible rate. A better material is the copper bearing steels which again start at a fast rate and then continue, but at a pace less than carbon steel. The most interesting was a steel which starts rapidly and then reduces to pratically no increase and over its lifetime would form approximately only 2 mils of corrosion material. Even though there was corrosion, the pattern was interesting. The next step was to secure test rack samples of this material to see exactly what its corroded state was like and to get more information. The first sample viewed was over 15 years old. After one clears ones mind of the nasty word "rust," the amazement was beautiful material as only nature can produce.



Comparative corrosion of steels (Moderate industrial atmosphere)

Not an orange rust but a purple-brown with a hundred subtleties that man cannot produce but are available in stones and woods. In retrospect, steel has two architecturally acceptable conditions: (a) when it is first sandblasted when its color is natural with strength, not the slickness of stainless steel, and (b) when it has corroded. Allowing nature to take its course produces the best product because of its color and depth of surface.

Following this conclusion the most interesting step was to sell the owner, a farm equipment manufacturer, and the steel people, both who have spent millions of dollars on fighting corrosion, that it is a superior material. Although the obstacle was not insurmountable, it took a definite re-orientation in their thinking. The steel we were interested in is designated by ASTM as A-242 with a suitable chemical composition for atmospheric corrosion resistance. This composition is manufactured by two american steel producers under the trade names of COR-TEN and Mayari R. In order to avoid trade names we had adopted the initials HSLA (high strength-low alloy) to designate it within our office. Although the types vary slightly they are basically the same. Each has a maximum 0·12 per cent ladle of carbon and slightly varying amount of manganese, phosphorous, sulphur, silicon, copper, chromium, nickel, and one manufacturer includes a small amount of zirconium. In addition to the corrosion resistance the strength of A-242 is higher than A-36, the ordinary structural grade. The yield point is a minimum psi of 50,000 compared to 36,000, the tensile strength is 70,000 psi compared to 58,000 psi, with a basic allowable tensile strenght of 30,000 psi for A-242 to 22,000 psi for A-36. Of interest is the fact that again the building use of this steel is a byproduct. Its original development was for high strength and more durability in things such as coalcars.

One of the most important steps for construction was a full size mock-up to reproduce the various conditions which would occur in the building. (See following figure). Each bent is the material of one of the manufacturers of this type of material. The various conditions under consideration are bolting, this was to see the effect around the head and nut, and area on the downstream side. Along with this is riveting for the before mentioned effects.

Probably the most important test was to see the results of welding with various types of rods plus the effect, if any, on areas adjacent to the welding operation. This shows the result of using the ordinary structural rod which produces a scar. The final selection was a series E-70 welding rod. The E-80 series would have been a better selection, however the amount of difference did not justify the cost differential on this building, of approximately $25,000. This test also showed the various conditions of water run-off and its effect upon beam and column corrosion.

A 242 Steel test bents

In connection with corrosion run-off we studied its problems under beams. The original white paint was put on at installation and a new coat of white paint was applied over one-half of it. After six months this was also studied at the base of columns. From this we evaluated the time to apply finish materials as well as the type of finish materials to use in connection with it. This also gave us directions for detailing at these points.

At this same location, paint test was installed. This was to compare what happened to paint over a similar period of time. Other tests were compatibility tests with materials which would be used in conjunction with the steel, i.e., Neoprene.

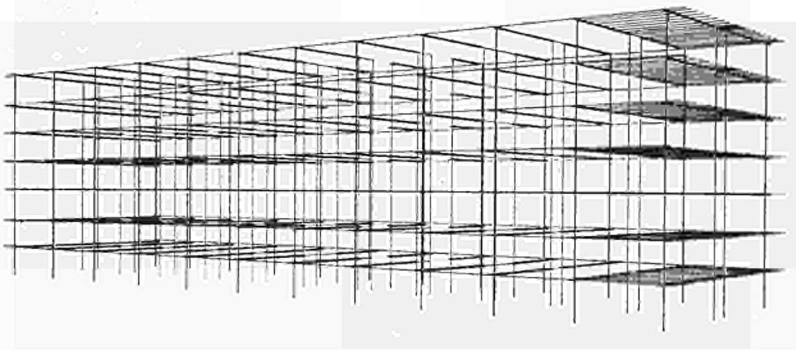
After the results of exposure gave us the technical information we needed the problem was to develop a building using this material as a structural base plus two other materials we were developing, (a) a laminated glass that reflected a large percentage of the heat before it entered the building, and (b) the structural neoprene gasket.

The building which evolved was one of great simplicity which used each of its basic materials to its fullest without additional ornamentation. It began with a structural frame of welded steel 390 ft. long × 90 ft. wide and 7 stories (107 ft.) high. This is a solid unit without expansion joints. An exploded view of this structure is shown in the following figure. The basic structure is 30 WF 108 columns, 21 WF 82 beams and 10WF 29 joists. To this basic structure was added a sub-structure (see first figure, p. 295) of 6 B 12 mullions and plates which were structural as well as the basis of the glass enclosure. The final enclosure (see figure, p. 296) was simply installing neoprene gaskets on the steel and putting glass into the gaskets without the usual addition of a window frame. By this system we have eliminated a trade, the curtain wall manufacturer, by simply applying glass into the structural frame. Also by this system, all expansion and contraction is taken up within each 6-foot module rather than accumulating. To all of this added the illuminous ceiling and air conditioning equipment on a modular basis and the floor and return air.

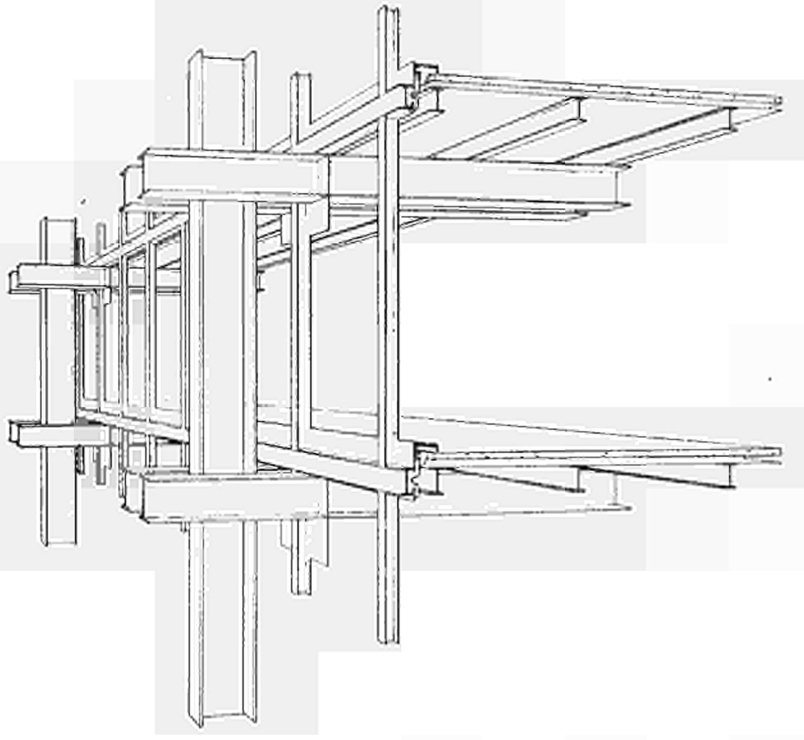
Upon resolving all this, one final mock-up was erected. (See illustration 1, p. 301.) This consisted of one bay plus 6 ft. (one module) on each'side of the bay. This was to study all final detailing including connections which were to be all welded and breaking of material, sizes and thickness of material, and in addition, provide space to study interior details, spaces, and furnishings. Fate and the unions interfered on this project and somewhat reduced its value. A steel strike made it impossible to get the proper sized members in A-242 steel so that A-36 steel from stock was substituted and painted because time was running out on us.

The result of the final test is the building shown on illustration 2, (p. 301.)

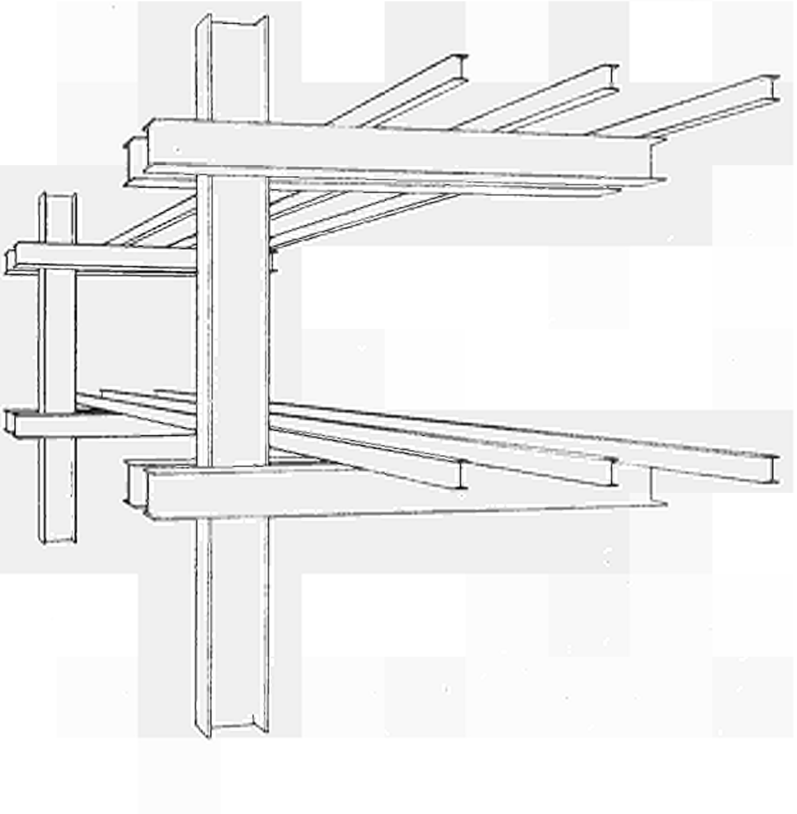
Since the completion of this building group which we feel has been very satisfactorily receiving the top A.I.A. (American Institute of Architects) award for 1965 and also the top A.I.S.C. (American Institute of Steel Construction) award for 1965, we have been searching for further advances, such as can the oxidation be accomplished before construction and accelerated (much as is done in anodizing aluminium). This would provide



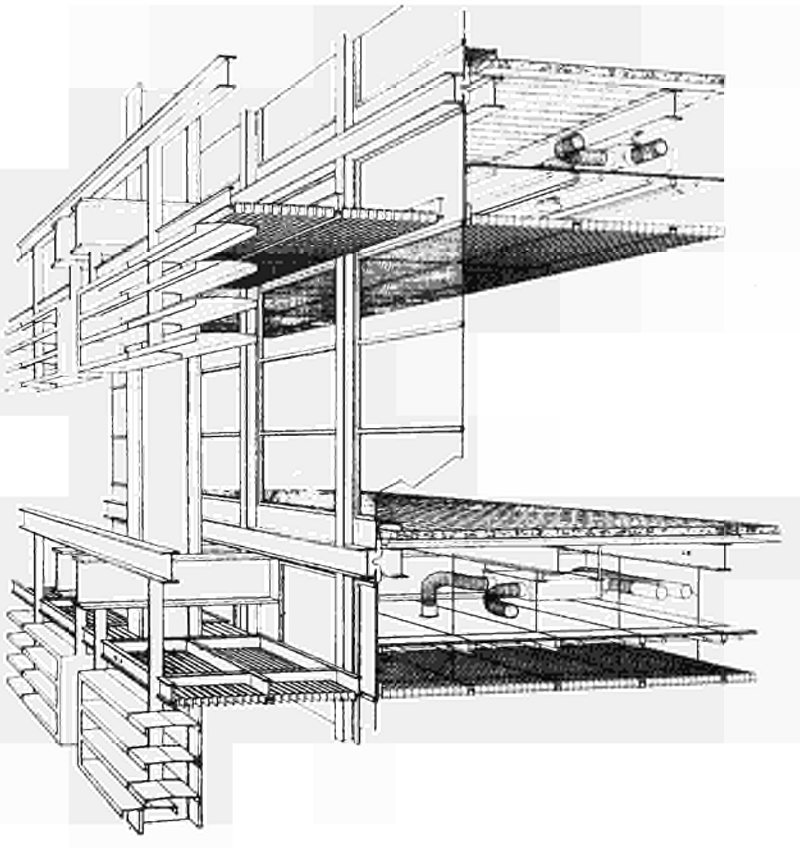
Schematic structural framing



Deere structural detail



Deere sub-structure

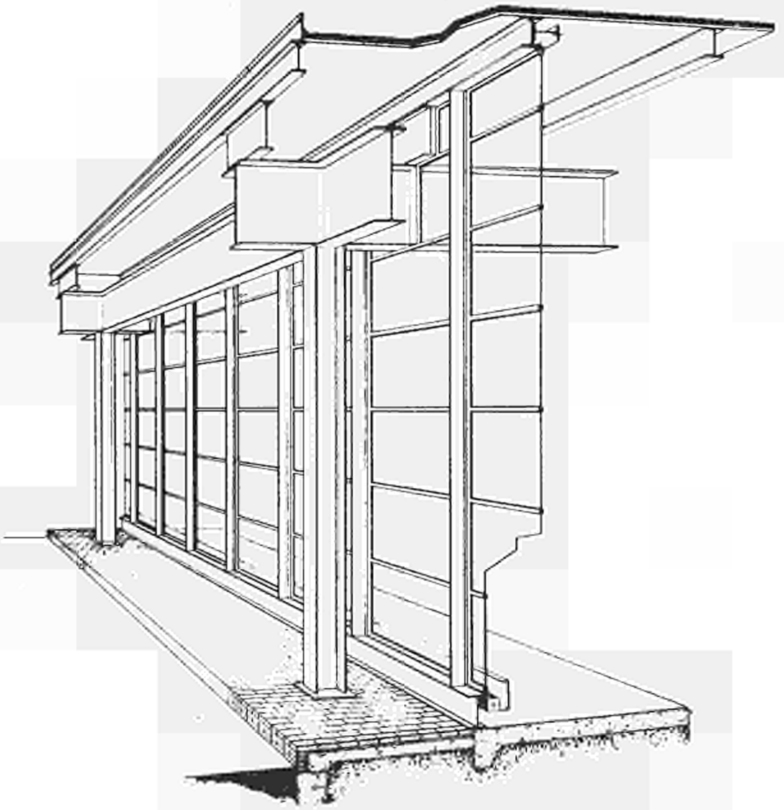


Deere total enclosure

a better product easier to erect, visually much more acceptable, at an early date. Also, what are the ramifications when not used as a structural material and in conjunction with a wider range of other materials? To this end we have conducted a series of tests that are directed towards pre-oxidizing simply by wetting several times daily, and several ways of protecting stone (granite in this case) from the early products of corrosion. This is best seen in the wet condition where it is easy to define the treated and non-treated surfaces. This experience is being used on an office building in New York City for the Ford Foundation. On this particular building, because of codes, the A-242 is being used only as enclosure wall, not as structure. In this case it is used in conjunction with large granite surfaces to enclose a court which is 165 ft. high. 33 WF 141 are turned on their sides horizontally to resist the wind pressure and support the small vertical members which form the exterior wall. Again glass and gaskets fill the final void.

The last project is a factory being built in Darlington, England for Cummins Engine, Ltd., large manufacturers of diesel engines. This was designed to create a building which had good working conditions and maximum flexibility for manufacturer's changes in the most direct manner possible. (figure below) Here again is a simple, direct structural system of 30 ft. × 60 ft. bays comprising a building 500 ft. long and 320 ft. wide. Provision has been made by the use of small blocks to create a space for utilities which will be changed quite frequently. Again the structural frame to receive gaskets and glass. In this particular case similar construction of steel I beams, gaskets and glass are being used for all interior partititions. This all has one difference from the previous example and that is the grade of steel. It was not possible for us to obtain a steel similar to the ASTM A-242 in England. After much study we decided to proceed using a steel similar to ASTM designation A-441. The basic difference between this and A-242 is that it does not contain any nickel, but does have vanadium. Although the corrosion record of this material is not as stable as the A-242, we believe for the size members and its use, it will be entirely satisfactory material. Already the corrosion color and pattern is better than we have witnessed on any steel, a point I would like to elaborate on later. We hope this will start an entirely new direction in factory design which is much needed in this era of progressive manufacturing and employee's relations that we live in. All of these advantages are microscopic in terms of what can be done and has to be done. We are, each one of us, a member of the most important team on earth — the producers of buildings, buildings which form man's environment from the time he wakes up until he again goes to sleep. Without his realizing it, these buildings play a big part in shaping his outlook. They surround him constantly, his house, his working place, and they line the paths he walks in. I believe we take this responsibility too lightly. It is more important than landing a man on the moon. So let us compare our progress to the progress in space. The building industry and development started when man left his cave and found he could make a more desirable house by bending branches for a structural system and covering it with leaves to keep out the weather. This probably was millions of years ago.

Man made his first powered flight in 1908 when the Wright Brothers flew 125 ft. Sixty years later we will probably be putting a man on the moon.

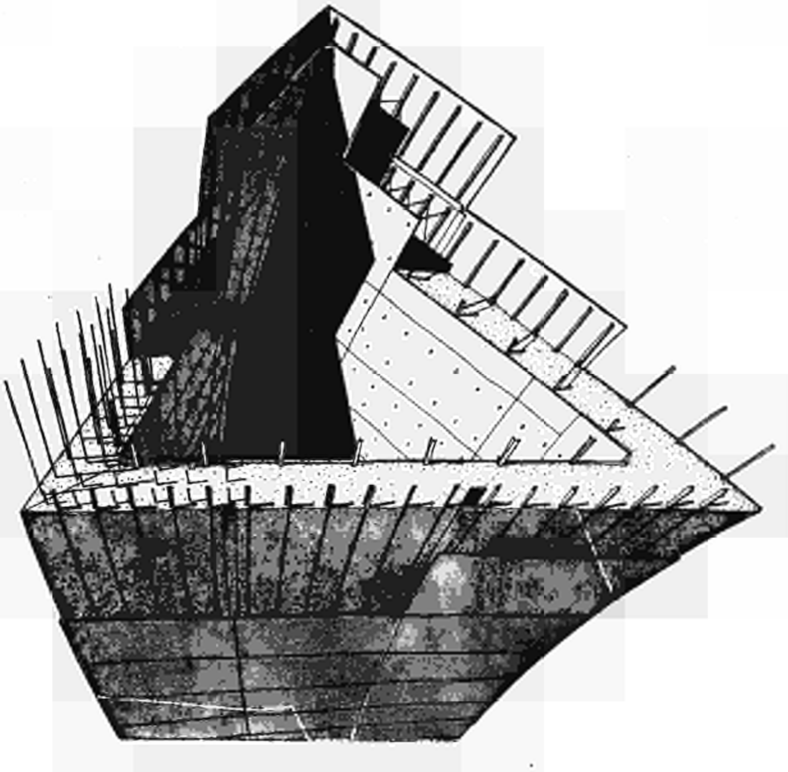


Cummins cut away section

The last significant development in the construction field was the development of the steel rolled section much before the 20th century. There is not one of us who can raise his hand with pride and claim any great breakthrough or real effort in that direction. Certainly there are great research departments and they are doing valuable work in manufacturing development, quality control, and better alloys, but the world of mankind desires something greater than this. Back to minor examples, the using of weathering steel. Not one thing has been done to take this basic idea and really carrying it much further to a superior idea. The entire effort is in selling it and deciding what all of the problems are. Nothing of significance has been done to improve the fire rating of steel since the problem was first discovered centuries ago. There are many unexplored possibilities such as composite construction if we can lose our pride and admit concrete is a good material in its place. In St. Louis we are building a memorial to our westward expansion. This is a weighted gateway arch 630 ft. high and 630 ft. across the base. The original proposal was to do a conventional steel skeleton frame and bend it. (figure below) However, even though it could work, it doesn't make sense to torture any material in this manner. The final solution, as it is being built, is a composite construction consisting of an outer stainless steel skin and inner carbon steel skin filled with concrete and strengthened by post tensioned rods. In this structure each composite is working to its fullest capacity in its ideal location. The cross brace is for construction purposes and will be removed when the top is closed.

One last plea for the new face of steel, and that has to do with housing. The most important place to any human is his home. Here is the basis of all human dignity. It is absolutely unforgivable that at this late date in the existence of mankind that there is not a manufactured steel home that provides for all human needs better, more economically than any house available today, that, also, can be shipped even to the moon.

We have a great task ahead of us so let us face up to it. We need solid progress, not gimmicks or trends. Big ideas, not small.



Composite Construction

Jacques M. DEFRANOUX

Weather Resisting Steels for Architectural Purposes

(Translated from French)

Stainless steel has been criticised here for having too polished and too bright a surface appearance —one which is said to be disadvantageous in its use for buildings.

A surface appearance of this sort would certainly be undesirable for large surfaces as would be produced, for example, by the simple juxta-position of sheets, particularly those with a 2 B finish, as delivered from the steelworks.

The ingenuity of, and ready cooperation between manufacturers and architects—given a free rein—have now remedied this in many ways as listed:

(1) Use of panels made from sheet with a matt finish such as 2 D (sand-blasting is not usually advisable, for reasons of corrosion resistance).

(2) Contrasts in adjoining finishes, presenting an appearance similar to that of marquetry or mosaic.

(3) Use of sheets with a " worked " surface, i.e. with undulations, corrugated patterns, etc. These sheets are commercially available in large sizes (up to 1 m. by 3 m., at least). Their patterns diffuse the light instead of reflecting it, and the sheets do not, therefore, present the polished and bright appearance so often associated with stainless steel.

(4) Use can also be made of stainless-steel panels coloured by chemical or electrochemical processes, particularly matt black (" ebonized ") panels, etc.

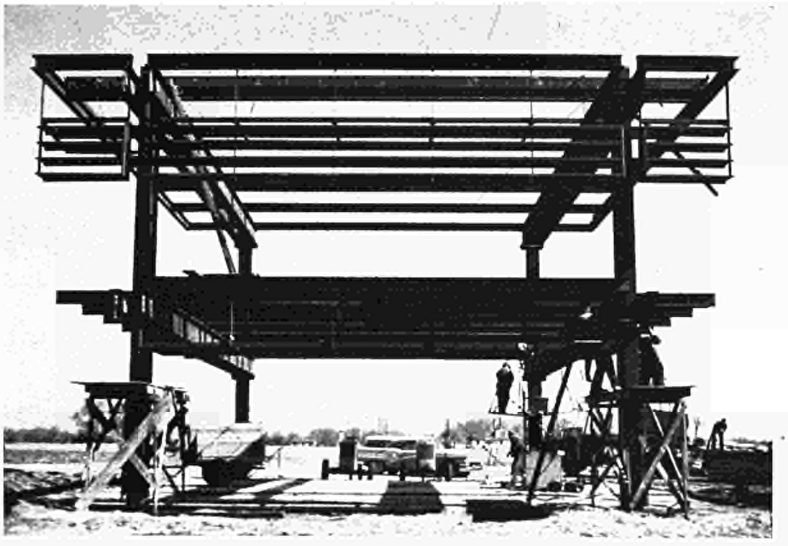
Alternation between these different surfaces, or alternation of stainless steel with other materials, together with a pleasing lay-out for all the component parts, produces a large variety of effects and gives the architect almost unlimited scope.

A combination of stainless steel with the " oxidized " steel which has just been introduced would perhaps, be very interesting, taking into account, of course, the siting of the building, its functional characteristics and the architect's tastes.

Certainly, buildings where stainless steel is employed are no longer a rarity, either in the U.S.A. or in Europe. The metal is seen in the form of small wall-panels, curtain walls, shingle-boards, coverings for other materials, decorative panels and frames, roofing, and guttering of different sorts. Stainless steel has been used everywhere: in office buildings, in industrial buildings (power stations, factories, etc.), air-terminals, exhibition halls, schools, and residential buildings of various kinds.

Some well-known examples are: the Millbank Tower in London, the Paris air-terminal at Orly airport, and above all the Empire State Building and the Chrysler Building; the latter were built about 1930 and remain as eloquent testimonies to the aesthetic qualities and durability of stainless steel.

List of Illustrations



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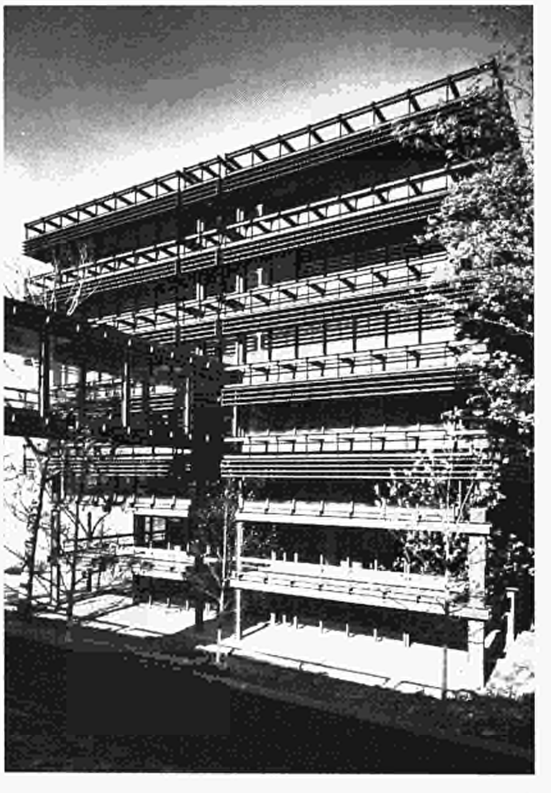

2

Mario SIGNORA

Surface Finish of Stainless Steel: its Preparation, Preservation and Maintenance

(Translated from Italian)

A discussion on stainless steel really amounts to discussing its surface and the nature of surface characteristics. The fundamental importance of surface appearance is a headache for the producer; he sees production costs considerably increased owing to expensive equipment being needed to obtain the required surface finish and because of the time-consuming processes which have to be carried out, the care needed in the operations, and the amount of material which has to be scrapped.

The High Authority of the E.C.S.C. has therefore well chosen, within the overall theme of the Second Congress "Progress in Steel Processing", the title of this brief review which I have the honour and privilege to give before this highly qualified audience.

The motto of the High Authority on this and other occasions is "Better Production and Better Utilisation".

This exhortation, the two parts of which must not be separated, is not merely a part of the stainless steel story, it is the whole essence of it.

In this review, I shall not follow the usual systematic methods of a "paper", with its formal chronological arrangement and its analytic basis. Instead, I shall try to include, in a context of subjective and sometimes personal views, most of the topics relevant to the theme of the Congress.

In any case, exhaustive review of the many innumerable surface grades of stainless steel, which are as numerous as the different requirements of individual users, can easily be found in the valuable and comprehensive scientific works published by the various steel makers, and this publicity material is readily available.

It is my view, a personal one, of course, that in all hotworking processes, including the very skilled techniques used in melting, pouring, conditioning, heating and rolling, there are no essential differences between stainless and other types of steel, special or otherwise, whereas all cold-working is fundamentally different in the case of stainless steels.

Obtaining a high quality surface (and sometimes absolute perfection of the surface of this product is a basic requirement) and the whole technique of processing requires a mixture of advanced craftmanship, clever and perhaps imaginative inventive ability, an intuition for solving unforeseen problems occuring in the complex plants, a delicacy of touch like that of an explosives maker, accurate control of the quality of all materials used, and many other things.

Each time I look at the complicated produres in the works, I recall the problems and difficulties I used to meet as a young graduate preparing metallographic specimens. I renember the emery cloth of multi-O grades, the precise technique for the careful elimination of scratches produced by the coarser grades previously used, the avoidance of any heating of the specimen, the absolute cleanliness and everything having to be just so, the delicate handling — and then at last, under the microscope, very often a disappointment and the need to try again.

The re-preparation of a specimen however is nothing compared with that of a hundred-metre roll of metal, or of several dozen sheets, downgraded and plastered with labels at the factory exit. There is no comparison between rejects and downgradings due to appearance and those due to inadequacy in mechanical properties or in corrosion resistance.

A hundred times a day, the inspector is faced with the choice — reminiscent of Hamlet — To despatch or not to despatch?

This is where the second part of the High Authority's motto — "Better Production and Better Utilization" — calls for consideration. It is this theme that I would like to deal with in my review.

The American term "Usable but Cheaper", which can be justified in every technological field, is a commercial necessity in dealing with stainless steels, especially when supply and demand are out of balance as at present.

In these recent long and difficult years, we have had a buyer's market.

But is it in the common interest, either inside or outside the Common Market, to ask for considerably more than is necessary just because it is given gratuitously in the conditions of ruthless competition existing between the different producers, who are sacrificing their economic due — a price differential — in this struggle?

Is this wastage not to the disadvantage of both parties and to the considerable economic loss of the community as a whole?

Is the provision of a "perfect" finish on both surfaces of a sheet of steel to the advantage of the user if it is going to be used in making a wash-tub which, after being pressed, cleaned and finished, is going to be sprayed with a sound-absorbent coating, so that its stainless surface will no more be seen?

It may be an apparent advantage for the fabricator to be able to utilize the other surface of the material when, because of bad storage (how many times have we seen batches with a 2B extra-fine finish, on both sides, parked out in the open!), one of the surfaces is damaged by incorrect handling. But what is the cost to the producer of this convenience for the user? It means a reduction in the "despatchability" of the material by 50%; raises problems of downgrading and a consequent unjustified loss of profit; an increase in second-quality stocks, and extra material to be stored; if sold cheaply, it provides an opportunity for the retailer to get an incorrect profit. In other words, for a reason that cannot be justified, it precludes reasonable differentials in the price of stainless steel, and puts the costs and profits for each quality out of balance.

A hollow-ware manufacturer who, for example, has to use a heat treatment in the operation of pressing because of its difficulty and depth, should never ask for stainless sheet with both faces absolutely perfect (that is, not even a surface scratch or small rolling defect, or some slight pin-point mark), though this may be in order if pressing is done without intermediate annealing. In fact in the first case, because of the oxide which forms during the heat treatment (which is given to eliminate work-hardening during drawing), he will have to have a polishing operation which will certainly remove any slight defects which might have been present in the sheet beforehand.

The saying "I'll have the best — it doesn't cost me any more" involves a loss for everybody in the long run.

Efficient manufacturers known all this of course, but do all manufacturers know it? And what do they do if specifying perfect sheet every time will simplify their stocks and their ordering?

These are matters which everyone should think about.

Once a tendency of this sort has, quite wrongly, become general, the necessity is automatically created for dealers and stockholders to demand for stock only material of the highest quality, without blemish on either surface.

This material will then most likely be used only in part for those applications where high quality is essential, and a large amount of money is thrown away because of this unjustified requirement — a waste which apparently does not only affect the user.

The same sort of thing happens when goods are squandered which are the property of the State, or of the community. There is only an apparent absence of payment, and the wastage is paid for, or has already been paid for, by the individual.

Experience gained up to now compels me to state that the problem would certainly be kept within bounds if the Common Market, and European customers, acted on the lines of those commonly adopted in the U.S.A., or at least if greater understanding and collaboration were established between customers and producers; there would then be advantages to both parties.

But I have been talking about the application of stainless steel before making any mention of its various qualities of finish; these qualities, as you all know, are designated by a system of numbers.

I shall mention briefly the essential characteristics which distinguish the various finishes from each other, but I am not going to tell you how stainless steel is produced! Too many of us are making it already!

But to be serious — it must be admitted that, for the very diverse qualities of surface finishes in which steel flat products are available, different production processes are encountered. These methods are decided upon by each producer firm on the basis of its own experience, its own opinions, and the different long-established relationships with the customers; the methods favoured determine the type of plant used.

The requirements relating to surface finish being, as we have said, very diverse, it is not possible to formulate very precise rules for application to stainless steels.

If one considers surfaces finished by cold rolling, as-rolled or subjected to heat treatment or various polishings, the final result after pressing or drawing, etc. will in fact be that decided upon by collaboration between makers and users, very often after practical tests.

We all know that the surface appearance, for a given designation (e.g. 2B), is different for the two main classes of stainless steels, the 300 and the 400 series. We must bear in mind, too, that the surface of the product depends very much on the number of cold-rolling passes. For a given final thickness, the surface resulting from a small original thickness is different from that resulting from a large one (owing to differences in the compression of the material). In general, the working processes used must depend both on the customer's wishes and on the type of equipment used by the producer.

When a customer has to choose a stainless steel for industrial applications in which the most important requirement is, say, refractoriness or corrosion-resistance (they will therefore, for the most part, be technical applications), surface smoothness will not be of special importance as the material is not normally polished. In such a case, No. 1 finish (IIa in Germany) will be chosen; this is the finish obtained by hot rolling to the required thickness, together with solution heat-treatment and pickling.

This finish is not correctly termed No.1 in the case of plate, because, in AISi standards, this designation is confined to hot-rolled annealed and pickled sheet.

We all know that, for both sheet and plate, and particularly in cases of very large widths, local rectification by grinding, sandblasting or brushing is permitted. A word of warning here — every trace of iron left by brushes or other tools made of or containing iron, must he carefully removed.

Whenever flat products in stainless steel are to undergo deep drawing followed by polishing, finish 2D (D signifies "dull") is recommended (in Germany, IIIb). This dull finish is particularly advantageous in the pressing process, as it enables the lubricant to be retained on the surface of the metal during the stretching and drawing which take place in this operation.

The dull finish is obtained by a final cold-working followed by annealing and pickling. A more uniform finish can be achieved by passing the material, when it leaves the heat-treatment and pickling production-line, through tempering cold rolls for a final light pass, using rolls sandblasted to a dull finish (2D special). This variation in the process, which gives surfaces slightly different from those of the normal 2D, and also different among themselves according to the grain size used in the sandblasting of the rolls, necessitates close co-operation (including practical tests) between customer and producer to obtain the most suitable choice for the particular manufacturing operations used by the customer.

When, as in the majority of cases, a normal finish without too long and costly a polishing process is required for the normal general type of finished product, the surface finish called for is 2B (B signifies "bright").

It is not, however, called for in the more difficult cases of deep drawing, because it is slightly harder.

With this finish, the material has a bright, dense appearance, obtained by cold rolling, annealing and pickling, as in the case of 2D, but with the addition of a light rolling in the tempering mill with polishing rolls. This is also the finish generally called for when a mirror-finish is required in the finished end product, in which case the notation "buffing quality" is added to 2B.

In this large family can be found surface finishes, for various aesthetic requirements, which are obtained by using tempering rolls ground with coarser wheels such as No. 120, instead of the No. 500 normally used.

This gives a special 2B finish constituting an alternative to No. 3, which is normally obtained by linishing the material, using grain size No. 120 or, sometimes, No. 100.

The finishes mentioned so far can be classified as "finishes *without* polishing." Those which follow are "finishes *with* polishing."

Finish No. 3, which we have already mentioned, is an intermediate finish used when a semi-polished surface is wanted which has to have a final polish during the manufacture of the end product.

Although linished, it is not much different in cost to 2B as, though requiring an additional operation, it permits the recovery of material which, because of slight marks or inclusions, would not warrant 2B standard and would be rejected.

If the material is successively submitted to the action of abrasives of decreasing coarseness, down to a final one of No. 180 or perhaps No. 240, then No. 4 finish is obtained; this is very consistent, bright, and has good reflection. It is generally used for equipment in restaurants, bars, kitchens, dairies and hospitals, and for internal and external sheathing in building applications. To obtain a good No. 4 finish, the material must initially be absolutely free from defects because the action of grinding reveals rather than hides defects such as inclusions, etc. It is to be hoped that No. 4 finish, with No. 3 and variations of both, will gain increasing favour in Europe. In the United States, a leading user of stainless steel, 50 to 60% of all that is sold is polished or buffed to a finish ranging from No. 3 to No. 8, and 70 to 75% of this amount is No. 4 finish. We must keep this in mind as a justification for some views that I shall express later.

To complete the picture, I must mention Nos. 6 and 7 finishes. They are, however, not in great demand, and are based on No. 4.

No. 6 is a dull satin finish, less specular than No. 4, and is obtained by treating No. 4 with Tampico revolving brushes, abrasive powder of the desired grade, oil and grease. It is used because of its subdued lustre, which contrasts with the bright finishes near it.

No. 7, on the other hand, has a high degree of reflectivity; it is obtained by polishing No. 4, but without eliminating the lines made by grinding.

There is also a No. 8 finish. This gives the maximum amount of reflectivity, and is obtained by carefull linishing with No. 600 abrasives, and then finishing with suitable extremely fine compound and cloth brushes. Obviously, this finish should not be adopted, for reasons of cost, when the material is to be pressed, formed on the lathe, or subjected to other similar operations.

All these numerous and varied types of finish (and there are others, obtained by combining the methods mentioned or other methods, and called hybrids or bastards) are successfully used in building applications and for decorative purposes, and give pleasing contrasts.

Perhaps I should have explained before, that the classification described applies only to sheet and thin plate, supplied in cut lengths or in rolls; it thus applies to the greater part of the tonnage of stainless steel on the market.

For strip, i.e. widths under 600 mm. in the U.S.A. and under 500 mm. for the E.C.S.C., supplied as strip or in rolls, the classification is simpler, though more exacting. Nos. 1 and 2 finishes correspond, respectively, to Nos. 2D and 2B for sheet. The finish of the mill rolls for No. 2 (strip) is, however, finer than that for No. 2B (sheet) finish.

But dwelling on the subject of classifying strip will not add anything new to what has already been said about sheet.

The limitations imposed on this paper mean that I shall not even mention the surface treatment of ground or polished round bar, or that of square, hexagonal, flat and special-section bar, as our talk would be prolonged and of no great interest. The same applies to tube material, for which the finishes correspond to the grade numbers of the abrasive bands used in linishing, or to the dull finish of pickled material.

There is no classification for wire, the finishes being determined by the manufacturing process itself.

Returning to our flat products — sheet and thin plate — we shall, for a moment, consider again the economic concept and its Siamese twin, the appropriate application of the product. Once it is decided that to manufacture, for example, a tray, it is necessary to have a special 2B finish with a complete absence of defects, the only thing to do is to make the material as requested; that is, it must be without blemish on either surface, and the price to be paid must correspond with the work involved and with the choice made. But if this same type of steel is to be used for a coffee-pot or thermos flask, for example, where the internal surfaçes are not visible and have little importance, a very brief calculation of the financial returns against the costs involved will be enough to show the absurdity of using this type of steel.

Let us suppose we have a normal working procedure, with its normal amount of wastage due to various losses on the production line, cutting losses, start-up losses, and scored rolls, leaving us with 100 sheets of 2B. Then on final inspection, we have:

Sheets inspected	**100**
scrap	5
downgraded	10
2B standard	85

If we want a minimum of one face absolutely free from all defects, the figures become:

Sheets inspected	**100**
scrap	5
downgraded	20
2B extra standard for 1 face	75

And if we want a perfect 2B finish on both faces, then:

Sheets inspected	**100**
scrap	5

downgraded	45
2B extra standard for both faces	50

Let us now look at the position with regard to the relative costs of these different standards. Assuming the production cost for 2B is 100, then:

No. 1 finish will cost	80
" 2D " " "	90
" 4 " " "	120

and again with 2B assumed to be 100:

2B, one face "good"	120
2B, both faces "good"	135

What does the customer think of these figures — the sort of customer who wants the moon, and nearly always wants it free of charge, so that the producer has to carry a considerable and sometimes intolerable burden?

Is it right to demand such a large waste of resources, merely to provide greater flexibility and convenience in the stocking of the material? Of course it is not!

It would therefore be so much better for the conservation of our common resources if we did everything possible, in accordance with the principles already stated, to provide the steel with a surface-finish quality to suit the *true* needs of the particular application, through a sincere, trusting and extensive collaboration between customer and producer (the same applies, of course, to all the other characteristics of the material). This would be reflected not only in an advantage to the producer, but also to the user in that prices could be revised in accordance with the new cost of production.

This is why it is always of fundamental importance to know the purpose for which the material is finally required, information which is extremely difficult — and seemingly impossible — to obtain in our countries. Please let me insert some relevant reflections at this point.

In the U.S.A., "end use" is a commonplace matter in communications between producers, dealers and finished-goods manufacturers. Here on the Continent, it is the subject of continual telephone conversations, endless telex messages, and eternal bickering between the works, the office, and the customer or agent.

In the U.S.A. — and I repeat this because I believe that it is essential for the appreciation of what I am saying — there is a spirit of understanding between users and producers of the material which is completely unknown in our countries. There, when there is a defect, the customer himself indicates to the producer the extent to which replacements are *not* required, that is, the extent to which the product can be used for the required purpose without loss to himself or detriment to the quality of the end product, and also without the producer being ashed for an excessive discount because of additional processing requirements.

This seems, especially for us Europeans, a state of perfection, but it is the only sensible and prudent way of doing business because it is to the advantage of both parties.

It would largely eliminate cases in which customers require material for deep drawing, or for forming on the lathe, which is without blemish on either surface and perfectly flat, and others in which they make impossible requests such as hot-rolled plate for mirror finishes or perfect flatness in very thin sheets measuring 0·8 by 1200 by 4000 mm., or again cases where they ask for 316 material of buffing-quality and electropolishing type.

I am so convinced about the importance of this co-operation between customer and producer that I should like, with all due respect, to suggest to the High Authority (if I might be so bold) that it should use all its influence to create an atmosphere of co-operation between the two parties by arranging symposia, meetings or informal cocktail parties. Customer and producer would then come face to face, and the opportunity would be created for discussing honestly and without inhibitions the mutual problems, both economic and technical, and perhaps for arranging carefully-conducted tests for determining the relationships between the various qualities of material and the different requirements of the end product. Further, there would be the opportunity of arranging visits to the U.S.A. by European producers and consumers, which could lead to talks with their trans-Atlantic opposite numbers on the lines of that felicitous idea arranged in 1951 within the framework of the First World Metallurgical Congress at Detroit. Truly surprising results would be achieved.

Another fortunate state of affairs in the U.S.A., and which is also desirable in Europe, is that concerning the development of applications for polished stainless steel with finishes in the No. 3 to No. 8 ranges. This would sometimes allow, e.g. in respect of No. 3 finish, the reclaiming of excellent material which would otherwise be scrapped in the last stage of production because of very minor faults in handling or because of insufficient care during the various operations.

The architectural field, which is viewed in such different ways by those in a position to judge the applications of stainless steel, is not yet developed here to the same extent as in the U.S.A. It could benefit from the use of the wide range of finished and combinations of these finishes; in other words, this is a market that should be actively developed.

There was an amusing instance in the U.S.A. which illustrates the power of persuasion and propaganda. In that country forty years ago, the market for timber for high-class work required that boards and planks should be entirely free from knots. You can imagine what trouble and wastage were caused in order to satisfy the tastes of the buyers. The idea was then slowly and steadily propagated that the presence of knots in the wood relieved the monotony of too much uniformity of surface, that the knot gave a more realistic and pleasant character to the product, and so forth. Now, "knotty pine" has become a wood of high esteem.

The makers of coffee machines, lifts, door and window frames and bar counters should bear in mind the effect given by a suitable juxtaposition of different finishes. The same applies to "rigidised" plate material. Here again, there is a market to be won.

In a continent, or rather in a world, where supply exceeds demand as at present, what solution is there if not that of forgetting all about a gradual and orderly increase in consumption and following the course pursued by those countries foremost in the consumption, per head, of stainless steel? New applications should be investigated in the very places where normal use of the material is already high; the more ordinary products (good ones, not rubbish) should be distributed in the depressed and backward countries where stainless steel is not appreciated because it is little known. The old idea that stainless goods cost too much will not be an obstacle in such market penetrations.

These efforts must be made collectively by all producers, and it will be no bad thing if here again the High Authority provides the nucleus for a great drive to create new markets and extend the existing ones. I mention in particular, because of its great importance, that there is no substitute for the hygienic qualities of stainless steel in the dairy, cheese and culinary industries, the food industries in general, and the preserves industry in particular; it has no substitute in the transporting and storing of these commodities. Much is being done at present, but much more remains to be done.

The energetic activities, far-seeing and far-ranging, which have taken place during forty years in a well-known light-metal industry, and the consequent formidable results (of which you are all well aware) should be instructive.

I must mention something about bright annealing, though I do not think it necessary to say much about this. It is done by passing the material through a continuous annealing plant in a protective atmosphere. The main points in relation to the reasons for the success of bright annealing are listed here:

(a) As there is no formation of scale, the material does not undergo pickling and its surface is therefore more compact;

(b) the surface of the metal must necessarily contain greater quantities of chromium than those conventionally annealed, there being no oxidation;

(c) for a given tonnage output, the cost of the plant is less than that for normal annealing and pickling.

These advantages are not felt so much in the U.S.A., as 50% of the production in that country is sold with finishes in the 3 to 8 range as already mentioned, and the difference in surface quality is therefore not such an important characteristic. Where the advantages are of less importance, it is difficult to determine the tonnage which would justify the installation. This problem is not easily solved with plant of this type, as the solution is closely bound up with the length of stops between one production run and another, and this in turn is related to atmospheric conditions which may cause difficulty in achieving the correct "dew point."

We might deal very briefly with the protection and maintenance of stainless-steel sheet surfaces. This is one of the greatest worries for producers during production, despatch and storage. The paper used for protection during the various forming processes during production amounts to some 5 or 6%, and sometimes even more, of the weight of the finished product.

The prevention of scratches during handling, of marks due to dust, midges and other foreign matter, and of scoring by the guide rollers, is a continuous problem. The weapons in this contest are paper, flannel, leather, asbestos and scrupulous cleanliness.

Care is needed to see that the paper or cardboard used for protection does not contain any moisture. Although the paper mill is required to use the maximum care to ensure that the paper material is neutral, any water content coming into contact with the metal will, in time, discolour the finish or cause the paper to adhere in such a way that it is difficult to remove without ruining the finish.

Some finishes, especially those ground and polished, are protected by adhesive paper which can be left on the steel throughout the manufacturing operations and taken off only after final assembly of the end product. More usually, such protection is provided by spray application of plastic substances dissolved in suitable solvent.

It is not necessary to say much on the importance of packing.

We all know how much is spent on protective measures for transport and storage.

I must, however, make a point of mentioning the storage of stainless steel sheets.

Dust, dirt, particles of iron, and moisture are the bitter enemies of stainless steel surfaces. Moreover, when sheet remains in store a long time waiting to be converted into the end product, the adhesive paper must be periodically inspected to ensure that it can be readily removed when required.

The removal from the finished product of paper which has become stuck, or of adhesive paper that has hardened, is both troublesome and costly, and the same is true for substances applied by spray.

Any infiltration of water through cement or mortar will, because of the chloride content, cause very serious damage to the metal surfaces.

I have dealt, if only briefly, with finishes for flat products. These finishes are, of course, required to retain their surface characteristics, obtained by such diverse and careful methods, in the manufactured articles.

A perfect final finish immediately attracts attention and provides an assurance of high-quality work at all stages.

The stainless steels keep their bright surface-finish better than any other metal. This is why paints and other protective coatings are very rarely recommended. Bare surfaces of stainless steel are, furthermore, the most practical to handle and easiest to clean, and are thus most economical to maintain.

Methods analogous to those already described for flat products are also used for polishing end products. These are: machine grinding (coarsest abrasive below grade 100), polishing (with finer abrasive), brushing with Tampico fibre, buffing with cloths and very fine powder, electrolytic polishing, tumbling, and sand-blasting both wet and dry. Dark and dull surfaces can also be obtained, by chemical and thermal treatments.

Because of the low heat-conductivity and high coefficient of expansion of the austenitic steels (about half and double that of ordinary carbon steel, respectively), grinding and polishing must be done very carefully to avoid overheating; this would be detrimental to corrosion resistance, and cause distortion in the case of thin articles. For efficient removal of metal, the important factors are: brush speed, steadiness of the work piece and type of abrasive. The pressure used must be as little as possible.

In general, there is little difficulty in maintaining the surfaces of stainless steel in their original condition. Those who use kitchen utensils know this quite well. Hospitals, with their strict standards of cleanliness and, very often, insufficient staff, solve the problem by the extensive use of stainless steel.

Ordinary, regular cleaning is the most practical and satisfactory procedure. This should be done with weak cleansing agents and soap and water, followed by rinsing and drying.

Any use of abrasive cleaning agents to remove discolourations and obstinate stains should always be done by rubbing in the direction of the original grinding to preserve the original finish.

A word of warning about cleaning. It is absolutely deplorable (though it is often done) to use brushes of ferrous material. Many complaints, disputes, and disappointments would be avoided if this advice was followed.

We now come to the final topic: two serious defects closely (though one of them not exclusively) connected with stainless steel surfaces. These are "inclusion lines" and "roping", and no talk about the finishes of stainless-steel flat products would be complete without a reference to these two phenomena.

They are a veritable disease, and are the cause not only of rejections and downgradings but also of many complaints being made to the producers by the users.

The first one, inclusion lines, concerns austenitic steels and in particular types 302 and 304, chiefly when they are intended for articles where surface appearance is very important. The defect is seen macroscopically as lines of either a dark or a light colour, according to the way the light falls upon the surface of the metal. The lines are parallel to the direction of rolling. Microscopically, the defect is seen as linear groupings of grains of material; the grains are so fine that it is not always possible to relate them positively to the presence of extraneous material in the metal. In the more serious cases, these inclusion lines can be more than 10 cm long and almost a millimetre wide. The number of them in a sheet can sometimes be considerable.

The trouble certainly has its origin in the steelworks. Many studies have been carried out, both in the U.S.A. and in Europe, with the object of understanding and eliminating this very grave defect. In some cases, success has been achieved in reducing it both in size and in frequency, but we are still very far from eliminating it.

The second of these two defects, "roping", affects the ferritic steels, in particular type 430, the type most used. It is essentially a macroscopic phenomenon of local deformation. It is seen during pressing, and is also met in the laboratory after a plastic deformation such as the stretching of the metal in the rolling direction. The defect originates in the steelworks during processing of the steel and during hot rolling. This defect, also, can be slightly reduced, either by adding certain elements to the steel or by the method of hot rolling, but it still constitutes a serious limitation in the use and production of 430 steel.

François DELATTRE

User Specifications as Regards Surface Finish of Stainless Steel Plate, Sheet and Strip

(Translated from French)

Mr. Signora is completely justified when he calls for closer co-operation between producers and users of cold-rolled stainless steel plate, sheet and strip with the ultimate use of these products in mind; it is indeed in our own interests to reduce the all-in cost price of finished stainless steel products as much as possible for this is undoubtably the best way of increasing demand for them.

We are, however, less pessimistic on this point than our lecturer appears to be. Perhaps this is because French producers have long since established just this kind of co-operation with their main customers. Perhaps also, we should give greater importance to the standard finishes of products sold from stock, the final use of which is, by definition, unknown. If we look at the United States, the larger part of cold-rolled plate, sheet and strip there is sold through stock-holders. American users thus seem to have managed to make what they manufacture suit standard products, both in finish and size and call for "made to measure" finishes only when they really need them. It is then that they show a really exemplary spirit of co-operation with their suppliers.

Undoubtedly, the present keen competition between producers encourages European users to extend their specifications beyond what is reasonable, and it is a pity that these specifications do not always involve an extra charge to the customer which would be the best means of dissuasion; no true, absolute progress can be claimed, in fact, unless the extra cost for the producer is reflected either in better quality or lower all-in price of the finished product. Whenever tonnage justifies it, technical progress consists precisely in having surface treatment previously executed by processers as a craft operation: e.g. polishing, mechanical or chemical etching, etc., carried out by the producers under better technical and economic conditions. It is accepted as normal that such processing should be subject to extra charge, and the same should apply also to all finishing work over and above the standard.

It should also be possible to solve the problem of products rejected for defects in finish by suitable re-cycling and by seeking out special markets. An excellent recovery method consists of polishing by abrasive belt, which eradicates small surface flaws.

We doubt very much however whether Nos. 3 to 8 polished sheet accounts for 50-60% of the total sales of cold-rolled plate and sheet in the U.S. as stated by Mr. Signora. In our opinion, the American market for polished plate and sheet is about 35,000 tons per annum, which would represent only about 10% of the total. We would be glad if Mr. Signora could give us more information on this point.

Be that as it may, bright annealed products continue to be important for certain markets where polished plate and sheet is not used, but where special surface specifications are required.

Werner KÜPPERS

Bright-Annealing of Strip and Sheet

(Translated from German)

Mr. Signora has given us a clear and graphic account of the different forms of stainless sheet. However, since the Congress is concerned with progress in steel processing, I feel it may be worthwhile to devote attention to a subject which he touched on only briefly, namely bright-annealing of strip and sheet.

BA is designated in the German iron and steel specifications (Stahl-Eisen-Werkstoffblätter) as Process IIId, and is there considered as relating mainly to narrow strip of up to 250 mm. Technical developments and pressure from the processing and manufacturing industries, however, have made it necessary also to market wider strip and sheet produced by this method.

The surface quality of bright-annealed sheet is the same as the bright-hardened surface following cold-rolling by Process IIIa, but with bright-annealing the soft state is produced as it is by Process IIIb (finish 2D). Consequently, the formability as regards material is the same, but the surface shows much less roughness and a higher gloss.

For flat workpieces bright-annealing makes for cost savings in the subsequent machining of the surface. Incidentally, bright-annealed guard coverings are sometimes employed without machining of the surface at all.

A point closely bound up with this high surface quality of the sheet and strip is that of protection in handling and machining. Reference has already been made to the value of adhesive paper and of plastic foils. But the subject is too wide a one to go into in detail here.

Where workpieces made from bright-annealed blanks are to undergo extensive forming, as for instance by deep-drawing, the smoother surface can cause difficulties with regard to the adhesion of the lubricating film. These can often be got over by using a different lubricant; it is sometimes helpful to employ varnish or lacquer as a protection and lubricant.

Certainly, the importance of bright-annealing should not be underrated' for it is a contribution to the steady improvement of the surface quality of the products supplied, and reduces the after-treatment costs at the consumer end.

Nevertheless, on the subject of surface quality, it must be very definitely emphasized that the processer too needs to be extremely attentive. It is not enough to protect the sheet against mechanical damage: the whole operating set-up must be such as to help preserve surface quality. For instance, where deep-drawn parts are process-annealed thorough cleaning before the heat treatment is absolutely essential, since otherwise a patchy oxide layer develops which is difficult to remove by chemical or mechanical means.

The annealing conditions themselves should be in line with the properties of the metal. The roughing of a surface in free forming is influenced by

(1) the type of forming;

(2) the degree of forming;

(3) the surface quality of the initial material;

(4) the texture of the initial material.

While the first two factors are usually already determined by the nature of the case, the other two may depend to a considerable extent on the processer. We have already heard about the surface quality of the initial material. As for the texture, it is desirable as a general rule to use fine-grained material, so as to keep to a minimum the roughening after forming frequently known as "orange peel". The processer can partly determine the grain size by process-annealing: coarse grain is produced by long, high-temperature annealing. By appropriate firing, coarse texture and hence the orange-peel effect can often be avoided even in parts which have undergone extensive forming and been through several process-annealing stages.

I do feel however that these points are better discussed direct between producer and consumer. This is a further argument in support of Mr. Signora's plea for close co-operation between the two.

Jacques M. DEFRANOUX

Deterioration Risks of Corrosive Resistance

(Translated from French)

The talk we have just heard is unquestionably of great interest to both producers and users of stainless steel. I would just like to add a few comments on the technical side of these considerations and, more especially, on the influence the surface condition of flat stainless steel products has on their corrosion resistance.

This influence has long been recognised in practice. It has long been known, for example, that the ridges left by insufficiently thorough polishing harbour dust and that this can cause local impairment of resistance of stainless steel to atmospheric corrosion, either by creating differential aeration cells or by its own corrosive action (due to the sulphuric acid and chlorides in soot).

Furthermore, modern electrochemical methods enable us nowadays to form a very precise assessment of the corrosion resistance of a metal part and of the intrinsic influence of its surface condition. They therefore constitute a very valuable guide for the producer and enable him to adjust his manufacturing methods and obtain optimum quality from his products .The same accuracy is obtainable in assessing the effect on corrosion resistance of operations carried out by the part producer.

This is the reason for the daily growth in importance of the "potentiostat" method of determining the metal-solution potential above which stainless steel becomes pitted in a chloride solution.

It is not possible to deal here with these methods, so I have listed a number of published articles at the end of this paper for the guidance of any reader interested in this subject. (See Bibliographic references.)

It has been possible sometimes in this way to detect a deterioration in corrosion resistance of the plate or sheet caused by forming operations or even polishing. This was found to be the case, for example, with strip that had been bright annealed, given a skin-pass and then put through a polishing process involving too violent a first pass with too coarse a grain and overheating of the metal.

In this case the technical quality of the product had been wasted. From the point of view of corrosion resistance the polisher could have arrived at the same result with a finish which was less thorough and therefore less costly.

This underlines once more the importance of contact between producer and user. Such meetings, let it be said, have already been arranged, with most advantageous results, between makers of special steels and the chemical industry.

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DISCUSSION

Mario SIGNORA

(Translated from Italian)

To enable them to step up sales from small stocks, all warehousemen demand top-grade products, and this has a bad effect on the cost-and-price position which was complained of. This warehouse service provides no selection of grades based on end use.

As regards *polished* types, from what I know of the Italian market the percentage is extremely small and I think the same is true of the European market.

According to my findings in America, the various grades of polished products account for over 80%.

Walter G. von BAECKMANN

Principles and Uses of Electrochemical Protection

(Translated from German)

From the aesthetic aspect there are many who would welcome the replacement of an old iron structure, which had become no longer usable as a result of corrosion, by one of the modern welded steel bridges to which modern design imparts so much lightness and elegance. But when one reflects that several billion dollars are spent every year in the industrial countries on making good corrosion damage, and on protective measures against corrosion in order to insure safety in service, the same assessment of the economic importance of carefully conducted protective measures against corrosion can be obtained (see table below).

Costs for Corrosion Damage and Corrosion Protection Measures in the USA from data of Uhlig

N°	Corrosion and Corrosion Protection Measures	Millions of Dollars	%
1	Paint applications (75% wages)	1,985	38
2	Galvanising	137	2·5
3	Tinplate and terne plate	316	5·8
4	Phosphate coatings and Cadmium plating	40	0·8
5	Nickel and nickel alloys	182	3·4
6	Copper base alloying	50	1
7	Stainless chromium/iron alloys	620	11
8	1.6 million km pipelines (gas, water, oil: maintenance and replacement)	600	11
9	Oil refining	50	1
10	Water tanks and boilers	291	5·5
11	Heat engines (internal corrosion: 38 million vehicles)	1,096	20
	Total	5,367	100

Iron and steel are in practice non-existent as naturally occurring metals. They are won from iron ore with an energy consumption of 7 million kilocalories/ton and are thereby transformed into an enhanced state of energy from which they endeavour to revert through oxygen absorption to the original ore form, which is poorer in energy and more stable.

The metal in question has to a certain extent an urge to return to its natural state, based on some kind of discontent with civilisation, i.e. in physical terms an urge towards a more favourable state of entropy. This urge can be regarded as a cause of corrosion, as it takes place in air, in water or in the ground, in short in the presence of an electrolyte. Corrosion is no defect of the material, but a natural process, dependent on the material and its surroundings. In the final state of corrosion, metals enter into chemical combination with their surroundings. During corrosion, however, the most important process is neither the formation nor the composition of this compound, but the breakdown of the metal. Breakdown constitutes the necessary condition for all secondary chemical reactions. The breakdown of the metal from its atomic bonding is the first step which all others follow. If it can be prevented in practice, complete protection against corrosion is achieved.

For many years attempts have been made to prevent corrosion by passive measures, by keeping the corrosive medium away from the metal to be protected by means of inert paints, coatings, etc. The progressive development of rust protective paints, insulating media and synthetic coatings has produced the result, that the advantages of metals — great strength, hardness, elasticity, ease of working — are not lost through the disadvantage of gradual destruction of the mechanical properties of metals.

Moreover, the possibility exists of giving the metal by alloying a structural state which prevents this destruction of its properties, or of providing the surface with a more favourable, corrosion-resistant metallic coating. These measures normally consist of forming dense covering layers, resistant to corrosion, by means of chemical changes on the surface (with aluminium and zinc for example), or of creating a passive protective film which is a conductor of electrons, as on stainless steels.

The susceptibility of iron and steel to corrosion is especially undesirable, where relatively thin walls are involved, for example in pipe lines, tanks, ships, etc. On such large objects it is normally impossible for constructional or economic reasons to obtain lasting protection against corrosion by means of paints or protective coatings. Even with insulating coatings having a thickness of several millimetres, damage, pores, cracks or defective areas occur after a time, after which the material is no longer separated from the aggressive surrounding medium. Here corrosion starts and gradually destroys ever larger areas of the protective coating and of the metal through under-rusting. In electrolytes having especially good conductivity higher local rates of corrosion readily result, and these lead to pitting and finally to perforation of pipes, walls or tanks, etc. In this way the whole plant becomes no longer operational, until the leaky places have been looked for and repaired, often at considerable expense.

The danger of pitting is more common in vast humid surroundings, as in the ground, in service water or in sea water. In recent decades increasing use has here been made of an electrochemical method of protection in addition to conventional protective insulation; this actively intervenes in the corrosion mechanism. An electrochemical intervention can, for example, result from the addition of inhibitors to the water. The above relates however to electrical intervention in the corrosion processes, which prevents by means of cathodic polarisation, any reaction between the surrounding agressive medium and those parts of the metal which have been (though often unknown to have been) rendered vulnerable by defects in the passive protective insulation.

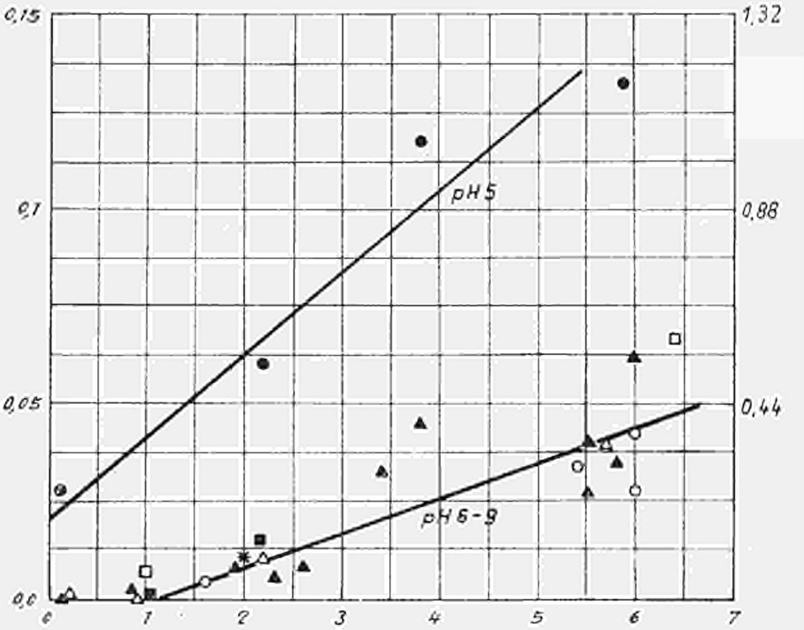
The table below presents a comparison between the individual protective measures, which are possible by means of the processes indicated:

Corrosion Losses and Protection Potentials

Passive corrosion protection	Chemically passive coating layers	Active corrosion protection
Non-metallic protective coatings	Metallic coatings:	Constructional measures;
	Dip coating	e.g. good drainage of water,
Inorganic protective coatings:	Galvanizing	protection against dust
		Removal of aggressive
Enamelling	Electroless plating	materials, e.g. water
Coating with ceramics	Metal spraying	preparation
Coating with cement	Vacuum evaporation	Addition of inhibitors:
		Anodic inhibitors
Organic protective coatings:	Material selection	Cathodic inhibitors
Paint applications	Chemical surface treatment:	Absorption inhibitors
Synthetic coatings	Passivation	Electrochemical intervention:
Rubber coatings	Phosphating	Anodic protection
Bituminous wrappings	Oxalic acid treatment	Cathodic protection

Principle of Electrochemical Corrosion Protection

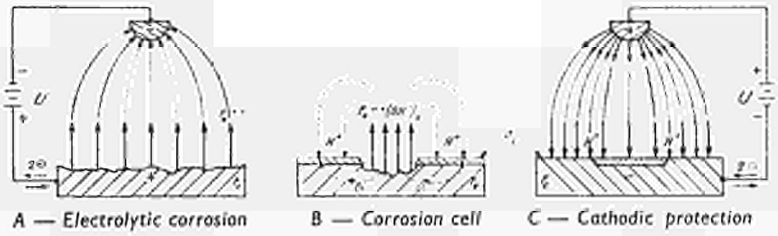
Even during electrochemical corrosion of a homogeneous metal it is always a matter of the balance of anodic and cathodic processes. At the anode some of the electrically neutral iron atoms leave the metallic bonding and move as positively charged ions into the electrolyte: $Fe = Fe^{++} + 2E$. At the same time, in accordance with their chemical valency, two electrons remain in the metallic bond. The metal is therefore negatively charged in relation to the solution containing the positive metal ions. At the cathode, electrons are at the same time being consumed in aerated soils or in water — mainly as a result of oxygen reduction: $H_2O + 1/2O_2 + 2E = 2(OH)^-$. Differences in aeration or changes in the concentration of the electrolyte, inhomogeneous covering layers arising from secondary chemical reactions, mill scale, corrosion products or small impurities in the surface of the metal, are sufficient to set up so-called locals cells, which are small zones in close proximity to one another with in-going and out-going corrosion currents. Since in the absence of an



Corrosion loss of steel as a function of the concentration of oxygen dissolved in unstirred solution of 3% NaCl from data of Schaschl & Marsesh

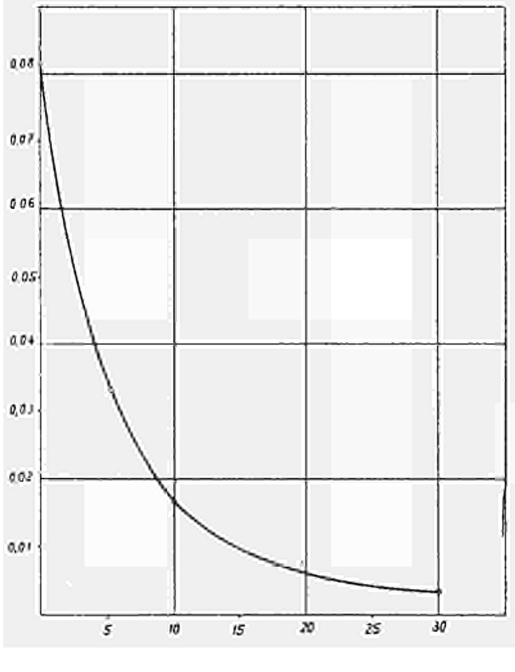
external current source electrical neutrality must prevail at the surface of the metal, at the anode points only as many iron atoms can pass into solution as electrons are consumed at the cathode surfaces. During oxygen corrosion, therefore, the corrosion rate is dependent on the number of oxygen atoms diffusing to the surface of the metal, and it increases with higher oxygen concentration. The figure above shows the corrosion rate for iron as a function of the oxygen content of the electrolyte. The following figure (B) shows a schematic representation of the corrosion cell described above. With a small extension of the anode area or during persistent inhomogeity the anode can become stabilised, causing the dreaded occurrence of pitting. Since iron can pass into solution only as positive ion, there is an outgoing positive electric current corresponding to the corrosion loss of iron. Conversely, a direct current emerging from an iron electrode (A) gives rise to electrolytic corrosion at the positive electrode (anode). This process has often led to extensive damage in the destruction of pipelines and cables in the vicinity of supply stations of direct current electric railways. The relationship between the magnitude of the current and the loss of material is seen from Faraday's Law to be 9·1 kg iron per annum at a direct current of 1 A, irrespective of whether the corrosion currents are set up by direct current electric railways, by galvanic potentials of dissimilar metals or by electrochemical reaction with an aggressive surrounding medium.

Electrolytic corrosion, corrosion cells and cathodic protection of a metallic surface



A — Electrolytic corrosion *B — Corrosion cell* *C — Cathodic protection*

If we describe the loss of material as a current flowing away from the metal surface, then corrosion must be prevented by the suppression of such a current. This takes place, for example, with inert protective coatings, through the rise in the transfer resistance from metal to electrolyte, or through the rise in the transfer resistance from metal to electrolyte, or through direct separation of the electrolyte from the metal. The outgoing corrosion current can, however, also be compensated for electrically by the superimposing of a protective current flowing to the metal surface. The figure above (C) shows how this protective current is generated in the electrolyte via an auxiliary anode additionally inserted into the electrolyte with the application of a battery of voltage U, and passes into the metal surface (cathode) to be protected. With gradual increase of the applied auxiliary potential or of the current flowing from the auxiliary anode finally all the current lines flowing from the anode (figure above, (B)) will be compensated, and here again an inflowing current will be enforced. For the whole surface of the metal the anode will thereby become the cathode, at which iron can no longer pass into solution, i.e. the electrode is cathodically protected. The figure below shows the result of a corrosion test of steel in moist earth; with increasing density of the cathodic protective current the outgoing corrosion current from local or corrosion cells is compensated, and the corrosion loss is thereby decreased.



Corrosion rate (mm./year)
Current density (mA/m²)

Fall in the corrosion rate of iron in moist ground as a function of the cathodic protection current density.

The process of cathodic protection can also be described electro-chemically as follows. The electrons consumed during oxygen reduction, which were previously given up by the iron ions passing into solution, are now supplied by the external cathodic, protective current source. In this way the potential of the iron surface to be protected is lowered to such an extent that the outflow of positive iron ions from the negative material is in practice no longer possible (see figure (C) on p. 319). The magnitude of this reduction in potential

Corrosion Protection Methods for Iron and Steel

Metal	Corrosion Loss kg/Aa	Corrosion Natural (1) Equilibrium Potential in the Ground	Practical Protective Potential	Theoretical Protective Potential	Negative Limit Potential
Copper	10·4	— 0·05	— 0·15	— 0·16	—
Lead	34	— 0·40	— 0·60	— 0·63	— 2,1
Iron	9·1	— 0·55	— 0·85	— 0·95	—
Zinc	10·7	— 1·05	— 1·20	— 1·26	— 1,3
Aluminium	2·9	— 0·95	— 1·05	—	— 1,2 (2)
Magnesium	4	— 1·6	—	—	—

(1) All potentials measured in volts against a saturated copper sulphate electrode.
(2) Aluminium possesses only a very small permissible range for the cathodic protective potential. Without potentiostatic potential setting it cannot therefore be cathodically protected, at least not within the range of influence of tramway stray currents.

Application, Protective Current Density and Costs of Cathodic Protection

Nature of Protection	Object of Protection	Passive Corrosion Protection	Current Density mA/m²	Installation Costs ca. DM/1,000 m²
External protection in the ground	Steel pipeline	Bitumen-glass wool, new	0·01 — 0·1	500
	Steel pipeline	Bitumen-jute, old	1 — 5	5,000
	Reinforced concrete pipeline	—	10 — 30	20,000
	Borehole probe	(Carburization)	10 — 20	15,000
	Artesian well casing	(galvanized)	10 — 50	17,000
	Super high-tension pressurized cable	Bitumen-glass wool	0·01 — 0·1	700
	Armoured cable	Bitumen-jute	10 — 100	30,000
	Corrugated steel cable	Synthetic material	0·001 — 0·01	200
	Storage tanks	Bitumen-jute	0·1 — 1	15,000
Internal protection (against service water)	Water mains	Bitumen centrifuged	0·1 — 1	40,000
	Water tanks	Thick paint applications or lining	0·1 — 2	4,000
	Wells	Paint application	50 — 100	18,000
	Heat exchangers	—	100 — 500	30,000
	Hot water boilers	Synthetic resin paint application or galvanized	100 — 200	—
(against sea water)	Ballast tanks of ships	—	80 — 120	20/30,000
External protection in fresh water	Bridges, weirs	Paint	10 — 20	20,000
	Sheet piling	—	20 — 80	30,000
	Ships, lying up	Paint	10 — 15	8,000
	Ships in transit	Paint	20 — 60	30,000
in sea water	Sluices, locks, pontoons, buoys, piers	Paint	20 — 30	25,000
	Sheet piling	—	20 — 50	35,000

can be determined on the basis of theoretical considerations and experimental investigations. It is relatively small, amounting only to about 0·3 V, as may be seen from the values given in table below. In the light of theoretical assessments the change in potential is roughly the same for all metals. Due to variable corrosion potentials, the setting of the protective potential is essentially dependent on the nature of the metal to be protected, and on the nature of the electrolyte (concentration of the metal ions).

On the other hand the protective current density required for this change in potential is determined by very many parameters:

1. Area of the unprotected steel surface
   (Size of the defective areas and nature of the protective insulation)
2. Nature of the corrosion reaction
   (during oxygen corrosion: concentration of the oxidision medium in the electrolyte)
3. Flow rate of the electrolyte (diffusion rate)
4. Formation of non-conductive covering layers
5. Formation of galvanic elements on the metal
6. Aeration of the electrolyte
7. Temperature of the electrolyte
8. Ohmic drop in potential in the electrolyte and in the defective areas.

These different factors can affect the magnitude of the protective current density often by many powers. The following table shows the protective current density required in practice for cathodically protected objects, but this is also very much dependent on the relevant protective insulation.

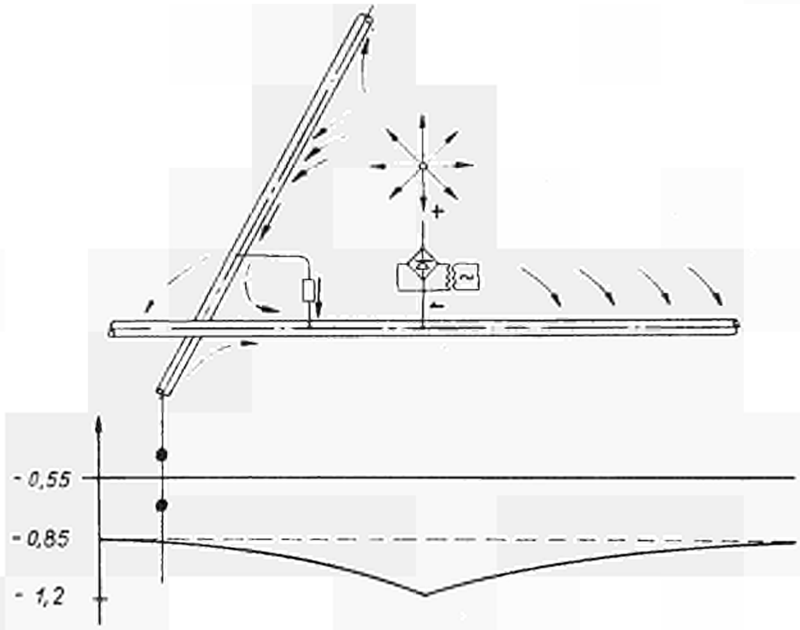
Protection of buried Pipe Lines and Tanks

Cathodic protection of underground plant has assumed great importance in ensuring that pipelines and tanks buried in the ground can resist corrosion. In the light of a questionnaire of the International Gas Union in 1960, more than 0·3 million kilometres of gas mains in the world were cathodically protected, for the most part in the USA, but in addition there were over 8,000 km. in the USSR, 6,500 km. in France, 3,000 km. in the Netherlands, 1,800 km. in Belgium and 1,300 km. in the German Federal Republic. The rapid increase in the amount of cathodically protected mains networks in the German Federal Republic may be seen from the following table.

Approximate length of cathodically protected pipelines in the Federal Republic of Germany

Object protected	Total length of main in 1964 km.	Cathodically protected km. 1960	1965
Long-distance water mains	12,600	200	400
Long-distance gas mains	6,000	1,100	4,300
Crude oil and petroleum mains	3,120	1,900	3,000
Water distribution network	109,000 (12% steel)	30	200
Gas distribution network	72,000 (30% steel)	60	500
Agricultural produce and industrial mains	1,700	300	500
Super high-tension pressurized cable	—	10	60
Long-distance heating mains	—	—	20
Total — steel mains, approx. Total	40,000	3,600	9,000

Steel pipe mains need only have very thin walls because of the high strength of the material. In contrast to massive iron constructions however, an isolated perforation leads to leakage. They are therefore very subjects to pitting, which often occurs in the ground, and of stray current electrolysis. It is true that steel mains in the ground are always provided with good external wrapping, consisting of a bituminous wrapping material having a thickness of several millimetres and incorporating glass wool supports. During laying of the pipes however, during filling-in of the pipeline trench, and during the laying of the mains in the earth, often with considerable pressure, it is impossible to avoid causing defective areas at which corrosion can set in. In the course of time the wrapping of the pipes is increasingly loosened by the voluminous corrosion products, and the size of the defective areas increases.



Principle of cathodic external current protection of pipelines.

Since the total cathodic protective current consumption for pipe lines and the larger storage tanks or tank installations often exceeds several amperes, such components are usually protected by the external current protection method. With well wrapped new pipe lines a section of main 30 to 40 km. long can be protected by a single external current protection plant. The above figure shows the principle of a cathodic external current protection plant. The positive pole of a rectifier, normally fed from the mains, is connected with one or more external current anodes, and the negative pole with the pipe line to be protected. The protective current then passes into the ground via the external current anode (s), spreads out in the ground over a great distance, and passes automatically into the defective areas of the pipe lines. Since the cathodic protective current is so to speak ever eager to flow into new defective areas as they arise, with the cathodic protection method it is also possible to talk of automatic protection. This applies especially where use is made of rectifier plants controlled by transducers, which keep constant the cathodic protective potential, when it has once been set, by means of a measuring probe. Illustration 1 (p. 331) shows such a potentio-static protection plant, such as is used under conditions of strongly fluctuating anode resistivities of strong fluctuations in potential due to stray currents, or of variable protective current consumption. Instead of the alternating current supply which is most frequently available in Europe, cathodic protection plants can also be supplied with current by windmill generators, small gas turbines or thermal generators.

The cathodic current consumption of the object to be protected is determined by trial feeding. On new, well-insulated pipe lines it amounts to a few amperes, but for older pipe mains and with stray current leakages, to some hundreds of amperes. The required initial potential of the rectifier is essentially dependent on the diffusion resistance of the external current anodes. In order to achieve as low a diffusion resistance of these anodes as possible, the anodes are placed in an area with low specific earth resistance, either as relatively extended horizontal or vertical iron scrap anodes bedded in coke, or else as a great number of anodes as inert as possible alongside or above one another in vertical or horizontal bores.

Illustration 2 (p. 331) shows the installation of silicon-cast-iron anodes in a surround filled with coke breeze, held together with wire netting, during insertion into a 20-m. deep, vertical bore. At a protective current consumption of 10 A and a diffusion resistance of 1 ohm, an initial rectifier current of about 10 to 12 V is necessary. The rectifier output including losses is about 200 watt; this amounts to about 5 kWh/day or less than 2,000 kWh per annum or current costs of only 200 DM per annum. Through economical layout of the external current plants the running current costs can be kept exceptionally low. These costs therefore are not incorporated in the table on page 319, which gives the installation costs for cathodic protection. External current anodes are usually laid down for a working life of 15 to 20 years.

Through the supply of the cathodic protection current the natural equilibrium potential of the pipe line which is most frequently measured by means of a non-polarizing copper sulphate electrode, is lowered in relation to the earth at least to the cathodic protection potential of — 0·85 V. Under the sketch in the figure on page 321 the curve of the potential along the pipe line has been plotted. In order to maintain an adequate protection potential at the end points of the pipe line, in the vicinity of the rectifier plant a more negative pipe/earth potential is required. From this figure it can be seen that at a high protective current consumption other pipe lines running in the vicinity of the external current anodes can also consume current, and on crossing over the cathodically protected main can release it again. This unfavourable effect, which can lead to corrosion damage on the other main at the point where the mains cross each other can easily be avoided by means of a potential link with the cathodically protected pipe main. The potential link is generally necessary only in the immediate vicinity of the external current anodes or for pipe mains with a high cathodic protection current consumption (over several mA/m^2).

Cathodic Internal Protection against Service Water

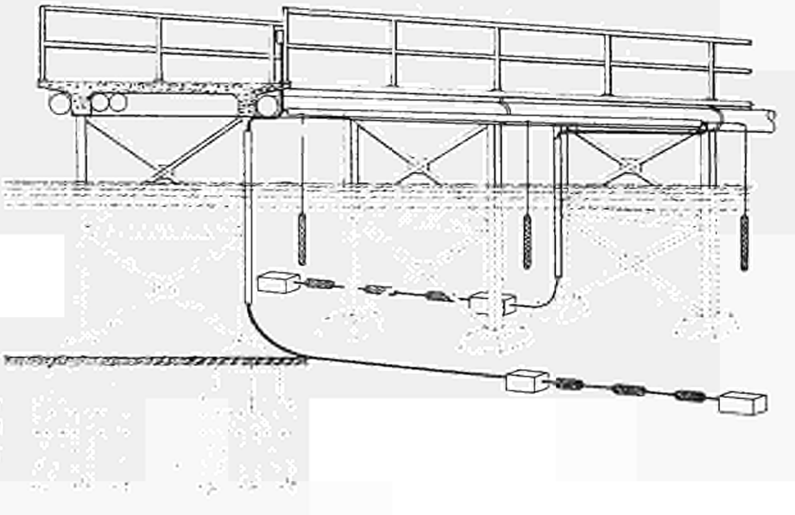
For objects to be protected with a small current consumption, for cathodic protection in sea water (which has good conductivity,) and for the protection of mainly narrow and angular interior surfaces of tanks against service water it is advantageous to use protective anodes of zinc, for service water mainly made from a magnesium alloy containing 6 to 8% aluminium and 3% zinc. The current discharge of the anodes is dependent on the one hand on their potential in relation to cathodically protected iron (Mg — 0·7 V, Zn — 0·2 V), and on the other hand is inversely proportional to the specific resistance of the surrounding electrolyte.

Zinc and magnesium atoms have a much greater tendency to pass anodically into solution than iron, so that they acquire a more negative potential. Where metallic contact exists between iron and the protective anode a current therefore flows in the link from the iron to the anode, or in the electrolyte a protective current flows from the anode to the iron. In this case the cathodic protection current is that of the potential of the iron-magnesium galvanic cell. Since under these conditions the less fine metal passes into solution to an increased extent, we speak of sacrificial anodes. The anodes, so to speak, "take on" the corrosion, which would otherwise occur on the object to be protected. In closed containers the protection current density is often determined empirically, since the protection potential cannot normally be measured directly. In general there has been shown to be a magnesium consumption of 1 to 2 kg/m^2 of free surface. By painting the internal surface of the container with dense, insulating protective coating the protection current consumption can be substantially reduced. If inspection of a tank shows that corrosion attack has not been fully suppressed in individual areas of the protected surface, then additional anodes can be built in. Illustration 3 (p. 332) shows the cathodic protection of the dome of a condenser with magnesium block and rod anodes. For the most part the anodes have to be renewed after some years.

External Protection against Sea Water

Steel structures in sea water are subject to extensive corrosion as a result of the high salt content, the associated low specific resistance of 20 to 30 ohms/cm., and the high oxygen content in the upper layers of the water. The corrosion rate of bright steel in agitated and aerated sea water is from 0·1 to 0·2 mm. per annum. Sea water is very advantageous for cathodic protection as a result of its high electrical conductivity and the resultant possible good current distribution, and also on account of the content of calcium and magnesium salts, which give rise to good protective layer formation and thereby a reduction in the cathodic protection current density. Thus it is possible to use plants in accordance with the external current process and also protective anodes. A zinc anode, about 1·20 m. in length and 20 cm. in diameter, can produce several amperes of protection current in sea water.

In harbour installations, where alternating current is amply available, cathodic external current protection is usually superior to galvanic anodes. Anodes can be hung on piers standing on steel piles, or between the piles (see figure below). For sheet piling, quays, and wharves for fitting out ships, the anodes are also

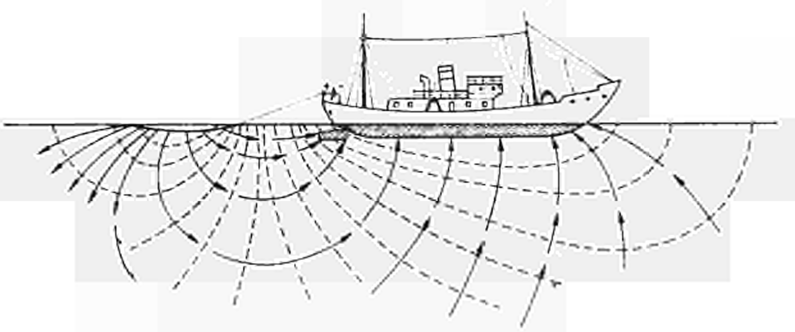


Cathodic protection of a pier in sea water by means of silicon anodes hung on it and laid on the bottom, fed with external current

laid on the bed of the harbour. After leaving the slipway, ships are often given cathodic protection if they are lying in the water for a long time or during their fitting-out period in port. In this way not only will the more visible paintwork be preserved, but also protection will be provided against the occurrence of stray currents, which often occur with direct current welding plants as compensating currents. In general, at the wharf there are central welding plants, which supply very high direct currents for welding to various parts of the ship and to other wharf installations or to ships lying in the vicinity. If welding is in progress on different ships, at various loadings and at unequal resistivities in the return current cables, considerable potentials can arise, which are compensated to the sea water via the defective areas in the paintwork on the outer skin of the ship which inevitably arise through rough handling at the wharf. Without cathodic protection considerable electrolytic pitting damage can then occur even on new ships.

As anode material for galvanic anodes, magnesium and zinc may be used, and for stray current plants graphite, silicon-iron, platinized titanium and frequently even scrap iron. On lock installations and on the sides of ships, galvanic or external current anodes can also be applied directly (see illustration 4, page 332). Cathodic protection of the outer skin of a ship and on tanks also, the internal protection of the ballast tanks, are today a matter of normal corrosion protection practice, just like the protection of pipelines. In Japan, who since 1956 has attained not only the greatest tonnage, but since 1964 also the highest new ship construction tonnage (3·7 million gross register tons, as against Sweden about 1 million, and the German Federal Republic and Great Britain each 0·8 million gross register tons), cathodic protection with zinc anodes is preferred.

Illustration 4 (p. 332) shows zinc anodes on the stern of a ship a part which is always particularly strongly vulnerable to corrosion damage. Through the eddy formation caused by the ship's screws, increased water velocities and greater oxygen aeration occur with a particularly strong tendency to corrosion. For the painting of cathodically protected steel surfaces, brine-resistant paints are used since the pH value is displaced into the basic range through the cathodic reaction. Nevertheless, where external current and magnesium anodes are used, considerable peeling of the paint and covering layer formation take place. With zinc anodes a completely uniform distribution of the potential can be achieved. On account of the low potential of the zinc anodes in relation to steel, on the one hand larger surfaces, or more anodes, are necessary, and on the other hand the effect of self-regulation of the protective current is strongest with this anode material. On ships in passage, a Dutch shipping line also employs a method, whereby an inert anode material or a daily replaced aluminium wire is trailed behind the ship as trailing anode (see figure below). Through a relatively wide distance of 10 to 20 m. between the anode the body of the ship an entirely uniform distribution of current around the whole outer skin of the ship is achieved. On the other hand, the anode must be drawn in before turning manoeuvres or inside harbour installations. It is therefore exceptionally suitable for tankers and freighters, which are almost continuously on the high seas.



Cathodic protection of a ocean-going ship with a trailing anode in accordance with a method used by a Dutch shipping line

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Heinrich FRINKEN

Cathodic Protection for Corrosion-Resistant Steels

(Translated from German)

Mr. von Baeckmann has given us a very clear explanation of the principles of cathodic protection, and the examples he showed of its application provide an excellent picture of the various conditions and factors involved. The representation of corrosion as the natural way for matter to follow the general law of entropy is particularly appropriate.

If this concept is extended, cathodic protection can be seen as a means which serves to prevent the increase in entropy by supplying energy. Physically, this means that external energy is added to the metal-electrolyte (corrosive environment) closed system, in order to maintain the required state.

The paper's description of cathodic protection for metal parts, the surface of which has been disturbed by external influences has prepared the way for the extension or supplement which I should now like to add: the cathodic protection of corrosion-resistant steels.

When dealing with this problem, we have to combine the laws peculiar to this group of alloys with the concepts of cathodic protection which have already been presented in the paper, and so obtain information additional to that which Herr von Baeckmann has given us.

A frequent difficulty when considering this matter must now be removed by describing a seemingly abnormal occurrence. The difficulty is this: ferrous alloys containing 15 to 40% or more of other metals, generally chromium, nickel and molybdenum, are still known as steels. Very often, this leads quite wrongly to the assumption that the treatments and properties normally applicable to conventional structural steels are also applicable, without reservation, to these alloys. This assumption is, however, not always correct — certainly not for corrosion behaviour and anti-corrosion measures. Herr von Baeckmann has explained that the corrosion rate of steel increases with increasing oxygen content of the electrolyte, but in the ferrous alloys, known as corrosion-resistant steels now referred to, exactly the opposite occurs. With increasing oxygen content, passivation increases and corrosion diminishes. The corrosion protection of these steels thus depends on the formation of an anti-corrosive film which constantly renews itself from inside the metal to the outside, as it were, and in the ideal case the steel itself does not come into contact with the corrosive medium.

In the cathodic protection of a constructional unit made up of steels of this type, the limitation is imposed that only slight deviations from the ideal condition of complete passivation must be compensated. Protection must never be carried to the extent that the natural surface-film becomes reduced.

As we have learned from the preceding explanations, electrons appear at the cathodically-protected steel surface, and these react with the oxygen in the electrolyte to produce a reducing atmosphere at the steel surface. This means, chemically speaking, that reactive hydrogen, instead of reactive oxygen, is liberated. While such an atmosphere is to be welcomed for ordinary steel, and has the effect of diminishing corrosion, with corrosion-resistant steels the hydrogen robs the surface of the natural protection formed by the products of oxidation. It cannot be the purpose of cathodic protection to remove natural protection so that it can then work alone. Otherwise, when ordinary structural steel is cathodically protected, no surface protection in the form of paint coatings would need to be applied. It is not, therefore, the task of cathodic protection to take over the work of nature; it should, if it is economically used, take care only of the balance that is needed. The hydrogen reaction at the surface of a cathodically protected steel has, in general, four different consequences :

1. Alkalization in the electrolyte.
2. Reduction of the passive layer on corrosion-resistant steels, or diminishment or even elimination of oxidation processes.
3. In the case of excess hydrogen, diffusion into the steel.
4. Formation of molecular hydrogen, which comes from the protected metal surface.

Which of these phenomena gains the upper hand, and actually takes place, depends on the potentials and activation energies of the processes.

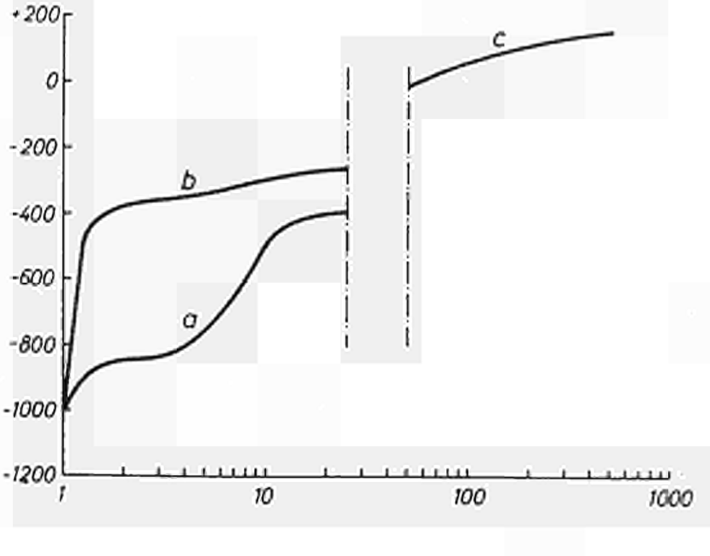
The potential limit at which free atomic hydrogen occurs, in a form and quantity detrimental to the steel, decisively depends on the hydrogen potential in the electrolyte concerned, the pH-value, and the hydrogen overvoltage of the steel in this electrolyte.

In neutral seawater, pH 7, for example, the hydrogen potential is —660 mV (saturated calomel electrode). The hydrogen overvoltage of normal structural steels is about 50 to 80 mV, and that of alloy steels is of a similar order of magnitude. From this, it follows that with a lowering of the cathodic potential at the protected steel surface to values below —700 to —750 mV (sat. cal. el.), undesirable reactions occur for alloy steels.

Corrosion-resistant steels are not used with the intention of having to bear in addition, the full expense of cathodic protection, but in order to maintain, in each case, a good natural corrosion protection. A cathodic protection must, as has already been said, therefore be of only moderate cost on rational grounds. It is possible that an electro-chemical protection installation may fail to work; in such a case, there will still be adequate natural protection to protect the part from destruction. If the cathodic protection has been too thorough however, even the best corrosion-resistant steel can no longer cope with this task of emergency protection.

As evidence of this, the following figure gives a graphical representation of the potential behaviour of an X 4 CrNiMo 18 14 steel as a function of time, after the steel had been kept in seawater for 100 hr at a potential of —1030 mV (sat. cal. el.). This potential lies far below the hydrogen potential, so that a large part of its natural passive layer was reduced. It can be seen from curve A, which indicates the behaviour in naturally aerated seawater, that the dangerous 700 mV limit is again passed, through self-passivation, only after about 10 hr. However, if pure oxygen is allowed to bubble through, then the equilibrium potential rises very much more steeply and good repassivation is obtained after only a few minutes. In harbour waters, which are in general poorly aerated and have a considerably greater corrosive effect than water in the open sea, the course of the repassivation curve is accordingly considerably slower and conditions favourable to serious corrosion are created.

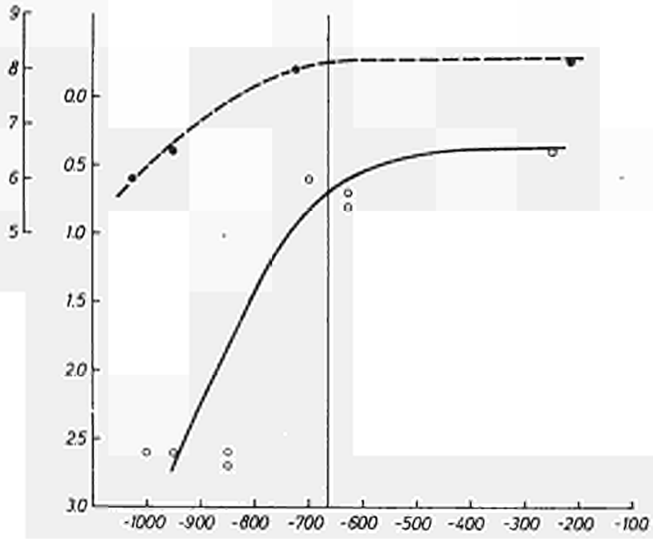
That both curves A and B relate to the new formation of covering layers of oxidation, which occur simultaneously with rediffusion of the hydrogen which has penetrated, is shown by curve C, which was obtained after 25 hr exposure in air at 150° C. Such a process causes the equilibrium poten-



Repassivation of × 4 CrNiMo 18 14 following cathodic protection at — 1,000 mV tial of the steel to rise immediately to values of about plus 100 mV (sat. cal. el.). After several days, such complete passivation is attained with this type of steel, which is one of the best corrosion-resistant steels, that practically only the redox potential of the seawater can then be measured. The complete system now behaves as if no steel at all were present in the water.

A further example, (in the next figure) shows an additional and undesirable attendant phenomenon in the case of a

Hydrogen absorption and notch impact strength as a function of the potential



17% ferritic chromium-steel; this is susceptibility to brittle fracture. The hydrogen diffusing into the steel lowers the notch toughness, after 8 days at potentials below —800 mV (sat. cal. el.), to almost half its former measured value. After such detrimental treatment, hydrogen determined analytically by the hot extraction method showed values between 25 and 30 ml of hydrogen per 100 cu m of steel, against about 0,5 ml initially.

With the strongly accentuated self-passivation of alloy steels in areated electrolytes, it might well be asked whether cathodic protection is really necessary in this environment. The answer, in most cases is very definitely in the affirmative, for the following reasons.

Steel is rarely subject to absolutely steady conditions of attack. This applies to both corrosive action and mechanical stressing. Sudden variations in mechanical stress, unless of a very small order, lead to fatigue failure. Whilst under purely mechanical alternating stresses with no corrosion present, the steel exhibits a definite fatigue value to which it can be stressed, and below which it will safely withstand such alternating stressing for very long periods or for very many load cycles, such a fatigue value is no longer displayed when corrosion is present. With a sufficiently large number of loadings, fatigue failure can then occur even if the stress range is very low. This is particularly so with corrosion-resistant steels, as strong corrosive attack occurs only locally and weakens individual points on the surface.

This phenomenon can be completely prevented by cathodic protection (see following figure.)

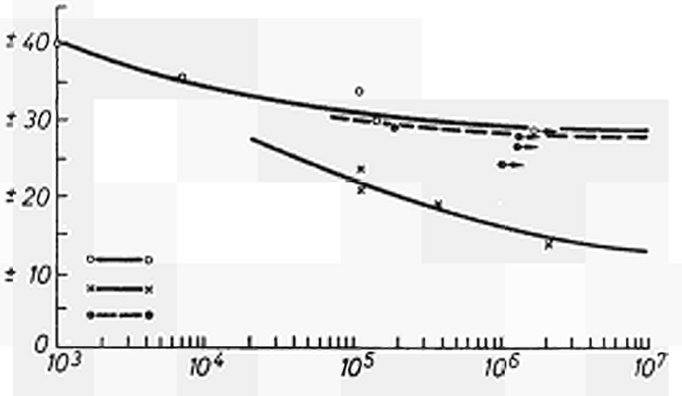
Furthermore, with alloys and particularly with austenitic steels, stress corrosion cracking may occur. This is certainly potential-dependent and can therefore be completely avoided by cathodic protection.

So far, we have been concerned only with potentials and have not considered current density. This seems to me to be impossible to specify, even approximately, for rust-resistant steels, because the defective places within the passive layer are not known. The definite connection between current density — in respect of the steel surface area without taking the passive covering layer into account — and the potential of the steel in an electrolyte is well enough known. For corrosion-resistant steel, the potential-range in which one should operate for maximum safety of the object concerned can be found from the appropriate current-density potential curves. If strongly positive values, i.e. the oxygen potential, are approached, conditions favourable for the formation of pitting at the unavoidable defective places in the passive layer will exist; if the potential is lowered too much, then the passive layer becomes reduced. The limits have already been pointed out.

The more or less strong passivation tendency of the numerous corrosion-resistant alloy steels is accompanied by the fact that each of these alloys possesses an equilibrium potential quite different from that of the others. Fundamentally this means that, in a combination of two different alloys, the steel with the lower equilibrium potential automatically becomes the sacrificial anode and goes into solution under a strong pitting action, although by itself it would have remained corrosion-resistant. This law is valid also for a combination with other alloys, e.g. bronze, classed as corrosion-resistant.

The concept of corrosion resistance cannot, therefore, be established absolutely, but must always be measured with the other materials comprising the structural unit (if they are connected electrically) being taken into account. Here, the surface conditions naturally play a decisive role. It can thus happen that a component part, having a very low natural potential but having only a very small portion of its surface exposed to the electrolyte, corrodes less or does not corrode at all, whereas a component higher in potential and of greater area has to bear the brunt of corrosion, provided, of course, that other components of a still higher natural potential are present. In practice therefore, cases have actually been met where, in a structural unit, a readily-passivating chrome-nickel-molybdenum steel has been combined with an ordinary structural steel and protection has been attempted with zinc as the protective anode. Because the zinc anodes were too small, they could not carry out their task and remained almost entirely free from corrosion; the structural steel alone went into solution at a high rate, and bore the brunt of all the corrosion in the system.

In choosing materials for a structural unit exposed to corrosion attack, the utmost care should therefore be taken to combine materials of the same or very similar equilibrium potential; consideration must not be confined to technological properties and questions of cost, on the grounds that



Rotating-beam bending tests of X 4 CrNiMo 18 14

cathodic protection will look after matters. The various non-corrosion-resistant structural steels (and these include all steels with less than 13% chromium) nearly all have a very similar equilibrium potential, about —700 mV (sat. cal. el.), for example, in seawater. They also behave in a similar way in other electrolytes.

The numerous corrosion-resistant steels show, on the other hand, a spectrum from —400 to plus 250 mV (sat. cal. el.); they vary at least as much in other electrolytes.

It would be outside the scope of this discussion contribution to go more deeply into particular details and examples of applications. The problems and principles of cathodic protection for corrosion-resistant alloy steels have, I think, been indicated. If it is appreciated that these steels behave differently from others, that is, in a more noble fashion, and that they show greater individuality in their behaviour, this should ensure that adequate care is used in the various applications and that, where necessary, specialist advice is sought.

DISCUSSION

René CASTRO

(Translated from French)

It is generally thought that cathodic protection can only be applied to ordinary steels, but Mr. Frinken was right to point out that it can also be used on stainless steels which are thereby enabled to passivate under first-rate conditions directly the protection is stopped. It has been used in the Rance Tidal Dam Power Plant in which many of the structural components are of stainless steel, but cathodic protection is employed because of the aggressivity of the chlorine ions in the sea water.

It might be useful if cathodic protection, either with a current source or sacrificial anodes, could be studied and discussed in a more general context so as to wider, its range of application and make it safer to use.

List of illustrations

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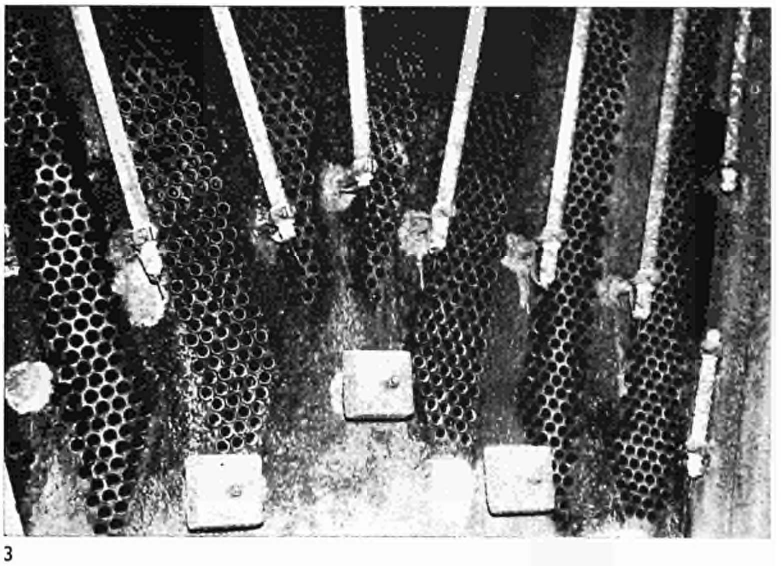

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Gilbert ANDRIEU

Continuous Chemical Treatment and Paint Application

(Translated from French)

Chemical treatment and painting of steel sheets before forming is well established, for we have had storage problems for a long time. The protection of metal against corrosion by some sort of chemical treatment prior to use, e.g. passivation or phosphating, is limited by a time factor, since such a passivation or phosphating on its own, is not satisfactory for prolonged storage. If, on the other hand, the base metal is protected by a layer of suitable paint (primer, wash-primer, zinc rich paint) then corrosion resistance is improved. In this latter case, the final protection may cause new problems when the metal is formed, since the paint layer ages and its mechanical properties deteriorate. It should not be forgotten that the primer layer is only very thin, some 5 to 10 microns.

Out of this arises the technique of treating steel sheets chemically (by passivation or phosphating) and then applying the final paint layer before forming, which automatically resolves the problem of the deterioration of the base material during storage, and allows stockholders to dispose of the sheets in good condition, already protected and coated without the stockholder having to do this.

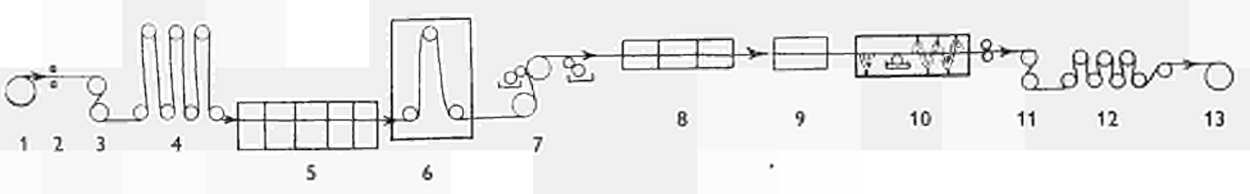
If it is possible to obtain the sheets in a condition sufficiently flexible to be processed in coil form, chemical treatment and the application of paint can be done continuously at a speed which makes production capacity extremely adaptable. This is true, for example, for strip-coating.

In the following paper, the features of a strip-coating line will be examined in detail, followed by consideration of the various categories of paint and their anticipated performances; finally, the economic aspects of the process will be considered.

In order to describe an installation of this type, it is advisable to consider it unit by unit along the line (see figure below).

1 — A coil of mild or galvanised steel of width between 1 and 200 cm, depending on the final application, and length about one kilometre, is uncoiled at speeds up to 30 m/minute.

2 — A welding machine which enables the end of one coil to be joined to the beginning of the next.



Strip-coating line

3 — The bridle roll controls the strip tension. It consists of two rolls, one fixed, the other able to move horizontally enabling the strip to be tensioned as required.

4 — Storage. This equipment consist of a series of fixed rolls at low level and a series of rolls which can move up and down. This accumulator avoids the need to stop the line when putting on a new coil 1. Thus, when a coil is nearly uncoiled, the looping towers are full and when the uncoiler stops, the moving rolls slowly descend the tower, keeping the line moving until a new coil is ready.

5 — Surface treatment or chemical pretreatment. Chemical treatment of sheets is necessary for the well-known reasons of improving paint adhesion to the base material and for corrosion protection. This chemical treatment may be slight. Passivation has to be considered here, i.e. surface attack of the metal by acidic solutions of alkaline phosphates operating at temperatures around 70°. A phosphate coating thus deposited is about 1 micron thick and forms a crystalline structure which is bound very strongly to the adjacent base metal. In the case of crystalline phosphating, the chemical attack on the metal is more important and the surface deposition of phosphates is correspondingly more important, the acid solutions used containing phosphates of zinc and manganese which form a crystalline layer between 5 to 10 microns thick.

A treatment line is usually made up of five sections comprising:

(a) Hot alkali degreasing

(b) Rinsing in hot water

(c) Chemical treatment at suitably high temperatures

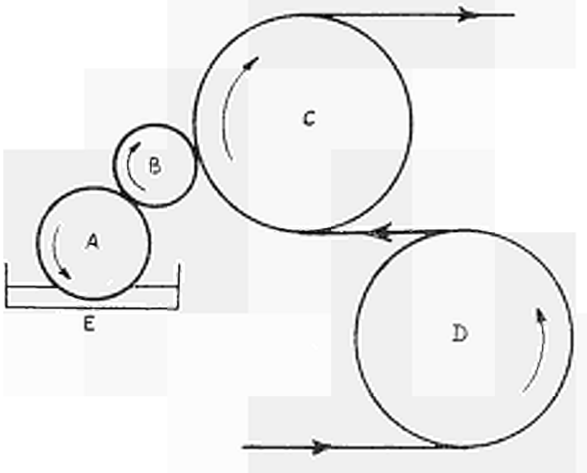
(d) Rinsing in cold water

(e) Rinsing in cold, dilute solution of chromic acid.

All these operations are affected by spraying both sides of the strip with jets, over a relatively short period of time, about 10 to 20 seconds.

This chemical treatment ensures that the metal is not soiled in any way which could affect the paint adherence, provides a perfect wetting of the sheet, and avoids the advance of corrosion under the paint film usually applied in single coat.

6 — Drying oven. Following the treatment line, the sheet must be dried by passing it through an oven which progressively heats it up to about 50° at the exit.



Schematic of a paint applicator

7 — Tension roll and paint applicator. The paint is applied to the metal strip, coating sides if necessary. The figure below shows the scheme of application: the rolls C and D control the strip tension, D moves horizontally as required, C is the driving roll. The roll A is a pick up roll leading into the bath E which contains the paint (or lacquer) to be applied; this is deposited on an applicator roll B, which deposits it on the metal strip. A, C, D, turn in the same direction as the movement of the strip, B turns in the opposite direction, thus giving rise to the English name "reverse-roll-coating". B and D are covered with synthetic rubber, A and C are in polished steel. All these rolls, except D, are controlled by independent motors and have diameters of the order of several tens of centimetres. Taking the linear speed of C as 100 then that of A is 90 and B 150.

The thickness of the paint layer deposited will in the first place be a function of:

(a) the solidity content of the paint, i.e. the quantity of non-volatile products in the paint.

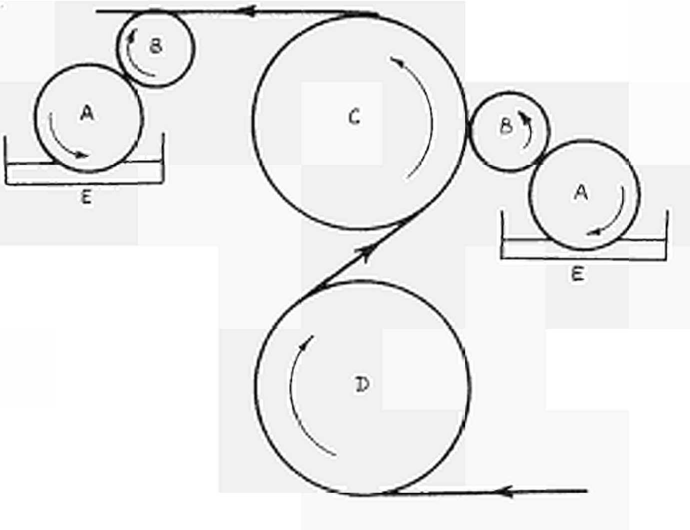
(b) the distance between A and B.

(c) the speed of B.

(d) .it is arranged that the pressure between B and C is the minimum required to obtain only a paint deposit on the strip.

Reverse roll coating only is considered here. Old processes may be encountered: for example there is conventional roller coating. In this process the applicator roll turns in the same direction as the strip movement. The application of the paint by this method is by no means as good.

As far as "two-sides application" is concerned, the previous system is used twice over as shown in the following figure.



Schematic of a "two sides" paint applicator

This method of roller application may be replaced by a battery of pneumatic spray guns or an oscillating gun, controlled by a photo-electric cell which triggers off one, two or three guns depending on the width of the sheet to be coated at any one time. In this latter method the paint is preheated to 70° and is conditioned in 200 litre containers near to the apparatus.

8 — Stoving oven. Pre-drying before stoving the paint is of an extremely short duration (of the order of seconds). Pre-drying may be effected by a jet of hot air. Stoving of the paint coating takes between 1 to 2 minutes and depending on the type of paint may be at 200° or 250° in air ovens (convection) with a temperature gradient as follows: first part of the oven 180 to 190° for solvent evaporation, 250 to 260° for curing the paint. Depending on the line speed, this temperature may be higher, bearing in mind that for a particular material being processed, a heat treatment at higher temperatures may change its mechanical properties. For tinplate it is dangerous to exceed 190° because of the melting point of tin. If a line speed of 20 m/minute and a stoving of 2 minutes is considered, the oven should be 40 m long, which is important when added to the other units in the line. As against a convection stove, a high frequency induction stove which takes up less space may thus be preferred. The principle is as follows: a high frequency A.C. electric field created between the electrodes by the high frequency voltage, causes material placed between the electrodes to be heated.

9 — 10 — Coolers. At the exit from the oven, the painted strip being at a high temperature, it is necessary to cool it, first of all by a blast of cold air and then by immersion in water to bring the strip to 40°.

11 — Tension roll. Similar system to that described under 3.

12 — Storage. For the same reasons as given under 4, here is a unit which allows storage of strip during coil changing; the moving rolls are in this case low down, occurring just before a coil is removed from the end of the line.

13 — Recoiler. Between the accumulator and the recoiler there is a shear to part the strip as required.

Various kinds of paint used for continuous strip coating

There are several well defined characteristics required of the combination of surface treatment and paint. They are as follows:

Application

For surface treatment, rapidly acting products are vital since, as has been pointed out above, the strip spends about 10 seconds in the phosphating unit; the products should therefore have maximum efficacity in a minimum of time. With regard to the appropriateness of a paint coating, it should spread easily without streaking along the axis of the strip; on this latter point reverse roll coating has shown a very definite improvement compared with the conventional direct roll system, i.e. a roll turning in the same direction as the strip movement. Finally, the paint must be able to withstand rapid cure at high temperature without change in its surface and gloss.

Mechanical properties

Because the prepainted strip is coiled up it is necessary that the combination coating be very flexible and that it should have perfect adhesion. Furthermore as the sheets will be pressed or formed they should have particularly good drawability characteristics. It is therefore sometimes required that flexible and adherent paints should be able to withstand a tight 180° bend and drawing up to the rupture of the sheet.

Chemical properties

Depending on its use, the combination may have to resist alkaline re-agents, e.g. if the sheet is to be used in washing machines or in kitchen utensils, or is to resist bad weather if it is to be used as wall cladding for buildings.

The different types of paint which are encountered will now be considered.

Alkyd (glycerophtalic) paints

These are currently the most used, the proportion being about 45% of those used; they have the advantage of cheapness, ease of use and durability on exposure. Their disadvantages are inflexibility and very poor resistance to chemical reagents.

Paints with a thermosetting acrylic resin base

These make up about 20% of paints currently used in this kind of process. Their characteristics are: easy application, good flexibility, good adherence, excellent resistance to chemical reagents, in particular to alkalis, an adequate resistance to weathering. Unfortunately, their price is higher than that of those in group (a).

Paints with a vinyl resin base

These paints are very easily formed, and have a good resistance to weathering; their application is perhaps a little less easy and their price by reason of their low solid content (percentage of non-volatiles, or in other words the dry film which remains after solvent loss in stoving) is fairly high. Relatives of the vinyl paints are the organosols and plastisols, i.e. products with a high solid content which are being more and more used in continuous strip coating. This group makes up about 35% of the total.

Similar to the three groups are also paints with an epoxy resin base which do not have a good outdoor life, polyurethane resins and finally siliconized alkyds, the polyvinyl fluorides. In this last category it is interesting to note the silicon alkyds which are used in the U.S.A. and which have the following properties:

resistance to weathering, good colour stability;

resistance to high temperatures;

chemical resistance to acids, solvents, etc.

The degradation of the film outdoors is slow, although not imperceptible, after five years. Unfortunately these resins are very expensive, being almost three times the price of acrylic resins.

Economic factors in continuous precoating

The end usages of these sheets are many. For example, in the building industry as curtain-walling, or for venetian blinds, kitchen furniture, refrigerators, lighting equipment, "caravaning", manufacture of packing cases, mechanical industry, etc.

The process does however possess certain disadvantages, the first being the change in the paint layer during particularly fast and deep drawing operations. It is proposed, in these cases, to pass the sheets between deformation rolls, which should cause a progressive deformation. For assembly, spot welding seems to be an appropriate solution at the moment, seam welding being prohibited. The point should be made again that pre-painted strip requires, during deformation, new tooling concepts, slow deformation, rounded corners, and overall careful handling at all stages.

Another important disadvantage is that, if the strip is cut up for use in fabricating refrigerators or washing machines, the cut edges may become important sources of corrosion. It is also necessary to design articles with no sharp corners.

The advantages of such a process are: uniform thickness of paint coating, paint wastage reduced to a minimum, considerable increase in the tempo of production. For example:

A continuous coating line 1 metre wide operating at a speed of 40 m/minute will treat 38,000 m² of strip over a period of 8 hours requiring only half a dozen workers. The cost of a plant is about 1,000,000 French francs. This figure appears enormous, but the viability of such a line has been demonstrated.

In the U.S.A. there are at present 80 lines, whilst Great Britain and France each have fifteen, more for application to aluminium than steel. In the U.S.A. in 1962, 263,000 tons of steel were treated by this process; in 1963, 390,000 tons; and in 1964 an increase of 30% has been forecast. These figures break down to surface areas of:

1962, surface of prepainted steel: 52,650,000 m²
1963, surface of prepainted steel: nearly 80,000,000 m²

In 1964, the U.S.A. should have reached the 100 million m² mark. The figures above should be multiplied by two if — as is often the case — both sides are to be treated.

Continuous chemical treatment and coating of sheets has just been described. The principle is extremely simple, the application is most certainly practicable, although complicated and having a few disadvantages in use, but the rapid increase in tonnage treated by this process in the U.S.A. as well as other countries, proves that it is perfectly viable, if only because the user of the sheet may thus eliminate his own complete chemical treatment and paint installation with the assurance that this same sheet will not be affected during prolonged storage.

DISCUSSION

Claude BREDA

(Translated from French)

I should like to enlarge briefly on Mr. Andrieu's very interesting paper.

As the speaker remarked, one advantage for users of prepainted steel sheet is that the material is in good condition and protected and coated.

It needs a certain amount of care, in the form of surface treatment and painting, to produce material with these qualities.

The preparation of steel sheet is a particularly exacting task, and it is highly advisable to supplement the phosphochromic rinse with a demineralized water-rinse to prevent blistering.

Equally strict precautions should be observed during the cooling of the painted strip, especially when the line has two coats of paint (the second coat is usually only applied to one surface).

The quality of water used in this cooling operation is also important.

The main reason for mentioning this is to stress that great care should be observed in preparing surfaces; prepainted steel sheet has a great future before it, and although the ideas underlying its manufacture may be a little far away they are still necessary.

François BLANCHARD

The Part Played by Surface Condition and Surface Contamination in the Corrosion of Stainless Steel Tubes

(Translated from French)

Metallic iron always tends to resume its natural state, oxide which constitutes corrosion. Modern technology employs two main methods for combating corrosion:

(1) The application of coatings whose main function is to isolate mechanically the surface to be protected against external corrosive agents,

(2) The use of alloying elements such as chromium, nickel, molybdenum, etc., which, by making the metal more "noble", impart to it a certain degree of chemical inertness to its environment.

I shall first describe some traditional industrial techniques employed for the protection of plain carbon-steel tubes, and then go on to deal with stainless steels, which are in themselves corrosion-proof and therefore require no special protective coating. We shall see that these steels, although stainless as such, cannot be fully satisfactory unless certain requirements, in particular as regards surface quality, are met.

The following types of coating are currently in use for the protection of plain carbon-steel tubes:

bituminous products;

galvanized coatings;

epoxy resins or epikotes.

Bituminous products

These are by-products of the distillation of coal and petroleum. This method of protection has found universal application, and it would certainly be very difficult to compute the lengths of buried piping in service today which are protected by bitumens.

The techniques of applying bituminous products are now well developed. Both the inside and outside surfaces of the tubes are treated at the same time.

The aim is to obtain on the inside surface a thick coating (1 to 2 mm) of a bitumen derived from petroleum (of the ENDOPLAST type, for example). Melted bitumen is injected by lance into the preheated tube placed horizontally. This is followed by centrifuging; an operation which enables the bitumen to be spread and distributed evenly over the internal surface.

A primer of (of the CARBOLAC type) — a solution of coal tar in suitable solvents is first applied to the outside of the tube. The tube is then wrapped helically (fig. 1, p. 327) with fibreglass impregnated with Carboplast, a bituminous product derived from coal.

The bitumen and its fibreglass support constitute a covering which is completely proof against rotting. The coating is normally 3 to 5 mm thick, according to the required degree of protection.

The tube surface is then smoothed and given a lime-wash for convenience of handling and checked for tightness by a dielectric test.

Where the terrain across which the pipe is to be laid is rough and stony, a wrapping of asbestos felt can be added to increase the resistance of the coating to puncturing.

Buried pipelines treated in this way are highly resistant to soil corrosion. As an additional safety measure however, many users apply cathodic protection by a reactive anode or by drawing off current, with the result that corrosion of the exterior of buried metal pipe-lines has become a very rare occurrence.

These coatings are very reliable and are applied principally to underground water mains and pipelines for petroleum (LINE PIPE) or other liquids. The main advantages of these coatings are their impermeability, flexibility, stability and chemical inertness, their resistance to the action of bacteria, and their low cost.

Galvanizing

This consists, as you know, of the deposition of a thin layer of zinc on the steel. The zinc protects the steel in two ways:

(1) when exposed to dampness, it becomes coated with a thin surface film of zinc oxides and carbonates, which in many cases have a protective action.

(2) by galvanic action; zinc is electro-negative to iron with which it forms galvanic couples, the zinc being anodic and the iron cathodic. The result is that the zinc is corroded instead of the iron, and acts as a "sacrificial metal" (to use the Anglo-Saxon terminology).

There are different methods of galvanizing, *i.e.* hot-dip galvanizing, electro-deposition, metallization by the Schoop process, sherardizing and coating with zinc paints.

For tubes the technique generally adopted is hot-dip galvanizing. This process is very convenient, as it enables both surfaces of the tube to be treated simultaneously, giving zinc deposits of practically equal thickness on the exterior and the interior tube surfaces.

The various operations involved in hot-dip galvanizing are as follows:

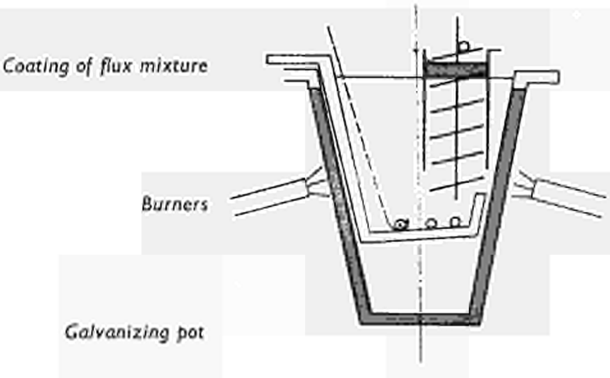
chemical pickling followed by rinsing;

pre-fluxing;

fluxing;

galvanizing proper.

The last two operations are also carried out simultaneously (see figure below).



Pre-fluxing is done by immersing the tube sections in a hot aqueous solution of double zinc ammonium chloride at a low concentration, with the object of

(1) protecting the pickled surface against re-oxidation before galvanizing can be started;

(2) eliminating residual iron salts remaining after pickling.

Fluxing of the tubes takes place in a bath of the same salt, but this time in the fused state. This bath usually forms a covering over the molten zinc, its main function being to prevent surface oxidation of the zinc bath. It is essential that the tubes should penetrate directly into the molten zinc without having to pass through a layer of oxide which would impair the quality of the galvanized product.

The temperature of the zinc in the galvanizing vat is 430 to 470°C.

On leaving the galvanizing vat, excess zinc is removed from the outside of the hot tube by wiping with an asbestos pad, and from the inside either by natural draining or by injecting steam under pressure.

I do not think we need go here into the details of the galvanizing process and of the important part it plays in combating corrosion. Galvanized tubes are highly resistant to corrosion by water and atmospheric pollutants. They are, therefore, particularly widely used for domestic hot and cold water mains, irrigation pipes, scaffolding and tubular steelwork.

Epoxy resins or epikotes

Epoxy resins or epikotes are thermosetting resins which produce adhesive coatings that are hard and highly resistant to shock and abrasion, and to corrosion by water and certain chemicals.

This process has only recently been developed and is not yet used as widely as the two other techniques just mentioned.

The base products look very much like conventional thick paints; they can be applied in two ways:

(1) by cold polymerization using catalysts which are added at the time of use;

(2) by high-temperature polymerization without catalysts, carried out by stoving at 170-200°C.

The second method is the more effective from the point of view of corrosion resistance. It is usual practice to apply several coatings, depending on the result required, but intermediate stoving must always be carried out between two coatings.

In current practice, epikoting is more generally applied to the interior of the tubes than to the exterior; the surface condition required is that produced by shotblasting or pickling and shotblasting.

The coating is carried out by moving inside the tube a pistol with a rotating jet mounted on a suitable device, with the tube in a horizontal position. On completion of the coating the tube is tested electrically for tightness.

We have tested epikoted tubes for resistance to corrosion by water alongside identical but untreated tubes by forced circulation of a highly aerated, hence aggressive, river water through tubes placed horizontally above ground, the water circulating continuously under pressure in these tubes.

These trials began in 1958. The last examination of sections taken from our different specimens revealed a deeply etched appearance of the untreated tubes, with a depth of corrosive penetration up to 2·40 mm. The epikoted tubes, on the other hand, had a new and bright appearance, with just a few traces of corrosive penetration of as little as 9/100 mm, although the trials had lasted seven years.

At present however, epikoting will obviously be used primarily for petroleum and natural gas pipelines (for both the extraction and the transportation of these products) because of its anti-corrosion properties, its excellent resistance to drilling slimes, salt water, concentrates satured with carbon dioxide and hydrogen sulphide, and to fatigue corrosion of the drills.

Epikoting will also be employed more and more because it produces smooth coatings which considerably reduce pressure losses. In some cases it enables the flowrate to be increased by as much as 25% with a pumping output reduced by 5%.

In addition, and this is not the least of their qualities, these coatings prevent the trapping of solid paraffins and asphaltenes, which tend to obstruct the pipes and are for that reason dreaded in some oilfields (Hassi Messaoud for instance).

Epoxy-coated pipes will unquestionably be used on an increasing scale in the highly promising offshore-drilling sector.

It would seem at present that the technique of epoxy coating is bound to develop. Pure resins are now available commercially in powder form and these should facilitate coating operations in future.

The coating would then be applied by depositing the powder under an intense electrostatic field, the metal being preheated. The particles would fuse on coming into contact with the metal, and polymerization would take place on passing through the stove.

This new technique seems attractive. Probably it will help to stimulate the advance of the epikoting process, as this will no longer involve either the handling of viscous products or polymerization by means of catalysts, a process in which the mixture, once prepared, must be used without undue delay and it will also make it unnecessary to superimpose several layers, since the coating process can henceforth be completed in a single operation.

We now come to stainless steels, which are employed under conditions very different from those of plain carbon steels. There is no need to isolate stainless steels from their environment; on the contrary, we shall even find that in many cases they can resist corrosion only when all interposition of foreign bodies (scale, stains and dirt of various kinds, oxides, etc.) between the exposed surfaces and the surrounding medium is prevented.

It is known that the excellent corrosion-resisting behaviour generally characteristic of stainless steels is due to the presence of a thin passive surface layer, caused entirely by the presence of chromium in the steel. This layer, which according to classical theory consists of a film of oxide, can be formed only in a relatively oxidizing medium. It is therefore fundamentally important for this layer to have a satisfactory structure and any condition liable to disturb it will promote corrosion of the steel. Thus it may be imagined *a priori* that the nature of the very narrow zones immediately adjacent to the layer (on the metal or the solution side), and capable of exerting an influence on it, can have a very important bearing on the behaviour of the material, quite apart from any considerations of the grade of steel used or at the mean composition of the external medium.

The case of a tube, simultaneously in contact with two media which often differ greatly in chemical composition, temperature, pressure and rate of circulation, and separated by distances of the order of a millimetre, provides very favourable conditions for testing the corrosion resistance of stainless steels.

We intend therefore to review the various forms of corrosion which we have encountered in practice, and to attempt in each case to see the importance of the thin surface layer located on both sides of the metal-medium interface.

Uniform corrosion (on the scale of the steel grain size)

This type of attack, often predictable within quite a good degree of approximation, if only from corrosion tables, does not in general cause any surprise. In this case the part played by the surface and by contamination of the steel is probably minimal. We will however quote two examples where surface contamination ceases to be unimportant:

(a) when accumulated deposits can cause considerable local overheating, which always favours accelerated attack;

(b) the case of inadequately descaled tubes. We have actually come across instances where residual scale, left after hot bending for example, could promote an accelerated attack in certain media such as acetic acid, even when the same tube is completely resistant to attack after normal de-scaling.

Intergranular corrosion

The case of intergranular corrosion, characterized essentially by loss of cohesion at the grain boundaries, does not appear to be very closely associated with any particular surface condition, but is more a function of the chemical composition of the steel (content of stabilizer and/or of carbon), and especially of the structural state of the grain boundaries (precipitation of carbides) promoted by heating at about 600-700°C. The only examples where the surface of the metal could have made an important contribution to this type of corrosion were provided by the surface carburization of tubes, which occurred accidentally while processing the metal (the tubes were contaminated with oil before hardening, prior to hot bending), or during service. To the best of our knowledge, this type of corrosion no longer poses a major problem; provided that care is taken to ensure a clean metal surface, no trouble should arise from this cause.

Pitting corrosion

This affects stainless steels in contact with media containing chlorides, bromides or iodides, and appears as minor, very localized zones of attack, about the size of a pinhead, which often hollow out a pocket or "cavity" under the surface (see figure below); perforation can take place very rapidly.

In a given medium (which is not always under control) the condition and surface contamination of the tube surface acquire considerable importance for this reason, and constitute one of the two very effective means by which this form of attack can be controlled (the other factor, which will not be discussed here, being the selection of the grade of steel).

Micrographic appearance of a corrosion pit on the internal surface of a tube 18-10 Mo-Ti.

Surface contamination

All the deposits accumulating on the tube (scale, various kinds of dirt and in particular, rust) are especially favourable to the acceleration of the pitting process; the deposits probably act in three ways:

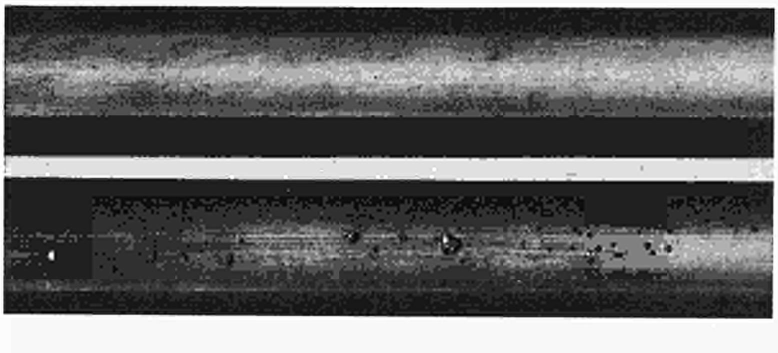
(1) they promote the formation of local concentrations of halides;

(2) being poor conductors of heat, they can lead to local temperature increases, which accelerate corrosive attack;

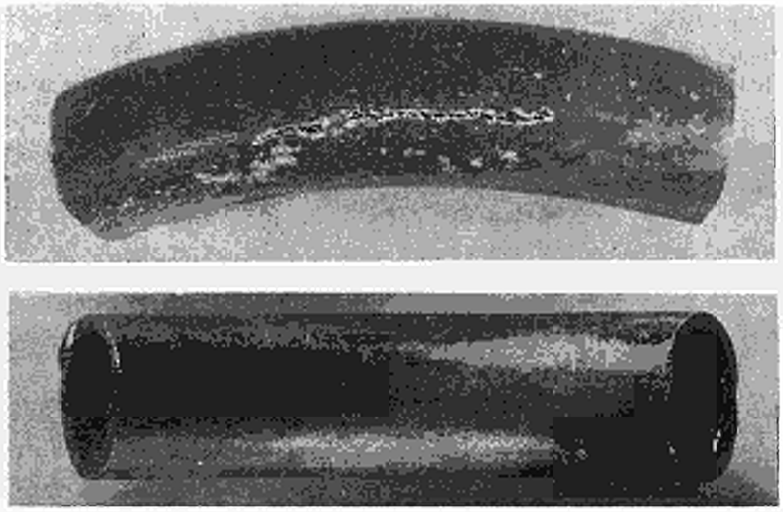
(3) as they are sometimes too strongly oxidizing (exogenous rust for example) for a halide medium, they can place the metal beyond its breakdown potential, thereby starting up the pitting process.

In fact, almost all the cases of pitting corrosion which we have encountered are produced in association with deposits arising from the external environment; exogenous rust appears to be particularly harmful in this respect. These deposits are often localized on the upper surface in the case of horizontal tubes, or at constrictions caused by obstructions (see figure below).

The oxide scale remaining on the tube after a bending operation, for example, is also very liable to concentrate the attack at this point (see following figure).



Lower and upper external surfaces of a tube 18-10 BC placed horizontally in service in an aggressive medium. Only the upper part where deposits have accumulated is pitted



Pitting and grooving formed preferentially on the only scaled part of a tube 18-20 BC, bent hot by torch heating the external part of the bend

Surface condition

Laboratory experiments have shown, for example, that fine mechanical polishing improves very noticeably the resistance to pitting of welded tubes of ferritic 17% Cr steel. In this case, the slightly greater susceptibility of the weld bead to pitting attack is greatly attenuated. The following table gives the results of the saline boiling test on the tube made in 17% Cr ferritic steel, in the as-welded condition and with a mirror polish.

These results have been confirmed by several determinations of breakdown potential in clear solutions of ClNa.

Saline boiling test (AFNOR) on specimens of welded tubes of ferritic Cr 17 % steel in the mirror-polished state (PM) and in the as-welded condition

Material	Surface exposed	Rusting after				Max. depth of pits in 1/100 mm	
		64h		120h			
		Untreated	Mirror polished	Untreated	Mirror polished	Untreated	Mirror polished
tube ⌀ 35 × 0.8	Weld	R2	R0	R5	R1	26	2
	Outside the weld	R1	R0	R1	R0	21	0
tube ⌀ 35 × 1	Weld	R2	R2	R5	R4	19	6
	Outside the weld	R1	R0	R1	R0	1	0
tube ⌀ 30 × 1.2	Weld	R3	R1	R5	R2	9	1
	Outside the weld	R1	R0	R1	R2	1	12

Rusting indicated in accordance with DIN 53.210
R0: no rust
R1: 0·5 to 1% rust
R2: ca 5% rust
R3: ca 15% rust
R4: 30 to 40% rust
R5: 50% rust

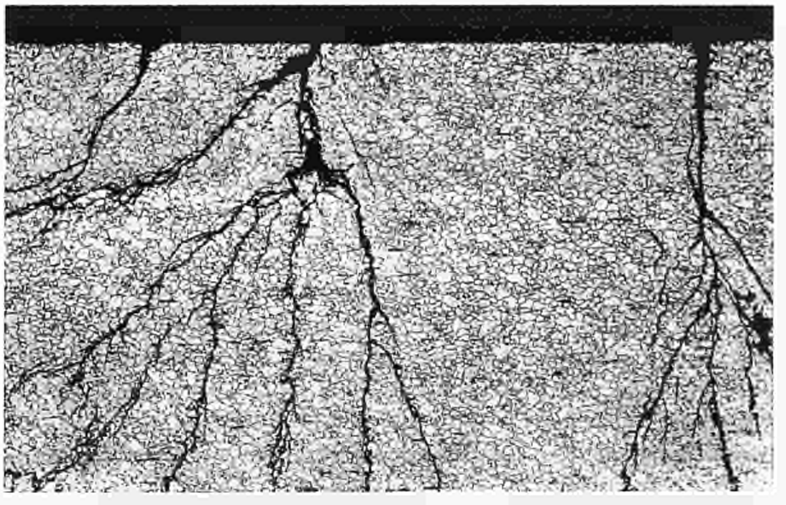
In this particular case of pitting attack, on the other hand, we found no advantage in using electrolytic polishing.

In any case, with current practice, the polished tube has the additional advantage of offering a surface which is less liable to retain dirt.

Stress corrosion

It is here that the environment of the metal-medium interface is most likely te exert the greatest influence.

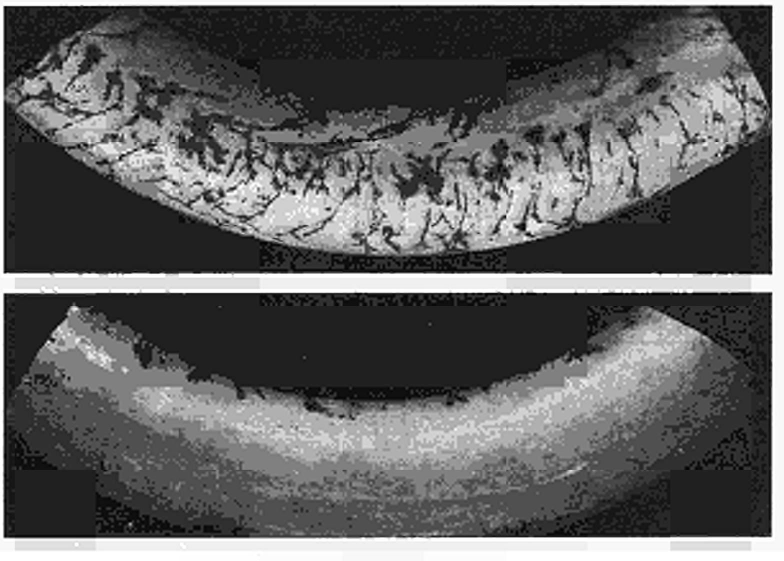
It will be recalled that this type of corrosion, which is found in most of the present-day austenitic steels, when subjected to mechanical or internal stresses, and when operating in contact with certain hot media which promote this form of attack (especially those containing chlorides), is characterized by the formation of deep, very penetrating transgranular cracks. (The photomicrongraph below shows the appearance of these cracks).



Micrographic appearance of transgranular corrosion cracking (exchanger tube in 18-10 Mo-Ti)

Surface contamination

This is again very effective in accelerating the process of stress corrosion. Again, almost every case which we have met of cracking under stress was associated with surfaces contaminated with scale, rust and various kinds of dirt. It is possible that we are dealing with a mechanism bearing some resemblance to that described above for pitting corrosion. The figure below gives an example of cracks occurring in service, and formed only on the upper surface of the tube in association with the deposits.

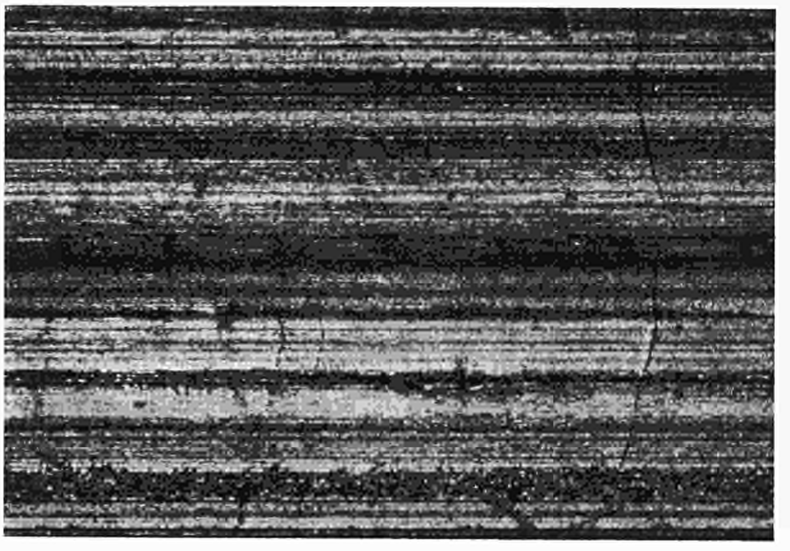


Upper and lower surfaces of a tube 18-10 Mo-Ti in contact with an aggressive medium (brine containing vinegar at 100 °C). The stress corrosion cracks are only found on the upper part where deposits have accumulated

Surface stresses

A second, far from negligible factor, is the presence of stresses of different origins lying completely within the surface layer of the metal.

When other favourable conditions are also present, it is not unusual to find that these stresses promoting cracking originate entirely at the surface.



Transverse stress corrosion cracks produced by longitudinal surface scoring due to the passage of a mandrel (steel 18-10 BC — medium: boiling M_gCl_2)

The above figure gives an example of transverse stress corrosion cracks produced by surface longitudinal scoring due to the passage of a mandrel. As far as the figure below is concerned, simple cold punch marking is sufficient to cause stress corrosion cracking when the medium is favourable (experiment in the presence of boiling $MgCl_2$).

Stress corrosion cracks produced at the point of application of a marker punch (steel 18-10 BC)

Another source of surface stresses which can reach very high values is thermal in origin. Its importance stems from the low thermal conductivity of the austenitic steels, combined with a high coefficient of expansion. Very rarely are internal and external walls of the tube the same temperature under service conditions. On the contrary, the function of the tube often requires its internal and external temperatures to differ considerably, in some cases by several hundred degrees. Sometimes the stresses thus developed can reach several hectobars, and can even exceed the threshold value of the elastic limit. When the medium within which the stresses are developed is favourable (as cold as possible) then stress corrosion cracking takes place.

In general, it is clearly impossible to eliminate those stresses which are necessary for the operation of the equipment. Instead, the problem will be solved by the following measures:

(a) by the selection when possible of a cold medium not liable to generate stress corrosion. The complete absence of chloride, oxygen in solution and dirt is often difficult to guarantee. It is sometimes more convenient to utilize a non-aqueous fluid (air cooling for example) in certain very vulnerable sections;

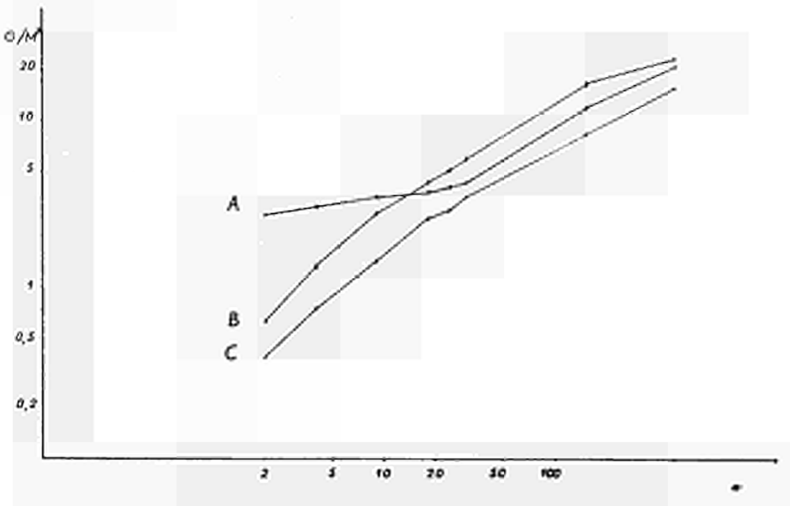
(b) by the selection of a more resistant grade of steel (high nickel or silicon stainless steel).

We will end on a more optimistic note, by pointing out that these stresses are capable of relaxation in time by flow processes, so that a degree of immunisation appears after a certain time in service.

Dry corrosion at elevated temperature

Many investigations reported in the literature have already shown that the steel composition (in particular the chromium content) has a decisive effect on the kinetics of high temperature oxidation.

During our laboratory tests in dry air, which were aimed at establishing the kinetic pattern in terms of the steel grade, we found that the surface condition also had an effect, at least at the beginning of the oxidation curve, say during the first 100 hours, and that the effect was significant. Thus a comparison of the curves of weight increase at 850 and 800°C of a high temperature steel (25% Cr-20% Ni) for the three states (a) as-heated, (b) cleaned and polished to grain 120, (c) cleaned and polished electrolytically, shows that the oxidation "plateau" is reached more and more slowly with increasingly fine polishing.



A — As-heated
B — Cleaned and Polished to Grain 120
C — Cleaned and Electrolytically Polished

Appearance of the oxidation kinetics of a high-temperature steel 25% Cr-20% Ni at 850 °C in dry air, for different surface states

In conclusion, we have tried to show, by means of concrete examples from practice, and by check tests in the laboratory suggested by works experience, how the surface zone of the stainless steel tube could in itself be an important factor in the initiation of corrosion. We have also been able to establish how any deposit accumulating on the tube has a harmful effect on its corrosion resistance during service. Constant attention paid to this particular point will ensure a longer life for the material, and is often a major factor in preventing the phenomena of corrosion.

DISCUSSION

Jacques M. DEFRANOUX

(Translated from French)

I would like to raise a number of practical points in connection with Mr. Blanchard's very interesting paper.

Steelmakers and the manufacturers of semi-finished products (flats, tubes, etc.) make every effort to get the best out of their material. This is achieved by continuous control and by constant improvements in the production processes at every stage, from melting of the steel to the final surface treatment.

It is important that the manufacturer of equipment in which these semi-finished products are used should also take every precaution to ensure that the condition of the material, including its resistance to corrosion in service, should be of the highest possible standard. Unfortunately this does not always happen at present.

Among the various causes of deterioration in the surface quality of stainless steel, I would draw special attention to the embedding of particles of ordinary steel in the stainless steel surface. These particles lead to discontinuities in the passive film which forms the basis of the corrosion resistance of the type of steel; they are particularly dangerous when resistance to pitting corrosion or stress corrosion cracking is desired.

Some of the most common causes of these embedded particles in our experience are the following:

(a) Processing stainless and ordinary steels side-by-side in the same workshop;

(b) The use of abrasives containing iron, or of brushes made of ordinary steel wire;

(c) Welding with coated rods, the core of which consists of ordinary steel, while the alloying elements are introduced by the coating. There is always a risk with these rods that fine droplets of ordinary steel will be spattered on to the stainless steel surface surrounding the weld.

It is certainly permissible to remove these iron particles by a "decontamination" treatment in which the workpiece is immersed in a solution of nitric acid, for example 15-20 wt % HNO_3. However, this treatment is always costly, often hazardous or uncertain, and sometimes impracticable. Would it not be better to eliminate the need for such treatment by taking precautions in the form of very simple working rules, to be followed from the time the metal is first put into use?

Ralph Victor RILEY

In the epoxide lining of steel tube by the powder process I have found difficulty in ensuring a film of resin completely sound and free from porosity. Could the speaker give further advice upon this matter?

François BLANCHARD

(Translated from French)

It is quite true that porosities are found, and the same can be said of all thin-film linings. These porosities are often in the form of small pinholes. I am sure this will be confirmed by the enamelling experts present.

At present, the difficulty is overcome by doubling, trebling and sometimes quadrupling the number of coatings, an intermediate firing being required for each. An electrolytic sponge is used for checking whether the porosities have disappeared.
With the new potentialities of epoxy resins in powder *form* the probl em ought not to arise as the thickness needed to overcome it could, in theory, be applied in a single operation.

Fabrizio ARNALDI

and

Antonio PRATO

Surface Protection of Rolled Steel in Shipbuilding

(Translated from Italian)

In the absence of precise statistics, it may be said that the total quantity of steel used for shipbuilding in the six Common Market countries averages about 1,400,000 tons per annum and the Italian share is about 200,000 tons per annum. Of the total quantity mentioned, about 14% is in steel sections and 1·86% is boiler plate exceeding 3 mm. thickness. It follows that the average quantity of plate used is about 1,200,000 tons.

The plate to section ratio is increasing due to a tendency to employ fabricated beams of plate and flats instead of large sections to reduce weight. This applies particularly to substitution of bulb sections. Production statistics for the European Community in 1964 show a total plate output of approximately 8,000,000 tons. It can therefore be assumed that about 15% of the total plate production is used for shipbuilding.

Considering technical and economic problems concerned with surface protection in the interval between steel production and assembly in the finished ship, this may be divided into four periods:

(a) Time lapse at the steelworks and in the stockyard.
(b) Transporting to the shipyard.
(c) Period in the stockyard before use.
(d) Shipyard processing time and that necessary to complete the ship.

An average total time usually exceeds one year during which the material is subject to progressive rust formation superimposed on the mill scale resulting from the rolling process. At the present time, both plates and sections are dispatched from steelworks to shipyards in the rough-rolled condition and must be suitably treated before fabrication. (Figure 1, p. 359).

Surface Treatment

To resolve problems arising from steel surface condition, the following processes must be carried out at the shipyard:

(1) shotblasting to remove mill scale and rust, and to provide a clean surface;
(2) surface examination for possible defects; provide for their elimination or discard defective plates;

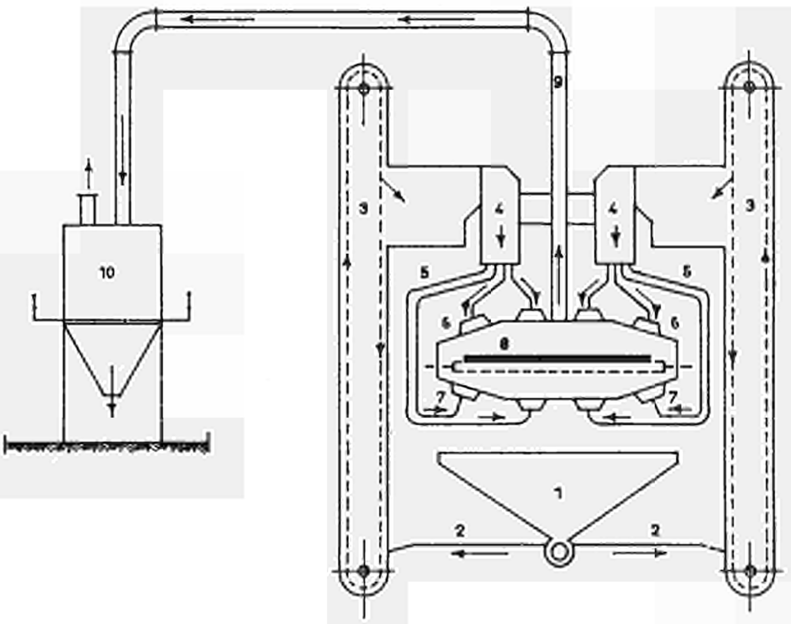
(3) provide surface protection for the processing period to avoid new rust formation;

(4) final surface protection of finished work.

These operations are examined in the following notes:

Shotblasting

Until a few years ago, surface cleaning of plate was carried out in the steel stockyard and with limited capacity hand operated equipment at the shipyard. (Figure 2, p. 359). Although the cost of these operations was high, the results were often quite unsatisfactory. Serious problems also arose from dust formation affecting operatives' health and causing damage to adjacent machinery. Shipyards with modern equipment



1 — *Sand collecting hopper*
2 — *Conveyors*
3 — *Sand elevators*
4 — *Distributor tanks*
5 — *Pipe feeders for turbines*
6 — *Upper turbine sand pipes*
7 — *Lower turbine sand pipes*
8 — *Steel plate*
9 — *Dust suction pipes*
10 — *Filter*

Unit for automatic sand-blasting of horizontally fed steel sheet

are now provided with automatic shotblasting plant in a completely enclosed building, the plates being carried through the machine on a roller conveyor in either the vertical or horizontal position (See above figure and figure 3 on p. 360), and both sides of the plate are cleaned simultaneously.

Such plants have sufficient power to remove completely mill scale and rust and part of the metallic grit abrasive is recovered for recirculation and the remainder discarded. Dust generated is removed to a filter and that adhering to the plate is automatically collected by a vacuum cleaning device within the machine. Plates emerge after shotblasting with perfectly clean surfaces, such results being obtained by appropriate preselection of abrasive grain size, blast power, and plate travel speed through the machine.

Visual Examination of Cleaned Plate

After cleaning, a careful examination is made for cracks, pitting, slag inclusions, etc., (See figures 4 and 5, p. 360, and 6, p. 361), to avoid processing material with obvious defects which otherwise would become evident at a later stage with consequent production losses.

Even when defective material is replaced in the early stages of processing, some interference with normal production flow is inevitable. Such production delays can be reduced if substitute material is available in the stockyard, but in the case of special material requiring replacement by the steel manufacturer, serious production losses can be involved. In modern shipyards employing a mechanized steel processing operation cycle to reduce production costs, its economic value is seriously prejudiced in consequence.

These considerations emphasize the adverse effects on shipyards of material being supplied by the Steel Industry in the roughrolled condition, surfaced by mill scale and rust, so that surface defects are not found before dispatch. The Steel Industry suffers in consequence too, in regard to objections from customers transport charges for replacement material, compensation to customers, etc.

The question therefore arises as to whether it would not be preferable to shotblast plate at the steelworks and examine for defects before dispatch, and so resolve a serious problem for both supplier and customer.

Surface Protection after Shotblasting

For economic and practical reasons, it is important to avoid rust formation on shotblasted steel due to lack of protection during fabrication processes. The cycle of operations begins with preparation of single components, marking off, cutting, bending, etc., and continues with welded fabrication of sections which are transferred to the building berth and assembled to complete the ship's hull. The complete cycle occupies about six months, and if surface protection is not provided immediately after shotblasting, either fabricated sections or the completed hull must be cleaned again by brushing or shotblasting (figures 7 and 8, p. 361). In this case, automatic equipment cannot be used and costly manual operations are necessary in adverse conditions where dust generation during shotblasting is particularly harmful.

An additional factor to be considered is that of minute surface pitting occurring during shotblasting which favours rust formation in wet and humid conditions. It is therefore even more important that, once cleaned, steel surfaces should be given immediate and adequate protection. At the present time, this problem has not been resolved completely and sasisfactorily in shipyards from the technical and economic points of view. The most desirable solution would be surface protection by automatic or mechanical application of a primer coat having the following basic characteristics:

(a) it must ensure adequate surface protection of all parts to be processed for the ship's construction period of about six months;

(b) it should be resistant to mechanical stresses during profiling, bending, etc., of the material;

(c) it should not produce smoke or poisonous fumes during gas cutting and welding operations;

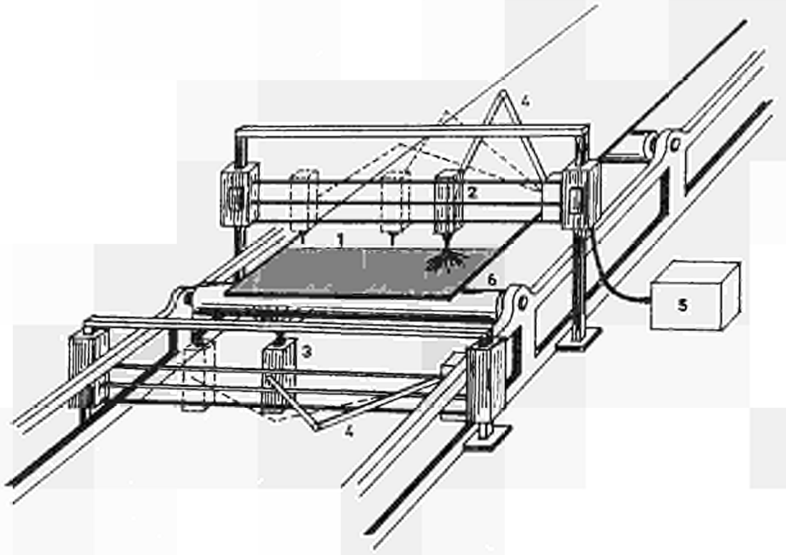
(d) it should not adversely affect weld quality;

(e) it should be suitable for application with mechanical or automatic paint spraying equipment;

(f) it should have rapid drying characteristics;

(g) it should constitute a suitable primer for a wide range of marine paints applied to completed ships.

This problem has been examined by paint manufacturers and an assurance given that primers can be supplied conforming in a large measure to these requirements. It is therefore considered that study and experiment with primers proposed by paint specialists will provide for automatic application in the near future with



Unit for automatic spray-painting of horizontally fed steel sheet

consequent economies in ship construction costs. The above figure shows a diagram of an automatic spraying plant for plates disposed horizontally. In a mechanized operation cycle, this could be arranged in line with the automatic shotblasting machine.

If the steel industry would examine the possibility of shotblasting steel before dispatch to shipyards, it may also be possible to conceive application of suitable protective primers, thus avoiding further cleaning operations before final painting of completed ships.

Final Surface Protection on Completion

Having completed ship construction operations, there remains the problem of surface protection of the finished ship by application of appropriate paints. It must be remembered that these types of paints must meet a multiplicity of requirements and are sometimes chosen by shipowners when construction is well advanced. It may be that final paint types to be used will not be known to the shipbuilder at the time of ordering the steel and when the protective primer is applied. When final painting of the finished ship is carried out, the following alternative conditions will apply:

(a) final paint type selected is suitable for direct application on the primer surface originally used;

(b) composition of the final paint type is unsuitable for the primer used and the latter must be removed.

Case (a) provides the most favourable conditions for full exploitation of the practical and economic advantages of initial surface protection. Case (b) requires removal of primer from the completed ship, but this can be done by normal brushing and does not compare with the lengthy process of rust removal. The advantage of initial protection therefore remains.

Conclusion

The object of this paper can be summarized by the following major points:

(1) To emphasize the necessity for ascertaining plate surface defects by shotblasting before the material is processed in the shipyard;

(2) To demonstrate the technical and economic advantages of surface protection immediately after shot-blasting;

(3) To draw attention to the possibility of operations referred to in points 1 and 2 being carried out by the steel industry before dispatching plates to shipyards.

Pierre BLANCHETEAU

Protection of Rolled Steel Products for Shipbuilding

(Translated from French)

Messrs. Arnaldi and Prato in their paper rightly emphasize the very large tonnages of steel, and particularly of steel plate, used in shipbuilding. Steelmakers have always attached the very highest importance to all problems connected with the shipyards, not only as regards the intrinsic quality of the steels, but also as regards the surface of the products.

The closest attention is given to the surface of the plates during production: the semis, the blooms or ingots, are meticulously rid of their defects (dross, blisters, cracks and so on) and reheated in carefully regulated furnaces, while modern sheet mills are equipped with high-powered water-jet descalers working at a pressure of 100-120 K° which fettle the plates thoroughly before each rolling pass.

Also, contrary to what was stated in the paper, the plates are closely scrutinized on both sides with the aid of special "turnover gear" before they go on to the finishing stage. All visible flaws are eliminated before the plates are shown to the inspecting agents, who examine them for surface as well as for quality, so it is extremely rare for plates with any significant surface defects to reach the shipyards.

One yard, in particular, has been supplied with thousands of tons by French steelworks, and not a single complaint has been received from them concerning surface defects. So the complaints we have heard from Messrss. Arnaldi and Prato can only refer to very exceptional cases of sheets probably coming from old and poorly-equipped plants, or even possibly bought in an emergency from stockists. The few unfortunate instances quoted in their paper are no justification for casting aspersions on ship plates generally.

Surface preparation of rolled products

By reason of their chemical composition, modern qualities of ship plate, since they have to be at once highly weldable and highly resistant to nicking, are found to be more liable to corrosion than the plate which used to be employed for riveted hulls. This problem has been exercising the minds of shipbuilders and shipowners for a good many years; one solution suggested, the use of special paints giving effective protection against corrosion, has come to be more and more adopted.

As painting can only be effective if the surfaces concerned are entirely free from rolling scale and rust, the question of surface preparation has come more and more to the fore, and the course has very naturally been taken of pickling the plates before use and immediately applying a primer to protect them until the final coats are added.

Now, at what stage can this best be done—at the steelworks or at the yards?

In the last section of their paper on "Final Surface Protection of the Finished Whole," Messrs. Arnaldi and Prato emphasize the difficulties which can arise if the choice of the paint for the final coats—which will only "take" properly with a specific primer—is left to an unduly late stage: we are informed by some shipyards that it is quite often left to the very last minute.

Another problem is that, out of a series of similar-sized plates, some may be for use in one part of the vessel and some in another, with the choice of the final coat depending on the location. The authors of the memorandum suggest applying the primer at the steelworks, but this makes extra work and means much extra expense for nothing. So, incidentally, would shotblasting alone by the steelworks without the application of the primer, since the sheet would have to be pickled all over again at the yard.

Furthermore, there are other objections as regards overlapping of responsibilities between the supplier of the sheet and the yard, which would raise very real difficulties.

Thus once the primer has been applied, the steel has to be handled with great care to avoid any deterioration or scratching of the protective coat. The various handling operations involved in transporting the sheet and storing it in the stockyard would inevitably cause deteriorations for which each party would blame the other.

Also, what would happen if for any reason the final coat turned out to be insufficiently resistant? Would it be held to be the fault of whoever applied the primer or of whoever applied the final coat? It is obvious what acrimonious argument there would be when one thinks of the financial implications of such a dispute.

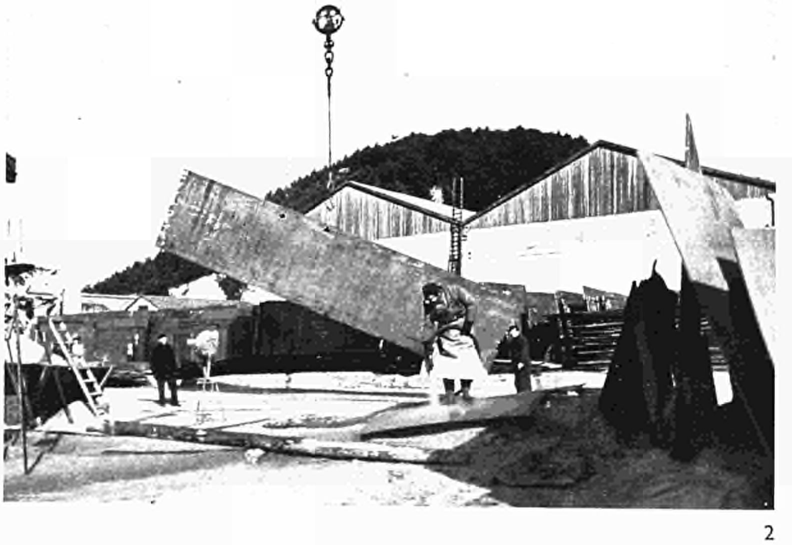
I wil say nothing of the difficulties that might arise in assembling steel products from different sources if the primers were found to be incompatible.

Then again, some shipyards have pointed out to us that the protection of personnel against the poisonous fumes produced in oxygen-cutting or welding of primer-coated steel may be impaired if the thickness of the primer, which needs to be very carefully regulated, is in some places above a certain critical value. The supplier of the steel could thus find himself involved in labour-relations difficulties arising in this connection.

On all these grounds, the shipyards we have consulted give it as their very definite opinion that it is for their industry to equip itself to carry out all pickling and protection operations, since it is felt that divided responsibilities in this matter would be entirely undesirable. Accordingly, a great many yards are either already equipped or are procuring the equipment to do their own sandblasting and prime-coating of the steels supplied to them.

List of illustrations

1



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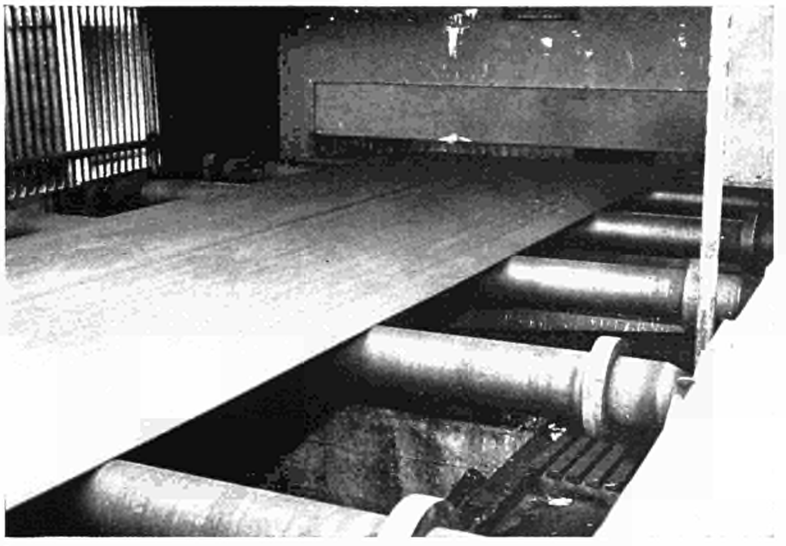

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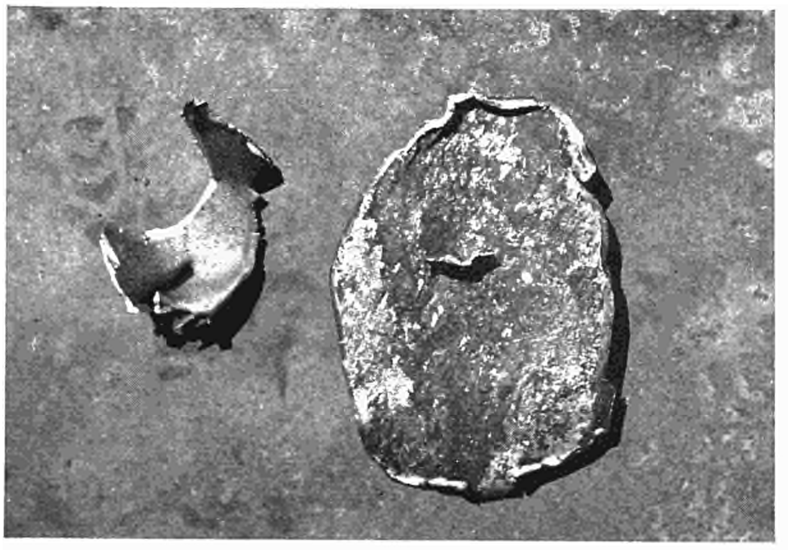

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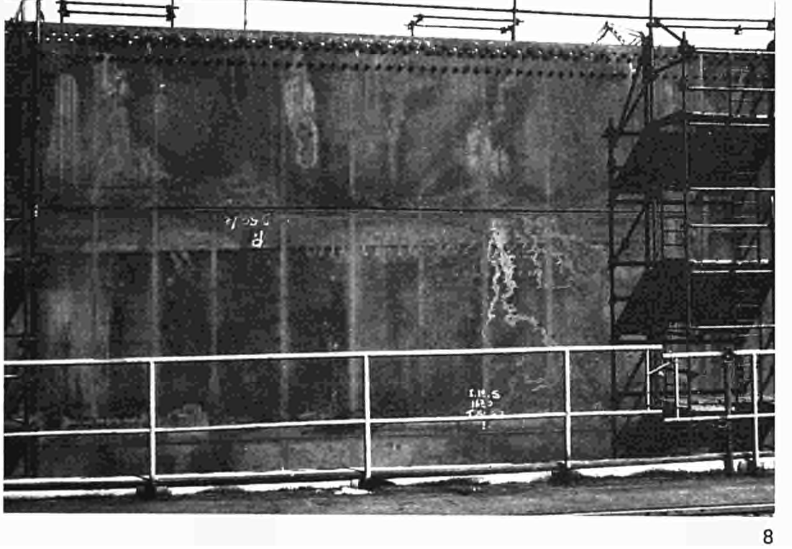


8

P. MORISSET

Establishment of Standards Concerning Protection of Steel by Metallic Coatings

(Translated from French)

A common feature of metallic coatings is that they can be defined by their thickness. Indeed, however they are formed, whether by electrolysis, chemical reaction, fusion of metal or any other method, the structure of the metal applied in this way is quite uniform and modifications of the steel at the interphase are negligible enough for the quality of the coating to be regarded as essentially dependent on its thickness. Furthermore, the metal applied must obviously be thick enough if it is to provide adequate protection for the steel.

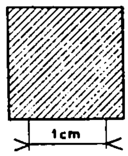
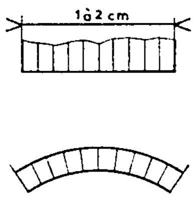
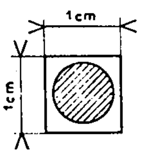
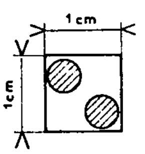
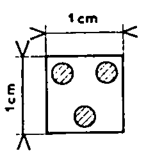
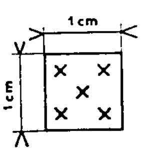
Thus, for each type of metallic coating, standardisation generally distinguishes a range of three, four or five thicknesses which define the same number of distinct qualities of protection provided for the underlying steel.

As a result, measurement of the thicknesses of metallic coatings is a basic operation governing the whole technique of manufacture and every commercial operation. This thickness measurement must be standardised so that it can be as independent as possible of the method or equipment used. The present progressive employment of equipment making use of physical phenomena, whereby practically punctual, non-destructive measurements may be taken, modifies, sometimes without our realising it, the traditional ideas of nominal, mean and minimum thickness, which had been adopted initially in the standards owing to the use of chemical methods involving the solution of the coatings.

Measurement of the thickness of a metallic coating by chemical means consists in dissolving the coating and then determining the thickness by the weight difference, measurement of a volume of gas liberated, determination of the coating metal or measurement of the solution time. In all these processes some of the coating is inevitably dissolved. As a result, the measurement is taken on an area generally varying from 1 dm^2 to 1 cm^2. Thus the strictest idea of minimum thickness, as in the present standards, with the use of chemical methods, appears to make it essential for the area on which the measurement is taken to be in the region of 1 cm^2.

New methods which came into use some years ago use physical phenomena and have the remarkable advantage that they enable non-destructive measurements to be taken. They include the following:

Magnetic methods for the determination of the thickness of a non-magnetic metal on steel, electrical methods with the production of Foucault currents based on differences between the conductivity of the applied metal and the steel forming the base, methods using X-rays, the sensitivity of which increase according to difference between the atomic number of the iron and the metal applied. Measurements are carried out either by contact with a feeler or by the impact of a beam of electrons. The area on which the thickness is measured is therefore generally much smaller than with chemical solution and the feeler often makes spot contact. Now the thickness of coatings is not generally uniform and quite wide variations may occur even between two points which are fairly close together. Surface form governs the regularity of the thickness of the coating and surface irregularities of the base metal may normally be quite considerable. An electrolytic deposit on a surface with very convex or concave parts, a hot-galvanisation coating normally comprising irregularly distributed iron-zinc alloys, or a coating provided by metallisation with a spray gun on a suitably sanded surface may be of excellent quality although spot measurements reveal variations of thickness amounting to 50% between two points only a few millimetres apart. This however is valid for hot galvanisation solely in the case of magnetic methods.

Number and distribution of measurements		*Measured surface in the method employed*
	*Single measurement*	*Measured surface greater than 1 cm.²*
	*Arithmetical mean of 10 measurements uniformly spaced on a 1 to 2 cm. line* *Single measurement*	*Linear measurements in a plane having a cross-section at right-angles to the coating (micrographic section)* *Diameter of the measured surface in the range from 5 to 10 mm.*
	*Arithmetical mean of two measurements*	*Diameter of the measured surface in the range of from 5 - 10 mm.*
	*Arithmetical mean of two measurements*	*Diameter of the measured surface in the range of 3 to 5 mm.*
	*Arithmetical mean of three measurements*	*Diameter of the measured surface less than 3 mm.*
	*Arithmetical mean of five measurements*	*Point measurements*

Calculation of the minimum thickness of metallic coatings on a control surface of the order of 1 cm.² as a function of the measured surface area in the method employed (extract from French Standard NF A 91-010)

The systematic errors which may arise from haphazard, quasi-punctual measurements of thickness may be imagined. It is essential, therefore, for standardisation to fix the dimensions of the reference area on which the minimum thickness must be determined at every stage of production, trade and utilisation at which quality is tested.

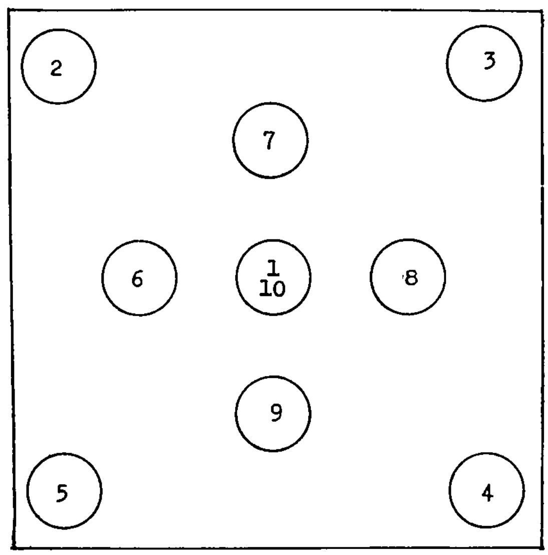
Take, for example, the commonest case of a piece of steel with an area to be coated of between 1 dm^2 and 1 m^2. In this case the value of 1 cm^2 may be standardised for the size of the reference area on which the minimum thickness is to be measured. According to the dimensions of the measurement area, the method or the equipment, as many measurements are taken as can be included in the reference cm^2. The French standard (NFA 91-010) thus provides that, according to the dimensions of the area to be measured, the arithmetical mean of two, three or five measurements must be taken within 1 cm^2, the latter being the limiting case of punctual contact by a feeler (see figure on p. 364).

Let us now consider the case of large areas to be protected, exceeding 1 m^2. Here too, the idea of minimum thickness must be standardised. On what area are we to determine the minimum thickness of the coating for a metal bridge applied by metallisation with a spray gun, or for a building to be clad in hot-galvanised sheet steel?

Lack of any standardised instruction may lead to the most absurd result. An example would be the consideration of a single magnetic punctual measurement or of the smallest reading taken on a micrographic section. Among the many possible standardisable solutions the following instruction may, for example, be accepted:

"For any metallic coating with an area greater than 1 m^2 the minimum thickness defining the coating will be measured on a reference area of 1 dm^2. If measurement is carried out by chemical solution or weighing methods the coating is dissolved on the whole of the reference dm^2. If measurement is carried out with feeler equipment (the contact area of the feeler generally being between a point and 1 cm^2) the arithmetical mean of 10 measurements regularly distributed in the reference dm^2 will be adopted as the minimum thickness defining the coating (in accordance with figure below)."

This instruction is simple. If it were universally adopted at every testing stage and in every country it would cut out a great deal of argument, lead to better understanding between producer and user and effectively guarantee the quality of the metallic coating at all times.



Conventional method of calculating the thickness of a metal coating on a 1 dm.² with finger gauges having a contact surface varying from a point to a square centimetre. The arithmetical mean of ten measurements distributed over the surface at points numbered 1, 2, ... 10 is taken as the thickness. The last and first measurements coincide (thus checking the reliability of the gauge).

The essential purpose of metallic coatings is to protect steel against corrosion. We will now examine the basic case of atmospheric corrosion. Steel should be protected against the atmosphere by covering it systematically with a metal that is less oxidable than iron. If metals are classified according to tensions we arrive at the following in the order of less and less oxidable metals:

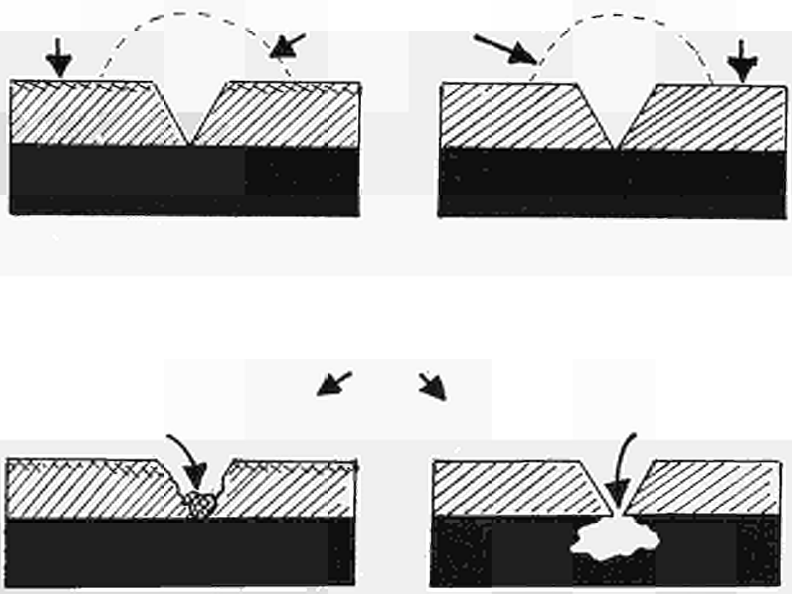
Aluminium, zinc, cadmium, iron, nickel, tin, lead, copper, silver and gold.

It is found that the most common methods for the protection of steel use a protective metal coming before iron in the scale of tensions, i.e. zinc or cadmium (anodic coatings) or a protective metal coming after iron in the scale of tensions, i.e. nickel, tin, lead or copper (cathodic coatings).

This anomaly is explained by the electro-chemical mechanism of atmospheric corrosion as applied to metallic coatings on steel.

With anodic coating, the metal applied, which is more oxidable than iron, is covered with a protective coat of salts, oxides or hydroxides which form slowly on exposure to the atmosphere. Consequently, in use, the metal applied is destroyed only by the removal of this protective coat by mechanical action due to the weather or by chemical action due to impurities in the atmosphere, as in sulphurous industrial atmospheres.

When discontinuity in the coating occurs (see figure below) salts form which block the discontinuity to the benefit of the base steel. Such a coating, of zinc on iron for example, provides protection which is generally in proportion to the thickness of the protective metal.



Anodic coating
Cathodic coating

Formation of protective salts
Atmospheric humidity (electrolyte)
Little or no surface deterioration

Zinc salts formed in the gap
Zinc and iron preferentially attacked

Corrosion mechanism applied to anodic and cathodic metal coatings. Compare these diagrams (showing a cross-section) with the carious standard plates shown on pages 368 and 369 (top plan view)

With cathodic coating, the metal applied to the iron is generally only slightly oxidable and therefore very resistant to corrosion. When discontinuity occurs in the coating however the base steel is attacked preferentially and its destruction advances under the coating. Such a coating, of nickel on iron for example, provides protection which is not generally in proportion to the thickness, and destruction may be rapid as soon as the steel is no longer isolated from the outer environment.

Thus anodic and cathodic coatings have their advantages and their disavantages. Both have been developed quite easily, being selected in view of their suitability for the conditions of use.

What part then can be played by standardisation to ensure that the protection of the steel against corrosion is in accordance with the contract entered into between producer and user?

Where anodic coatings are concerned it is generally accepted that the protection provided is in proportion to thickness. Measurement of the thickness of the coating is therefore regarded as an adequate guarantee of the protection against corrosion corresponding to that thickness. Standards for anodic coatings do not generally mention corrosion tests.

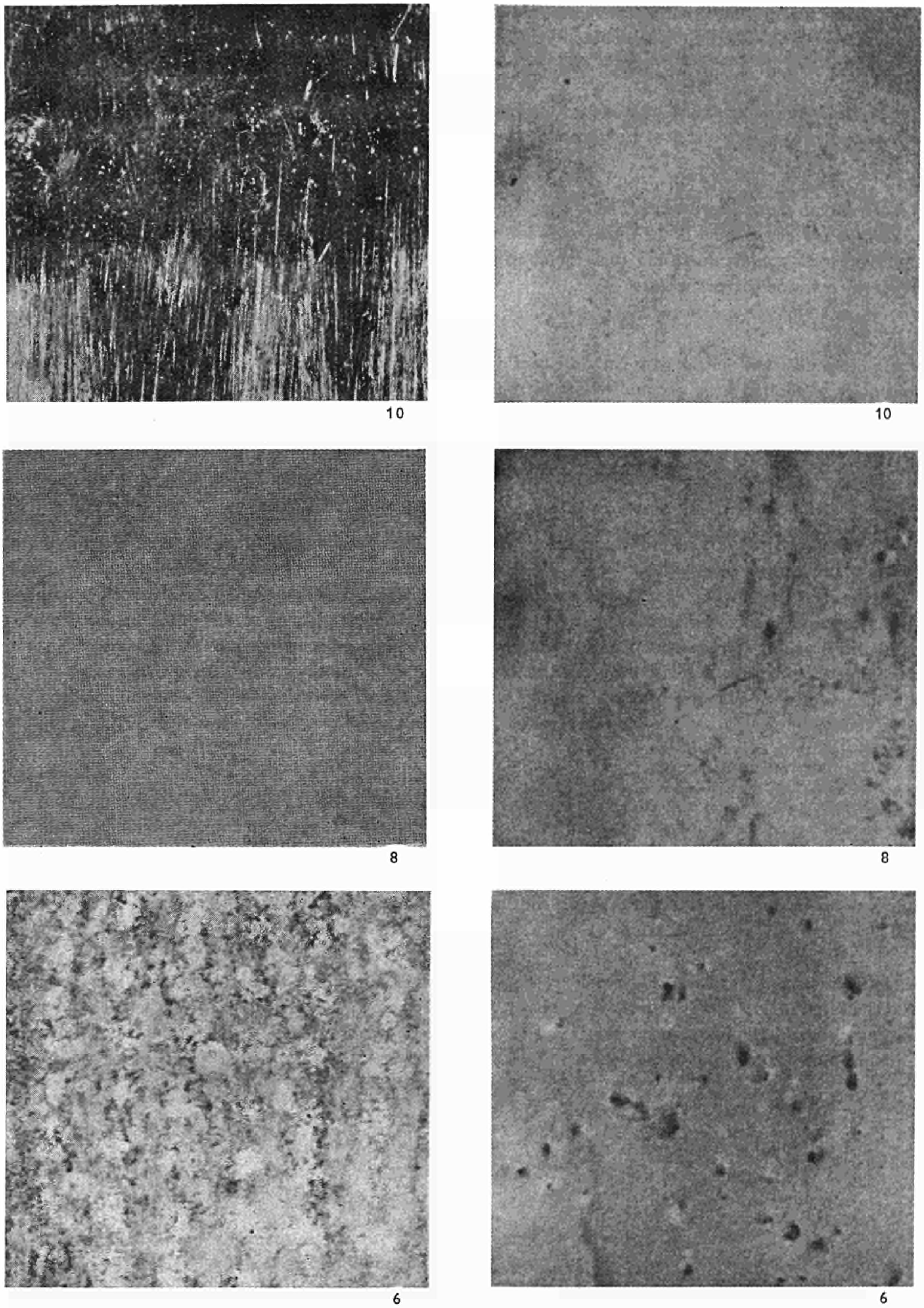
It is quite a different matter with cathodic coatings; here corrosion tests with the object of confirming the continuity of coating have gradually been introduced. We have already seen that any discontinuity may cause rapid deterioration, and this discontinuity cannot be detected by thickness measurements. So the last decade has seen the development in every country in the world of the use of saline-mist tests with various modifications to check the electrolytic nickel-plating of steel.

Corrosion tests, used at first only for checking the continuity of cathodic coatings, have developed considerably in the last few years. Their users say they want the effectiveness of steel protection checked by a test involving corrosion phenomena. Specifications, even international ones, provide for the receipt of materials with subjection to a corrosion test or corrosion cycles. These materials may consist of either anodically or cathodically coated steel articles. Often the specifications do no more than indicate the duration of the test, after which the coating must still be in good condition. If we recall the already explained differences between the behaviour of anodic and cathodic coatings when attacked by corrosion we can easily understand the wide variety of interpretations and the errors that may be committed. Errors have often brought the use of corrosion tests into disrepute.

We do not intend to discuss the justification of corrosion tests with regard to the protection of steel. We shall merely try to see how standardisation on an international level can improve the present situation by harmonising an interpretation of corrosion tests, while taking account in its general principles of the various stages of behaviour of anodic and cathodic coatings already described.

A test on these lines is being tried out in France on the protection of steel by zinc and nickel. It is suggested that the results of the corrosion tests should be interpreted by plotting on a graph against the duration of the test (abscissa) the behaviour of the coatings with reference to a figure 10, 8, 6, 4, 2, 0 (ordinate) of a series of standard plates materialising the various stages of deterioration.

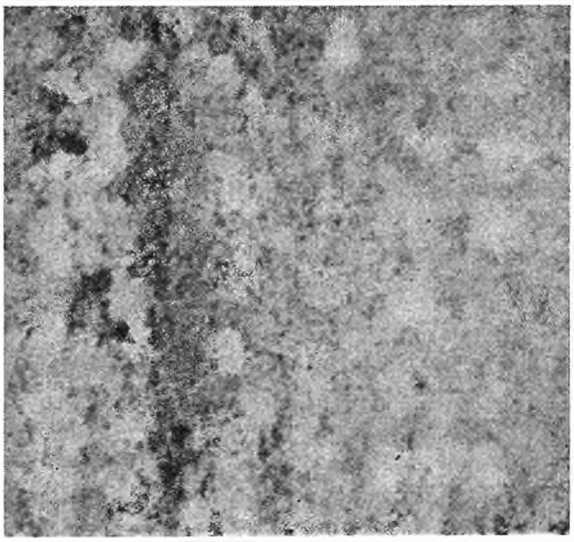
Anodic coatings Zinc on iron | Cathodic coatings Nickel on iron



Standard plates for corrosion testing of metal coatings — Anodic coating — Electrolytic zinc deposit on steel subjected to the salt-spray test (PN X 41-002)

Anodic coatings Zinc on iron

Cathodic coatings Nickel on iron



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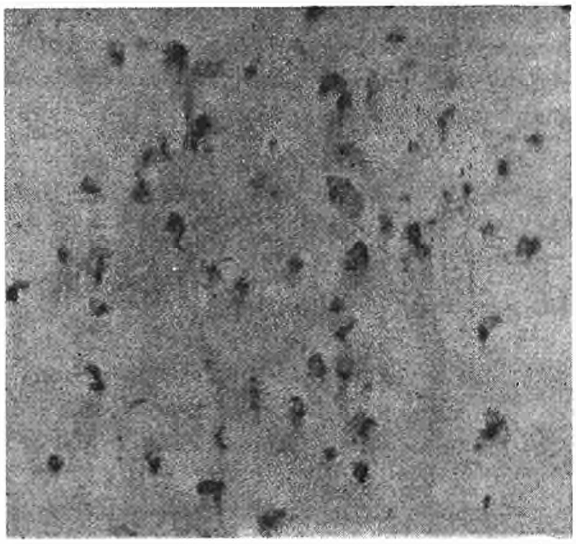

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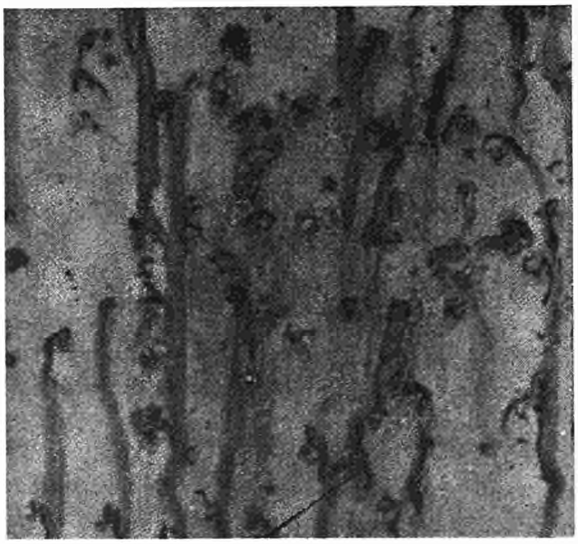

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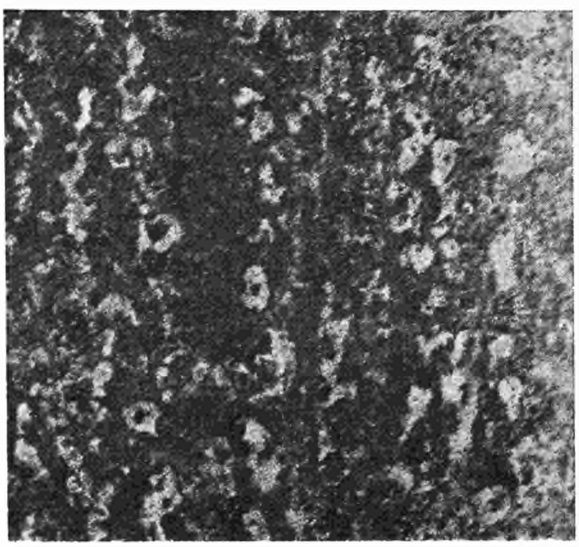

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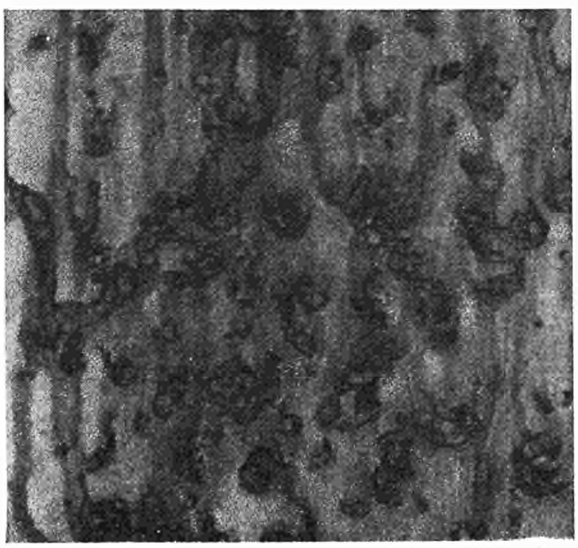

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Standard plates for corrosion testing of metallic coatings — Anodic coating — Electrolytic nickel deposit on steel subjected to the salt-spray test (PN X 41-002)

A first series of plates is for anodic coatings of zinc on iron and a second series for cathodic coatings of nickel on iron (See figures on the two preceding pages). This recommendation is given in the "Fascicule de Documentation FDAn° 91-020" of the French Standards Association; the French Corrosion Centre has co-operated in the production of these plates.

The following code has been adopted for the behaviour, of anodic and cathodic coatings shown diagrammatically in the figure on p. 366.

10. Unaltered initial state.

8. Anodic coating, alteration of coating metal without rust. This state, which is distinctly different from the initial state, is normal and does not indicate that the coating is deficient. It corresponds to the formation on the surface of salts, oxides or hydroxides of the metal applied.

   Cathodic coating, possible loss of shiny appearance. The general appearance of the surface is only slightly different to the initial appearance.

6. Anodic coating, coating metal attacked without rust and possible tendency towards yellowing. Although this state shows indications of destruction it is normal and corresponds to the period in which the self-protection of the iron, characteristic of anodic coating, is playing its part.

   Cathodic coating, isolated pitting by rust which can be rubbed off. At this stage the coating need not be regarded as destroyed since rubbing will restore the rust-free appearance of the nickel-plated surface to a normal appearance.

4. More destruction of the coating characterised as follows:
   Anodic coating, brown rust mark. There cames a time when the quantity of zinc remaining at a point of the sample has become inadequate for self-protection to continue. This is generally recognized by the appearance of a distinct rust mark.

   Cathodic coating, enlargement of pittings with persistent rust. The pittings are then surrounded by destruction of the coating so that after they have been rubbed a rust mark discernible to normal vision remains behind.

2. Extension of rusted areas:
   Anodic coating, enlargement of brown rust mark.
   Cathodic coating, increase in number and dimensions of rust areas.

0. Extension of rusted areas to a state conventionally accepted as the limiting state of observation.

This recommendation to interpret the results of corrosion tests by reference to these standard plates and with the curve of a graph has the advantage that results can be judged according to at least four or five observations graduated in time. This reduces considerably the scatter of results obtained from a single observation after a set duration of the test. Moreover, it eliminates inaccuracy due to the fact the duration of the test laid down in specifications is always too low in relation to the value of the coating, a wide margin of tolerance being indispensable owing to uncertainty over the state from which the coating must be regarded as deficient.

Present experiments in France on these standard plates have shown that results did not differ much from one observer to another. It still has to be decided how far the use of these plates can be extended to coatings involving metals other than zinc and nickel for the protection of steel.

The few suggestions made in this paper seem to depart a little from the conventional methods customary in international standardisation. They consist in selecting by agreement a few common reference points to serve as guides, but they do not offer exact solutions of the problems set such as are usually contemplated in the establishment of standards.

Nevertheless, all the work of the ISO (International Standardising Organisation) is moving in the direction of recommendations, and in standardisation it is often more effective to agree on a few simple principles which embody the problems set, rather than to try to resolve individually and precisely the many particular aspects they may present.

The adoption by agreement of a universal idea of minimum thickness of metallic coatings measured on a reference area of standardised dimensions and the issue of instructions on the interpretations of corrosion tests according to the nature of the coatings, and with reference to standardised plates, are suggestions that fully satisfy the idea of a recommendation and, by their simplicity of application, have the best chance of being rapidly effective on an international level.

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— NF A 91-010. Metallic coatings and surface treatment of metals. Terminology, classification and symbolisation.

— FD A No. 91-020. Metallic coatings. Standard plates for corrosion tests.

Marcel NEPPER

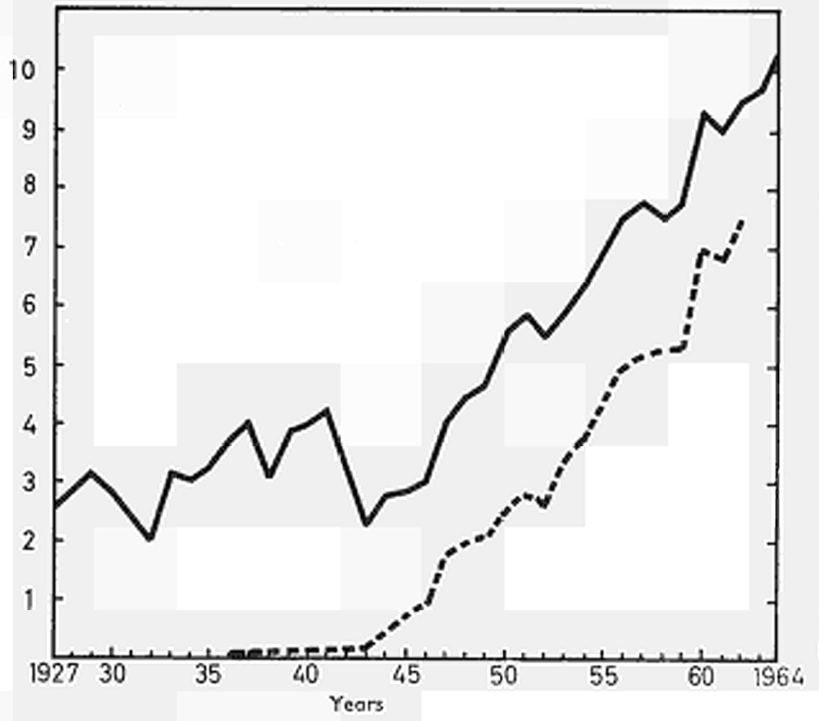
Progress in the Tinplate Industry

(Translated from French)

Production and properties of tinplate

Production of tinplate is higher than that of any other type of coated steel plate. The tonnage produced in 1963 amounted to 3 per cent of total world steel production.

As may be seen from the following figure, (Dr. W.E. Hoare, in *Steel Times*, February 27, 11, 1964). and in the table below world tinplate production is expanding.



World tinplate production 1927-1964
Production in '000,000 metric tons

Tinplate production

Year	World tinplate production in metric tons	E.C.S.C. tinplate production in metric tons	BENELUX tinplate production in metric tons
1958	7,371,000	931,000	200,000
1960	8,977,000	1,377,000	292,000
1962	8,960,000	1,562,000	417,000
1963	8,997,000	1,710,000	476,000
1964	9,839,000	1,804,000	495,000

The hot-dipping process is very old. The sheet is dipped into a bath of molten tin; the tin coating produced is thick and irregular. A very adherent layer of tin-iron alloy is formed. This process is now obsolescent, as for most purposes it is wasteful of tin.

Tinplate is now manufactured by electrolytic deposition. This method, which was being worked on before the war, was taken up in a big way in the United States in and after 1942, when tin was in short supply. It consists in the electrolytic deposition of tin from an acid or alkaline solution of a tin salt. The resulting tin coating is very even and the fact that it can be lighter than by the older hot-dipping process while affording better protection, is of great importance.

The following table (from Euronorm Standard 77-63) shows the usual tin coating applied by hot-dipping and by electrolytic deposition.

The E.C.S.C. has now adopted a metric unit; the Anglo-Saxon countries still use a unit called the "pound per basis box", corresponding to a surface of 20,232 sq.m.

Manufacturing process	E.C.S.C. abbreviated designation	Average coating weight (both sides)		Minimum coating weight (both sides) gr/sq.m.
		gr/sq.m.	pound/basis box	
Electrolytic deposition	E.1	5·6	0·25	4·9
	E.2	11·2	0·50	10·5
	E.3	16·8	0·75	15·7
	E.4	22·4	1·00	20·2
Hot-dipping	F.24	24·0	1·10	21·0
	F.30	30·0	1·35	26·0

The coating weights listed above are for equal tin coatings on both sides. Different coatings on each side ("differential coating") or a coating on one side only, are also available: these will be referred to later. It should also be noted that modern electrolytic tinning lines are designed for the production of heavier coating weights, up to 30 gr/sq.m. (both sides).

The next table (also from Euronorm Standard 77-63) indicates the main advantage of electrolytic tinplate, namely the great regularity of the tin coating.

Coating weight in gr./sq.m. (both sides)		
	Hot-dipping	Electrolytic tinning
Average coating	24	16·8
Minimum average coating	21	15·7
Minimum coating on small isolated specimens	14	14·1

Development of electrolytic tinplate was made possible by a series of changes in steel-sheet rolling methods. Hot rolling of steel sheets was replaced, in the early '30s, by continuous cold reduction, resulting in a product with much more even thickness and better surface.

The combination of these two major advances, cold reduction and electrolytic tinning, produced numerous improvements:

(a) more regular thickness tolerances;

(b) thinner and more even tin coating, consistent with excellent solderability;

(c) improved cold formability (folding and bending, deep drawing);

(d) reduced tendency to ageing and panelling;

(e) possibility of controlling surface finish and thickness of tin coating;

(f) possibility of shipping the product in coil form.

Properties of electrolytic tinplate

An ordinary tinplate sheet is about 0·23 mm. thick coated with a tin layer of about 1 micron. It usually goes to be lacquered or printed, and then cut up by means of automatic slitters or pressed and made into can bodies and can ends for the packaging industry, or into crown corks.

These operations are carried out on automatic high-speed machines which must be fed with sheets of absolute regularity. The main aims of the producer are to achieve tinplate which is completely flat and completely even.

The properties of tinplate may be subdivided into four groups:

(1) dimensional properties (size, thickness, flatness);
(2) mechanical properties (hardness, ductility, folding and bending capacity, sensitivity to panelling);
(3) surface appearance;
(4) chemical properties (corrosion resistance, lacquerability, printability, solderability).

Dimensional properties

Size — Size varies in accordance with the purpose of the product. It is considered nowadays that there are too many sheet sizes on the market and that standardization is desirable.

Example of a manufacturing programme:
Width : 600-950 mm.
Length : 460-960 mm.
Permissible variations : $-0+3$ mm.

Thickness — The usual thicknesses produced in Europe range from 0·17 to 0·28 mm. with thickness tolerances of $\pm$ 0·02 mm. Such tolerances are determined by the narrow margins allowed by the processing machines (presses, hooking machines, etc.).

Flatness — Flatness is very important for printing and all automatic operations.

Mechanical properties

In order to be able to manufacture articles of varying complexity, it is necessary to have tinplate covering a wide range of mechanical properties, and perfect regularity is indispensable. When a bodymaker is set to turn out 10 cans per second using a given tinplate, it will stop if fed different tinplate qualities at the same machine setting.

Hardness — Tinplate is supplied in four classes of hardness under the new Euronorm standard or in "tempers" under the conventional American classification.

Rockwell 30 T classes of hardness Euronorm 77-63			
A	B	C	D
48/56	54/61	57/65	66/73

American tempers					
T.1	T.2	T.3	T.4	T.5	T.6
46/52	50/56	54/60	58/64	62/68	67/73

The concept of "temper" is a complex one: theoretically, temper is measured by Rockwell 30 T hardness but in fact it represents a combination of interrelated mechanical properties, namely hardness, rigidity and ductility. The correspondence between Rockwell 30 T and temper values was initially determined for open-hearth steel, and is less strict for other steel qualities. It may be added that each temper value is associated with definite applications.

Erichsen cupping test — This determination is not used in the United States. Euronorm 77-63 prescribes the minimum values as follows:

Thickness in mm.	Minimum Erichsen Index Values for the following classes of hardness		
	A	B	C
0·20	7·1	6·6	6·1
0·30	7·9	7·4	6·9
0·40	8·5	8·0	7·5

Folding and bending — Tinplate fabrication frequently involves severe folding and bending operations, for example in hooking the edges of the can body and seaming the ends. Suitability for folding and bending may be determined by two-way bending tests, as for example the Jenkins test. Conventional tinplate generally stands up to this without difficulty.

Panelling — A tinplate subject to panelling gives a can body which is not cylindrical but polygonal. This effect is due to the presence of a level in the progression of the tensile curve, and is related to the ageing of the steel.

Surface appearance

Tinplate often has to be made decorative and so defects in surface finish or appearance cannot be tolerated. These can be avoided by strict control during fabrication.

Chemical properties

Non-injuriousness of tin — Tin is harmless to human organism.

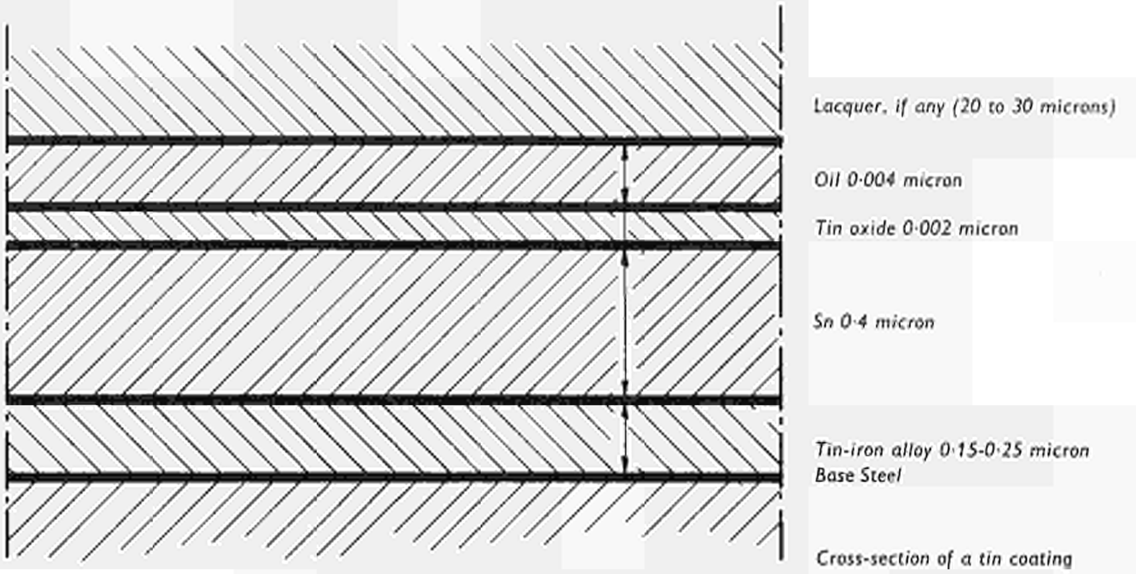
Corrosion resistance — Tinplate must react as little as possible both with the can content and with the surrounding air. This is often ensured by the use of a protective lacquer, but tinplate's own corrosion resistance governed by the base metal and the tin coating, is most important.

Several testing methods have been developed to determine the corrosion resistance of tinplate.

The figure below shows the different layers making up electrolytic tinplate. Research has demonstrated that it is principally the compactness and the crystalline structure of the tin-iron alloy which determine the resistance to corrosion.

Lacquerability and printability — Tinplate users are rightly very particular about these properties. The oxide layer and especially the oil film, as well as the flatness of the product, are of importance in this connection.

Solderability — Tinplate is usually readily solderable provided proper care is taken in the manufacture.



Cross-section of a tin coating

Conventional manufacturing processes and new developments

Base steel

Conventional processes

In the United States, cold rolling and electrolytic tinning were developed using open-hearth steel. More recently however the open-hearth process has been losing ground to the new L.D. oxygen-blown process.

In Europe especially in our regions, the situation has been different, and reliance has been placed more on the basic Bessemer process. Our tinplate has up to now been made from basic Bessemer steel, which, contrary to early fears has caused no difficulty as regards either cold reduction or corrosion resistance. Since 1950, our works have succesfully produced hundreds of thousands of tons of electrolytic tinplate from basic Bessemer steel.

Naturally, all the techniques which could contribute to the improvement of that steel have been employed, including oxygen enriched blast (or in some cases blowing with a mixture of oxygen and water vapour) reduction of the phosphorus content by means of slag control, strict control of temperature, etc. The well-known practice of pouring into "bottle top" moulds (i.e. ingot moulds closed mechanically by means of a cover as soon as the steel has run in) has also been adopted.

Thanks to these improvements the tinplate produced has been first-class. Control of phosphorus content has done much to overcome problems of corrosion.

Indeed, paradoxically enough, basic Bessemer steel has long been considered particularly suitable for the production of tinplate. The more usual tinplate quality (corresponding to tempers 3 and 4) requires a certain degree of stiffness readily obtainable with basic Bessemer steel. To produce tempers 1 and 2, it is necessary to blow with a mixture of oxygen and steam, which, as is well known, results in very low nitrogen contents; on the other hand, to produce the highest temper (N° 6), re-nitrogenized and re-phosphorized steel is used.

New developments

All this however has been very much under review since industry began to turn over to the LD process, which consists, as we know, in blowing pure oxygen through ultra-pure pig iron, yielding steel with a very low content of impurities such as nitrogen, phosphorus, copper and residual elements of all kinds.

LD steel, which is now being produced on a large scale, is opening up new possibilities in every field of cold reduction, and especially in that of tinplate. Two new points are as follows.

First, the steel produced is purer, consequently, it is less stiff but at the same time more ductile.

This means that mild, ductile steel is more easily produced. Low tempers are therefore no problem; the intermediate tempers (Nos. 3 and 4) can at any rate be easily produced by making use of the hardening effect of carbon and manganese.

It also means that LD steel is better able than basic Bessemer to produce light-gauge tinplate of the desired temper and at the same time of excellent ductility.

Secondly the reduced incidence of impurities has the effect of improving corrosion resistance. There is, for example, a special "low residuals" quality of tinplate which is used for certain specific applications such as containers for citrus fruit juices. For this quality the maximum P and Cu contents are 0·015% and 0·060% respectively; using LD steel it is possible to achieve these.

Cold reduction, annealing and skin-pass processes

Conventional processes

The base material is a continuous hot-rolled coil of wide strip rolled down to 2 mm. thickness. This coil is pickled, oiled and then cold reduced on a reversing four-high mill or a 5 or even 6-stand tandem cold mill with a delivery speed up to 1800 m./min.

After cleaning, the strip is subjected to the annealing operation. There are two methods of annealing, either in stationary furnaces where the coils are heated under a heating cover, or in continuous annealing furnaces. The latter can anneal up to 600 m. of strip per minute. The continuous annealed coil is harder and more rigid than coils annealed in batch-type furnaces; its grain size is finer; it gives a relatively high temper, known as "Universal," and the coil keeps a good workability.

After annealing, the coil is subjected to a surface cold working treatment ("skin-pass") aimed at

(a) providing the desired surface finish;

(b) improving flatness;

(c) securing the desired temper;

(d) preventing panelling.

The use of rolls with suitable corrugations enables the surface finish of the strip to be controlled; a very important factor in the quality of the final product.

New developments

Keen competition from other materials is compelling tinplate producers to devise more and more economical methods. One step in this direction has been lighter gauges, offering the consumer a larger surface of tinplate for the same price.

The conventional processes give minimum thicknesses of 0·18 and even 0·17 mm., which are quite commonly produced in our rolling mills. Anything from 0·17 to 0·20 mm. in itself rates as "thin" tinplate.

The diminution in thickness has if possible to be proportionately offset by increased stiffness, obtainable either by using a harder base steel or by appropriate reduction, annealing and skin-passing.

There are limits to the first alternative, since the harder the base steel the less it lends itself to cold reduction. However, down to 0·18 and 0·17 mm. conventional cold reduction and annealing processes are perfectly adequate for the usual steel qualities.

The present trend, however, is towards still lighter gauges. There are a number of possible approaches.

The conventional cold reduction plant will roll strips of normal tinplate width down to very low thicknesses of around 0·10 mm., but if this is done without intermediate annealing, and the strip is merely subjected afterwards to conventional annealing treatment, the resulting product is much too mild, with no stiffness at all and is quite unusable for the purpose.

After a great deal of experiment, a solution has recently been found in the United States, namely double cold reduction before tinning. This consists in effecting first one cold reduction, then an intermediate annealing and then a second 30-50% cold reduction giving the strip the desired rigidity. Double-reduced tinplate is very much more rigid than normal tinplate of the same thickness, There are at present 17 double-reducing tinplate lines in operation in the world, 14 of them in the United States.

This is a major advance which has enabled tinplate to stand up excellently to competition from other materials.

The double-reduced light-gauge tinplate now on the market is mostly 0·15 or 0·16 mm. in thickness; it is used principally to make cans for beer, motor oil, fruit juices and vegetables.

As well as double-reduced light-gauge tinplate, the double reduction process can also be used to produce normal gauge or heavy tinplate (0·23-0·28 mm.) needing to be made particularly rigid as for instance with the high tempers required for beer and soft-drink can ends.

In regard to the quality of the product, it should be borne in mind that double reduction gives tinplate strongly directional-properties. This faces the tinplate user with a whole series of new problems.

Another point against it is the question of production cost. It is certain that the manufacturing cycle is relatively complicated and that the additional cost wholly or partly offsets the gain in weight per unit of area. For this reason, other processes, aimed at producing thin tinplate of better quality at lower cost, are also being evolved.

Our steel industry is closely watching these developments in order to be able to adopt whichever of these seems the most efficient as quickly as possible.

The rival processes are :

(1) the BISRA process, continuous annealing with quenching in a bath of Pb-Bi and subsequent tempering at about 200-300° C ;

(2) the KELLER process, continuous annealing in liquid sodium (still only in the pilot-line stage) ;

(3) continuous annealing and subsequent water-quenching: cold rolling down to the final thickness, followed by continuous strand annealing and subsequent water-quenching ;

(4) cold rolling down to the final thickness, then continuous but incomplete annealing producing only partial recrystallization of the metal ;

(5) increase of the nitrogen content either during steelmaking or by means of a nitriding annealing on the cold-rolled strip to ensure the desired stiffness.

A recent advance in the field of cold reduction has been the manufacture of extra thin tinplate sheets (foils) of 0·05 mm. thickness.

Electrolytic tinning

Conventional processes

The annealed and skin-passed coil passes first, if required, through a preparation line, and then through the electrolytic tinning line. The process using tin phenol-sulphonate is the most commonly used (65 per cent of the world production). On coming out of the plating solution, the strip has a matt appearance. To make the tin coating bright and compact, the tin is melted at about 250° C and afterwards quenched in a cold water tank. The tin-iron alloy layer is now very adherent and offers good resistance to corrosion.

The strip is next subjected to the final treatments, passivation and oiling. Passivation consists in a controlled oxidising operation, to combat the tendency to tarnish. This operation is carried out by electrolytic deposition or by immersion in a chromate solution. The purpose of oiling is to improve stability during, storage, to reduce the scratches resulting from all handling operations, and to facilitate the application of points or varnishes.

The last stages of the line include continuous gauge control, flying shears, sheet sorting and counting units, and automatic defect-detecting devices.

All these operations must be very carefully controlled in order to ensure a high standard of quality and regularity.

New developments

The tinning lines which have been described normally produce tinplate with equal coatings of standardized thickness on both sides. For the sake of economy, tinplate coated to different thicknesses on both sides, or even coated on one side only, has recently been developed.

In the first case, "differential coating," the most usual system is tinplating with 22·4 gr. of tin per sq.m. (double face) on one side and 5·6 gr./sq.m. (double face) on the other; rates of deposition of 30 against 5·6 gr./sq.m. and 16·8 against 5·6 gr./sq.m. (double face) are also found. The heavily coated face is used on the side where corrosion resistance is expected to be greatest — generally on the inside of the container — but in some cases on the outside, to resist corrosive atmospheric or climatic conditions.

In the case of coating on one side only — for example coating with a rate of 2·25 gr./sq.m. (double face) for oil cans — the problem of corrosion does not arise, but a very light tin coating on the outside of the can is necessary for decorative purposes. Because of its lower cost, further development of this type of tinplate may be expected.

For a few special applications requiring a heavy coating weight, hot-dipped tinplate has up to now continued to be used but here too electrolytic tinning is coming in, now that it is possible also by this process to produce tinplate with a heavier coating weight (rate of deposition 30 gr./sq.m. — double face).

Applications of tinplate

Tinplate is particularly suited for the manufacture of packages requiring such varied properties as corrosion resistance, rigidity, non-toxicity, solderability, decorative surface qualities, printability. The numerous applications may be classified into several groups:

(1) packaging of inedible products (motor oil, paints, cigarettes, etc.);

(2) packaging of canned foods and beverages (vegetables, fruits, fruit juices, beer, soft-drinks, wine, milk, meat, vegetable oils, etc.);

(3) crown corks (caps for beer, fruit juice milk, and soft-drink bottles);

(4) aerosols (insecticides, paints, cosmetics, scents, creams, etc.);

(5) miscellaneous (toys, hardware, electrical appliances, kitchen utensils, etc.).

Each application is a specific case requiring specific fabricating conditions — quality of steel, rolling and annealing conditions, thickness of tin coating, tinning process, including passivation and oiling, quality of lacquer, fabricating practice. Only close co-operation between the producer and the user of tinplate can enable each specific group of problems to be overcome. Since it is not possible within the scope of this paper to describe in detail a large number of applications of tinplate, I propose simply to cite a few examples, indicating briefly the properties required for each.

— *Example 1* : Biscuit tins

This type of container must possess some properties of resistance to atmospheric corrosion, together with adequate rigidity. Moreover, it must be decorative in appearance, a major factor in sales promotion.

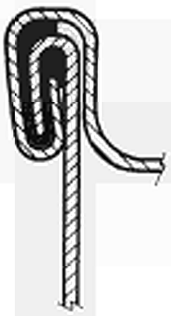
Square cigarette tins present problems as their forming is difficult, requiring an exceptionally mild quality of tinplate.

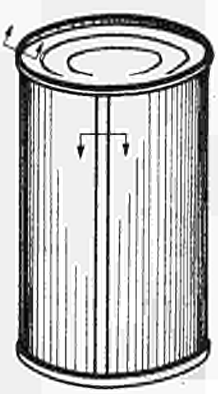
— *Example 2* : Crown corks

After decoration by repeated passes through lithographic printing machines, the tinplate sheets are next cut into caps on highspeed machines. Obviously the sheets have to be of absolutely even thickness and perfectly flat (figure 1, p. 393).

— *Example 3* : Cylindrical cans for preserved foods

These cans are manufactured by means of high-speed machines, the "bodymakers," for which extremely even tinplate is needed; at the same time, the tinplate must be perfectly solderable and free from panelling, as the hooking operations are completed by an application of flux, and in bending the can body into shape it is important to avoid the formation of panels. Needless to add, the tinplate must be also properly corrosion-resistant.





Cross-section of side seam

Cross-section of double seam

For some corrosive products increasing use in being made of differential tinplate, with the inside coating thicker than the outside, since the latter is required to resist only atmospheric corrosion.

Cans containing fizzy drinks are under considerable internal pressure (in the order of 7 kg./sq. cm.): the can ends for this purpose have to be made from stiffer steel with a higher temper.

— *Example 4*: Aerosols

This is a comparatively new application which is rapidly expanding. The upper part of the container offers some difficulty for deep drawing and requires the use of special tinplate quality. The inside of the container must resist the corrosive effect of the product contained in it. Also in, the case of scents or cosmetics, the fact that they are luxury commodities makes it necessary to pay special care to their external appearance (figure 2, p. 393).

— *Example 5*: Ultra-light-gauge tinplate (0·05 mm)

In conjunction with cardboard this type of tinplate gives an appropriately rigid and air- and liquid-tight container. This product is also used for the packing of pre-cooked meals supplied by caterers for reheating at home.

Thanks to a series of advances made in the various stages of fabrication, tinplate is easily meeting the keen competition it is encountering.

The base steel used is more and more pure LD oxygen steel which gives tinplate that is thinner, more ductile and more resistant to corrosion.

Cold reduction is producing lighter- and light-gauge tinplate to which the subsequent annealing is designed to give the physical properties required efficiently and economically.

Thanks to fuller control during fabrication, it is now possible to supply tinplate in coils.

Finally, electrolytic tinning can provide differential coating of tin, coating on one side only, or especially heavy coatings.

By means of a few examples, we have shown how producers of tinplate are taking advantage of the numerous possibilities offered by present day technology to match their products to the varied requirements of their customers.

Tinplate as manufactured nowadays displays such a remarkable combination of advantages as regards both appearance and dimensional, physical and chemical properties that its future seams to be well assured.

Yoichi KITAMURA

Properties and Applications of Electrolytically Chromated Steel, Hi-Top

Electrolytic chromating is a process in which hexavalent chromium ion derived from chromic acid, chromate or dichromate is electrolytically reduced to trivalent state to form a protective coating of hydrated chromic oxide on a cathode metal. Therefore, the process is quite different from that of producing conventional chromate conversion coatings on the surfaces of zinc, cadmium, aluminium, magnesium and copper.

The attempts for applying this process on a steel surface have been made and patented by several steel manufacturers to make a substitute of tinplate or black plate. There had been no commercially successful processes because of the difficulties of selecting a suitable addition agent and of determining an adequate composition of electrolyte, before Hi-Top process was commercially applied by a Japanese Company in 1961. Hi-Top is a trade name of electrolytically chromated steel produced in Toyo Kohan. It has been used partly in the application fields of tinplate and black plate.

In this paper, the unique properties and the application problems of Hi-Top are briefly described.

Manufacturing Process

The manufacturing process is very similar to that used on the electrolytic tinning line. Accordingly, electrolytic tinning line can be easily converted to Hi-Top line by applying a slight modification. The converted line can produce both tinplate and Hi-Top in same plating tanks at a different time when the line is equipped with separated storage tanks and different pipe lines for two electrolytes. An exclusive line for Hi-Top is much simpler than tinning line because of no necessity of flow brightening of tin.

The manufacturing process consists essentially of alkaline cleaning (1), water rinsing (2) and scrubbing (3), acid pickling (4), water rinsing and scrubbing, electrolytic chromic acid treating (5), water rinsing, after treating (6), water rinsing, drying (7) and oiling (8) as illustrated in the figure. Strip steel thus treated is finally coiled or sheared. The product is sometimes oiled, if the customer requests it. In the process, after treating is always necessary to improve the corrosion resistance under a highly humid condition.

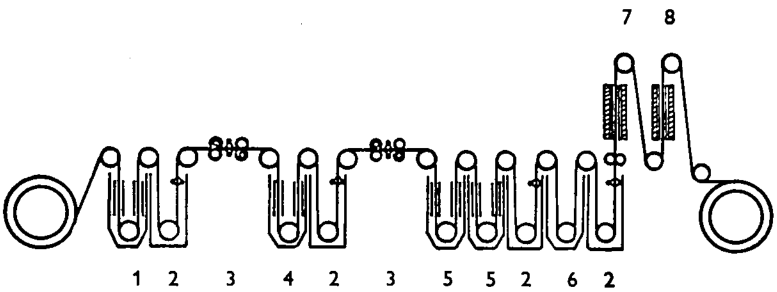


Diagram of Hi-Top manufacturing cycle

In Japan the thickness of treated strip steel is ranged from 0·2 to 0·6 mm. and the width is from 457 to 1016 mm.

Surface Film

The surface film is much thinner than the tin coating on tin plate. It is estimated to be less than 0·1 micron in thickness. The surface chromium can be easily determined by colorimatric or polarographic method on anodically dissolved chromium from the film in 1 N-NaOH solution at a current density of 5 mA per square cm. The chromium content in the surface film is within a range of 0·90 to 1·40 mg. per square dm.

The results of electron microscopic observation and electron diffraction show that the film is not crystalline but is quite dense and uniform. The appearance magnified is somewhat resembling to that of electrolytic tin plate. When the film is irradiated by electron beam, it gradually changes the structure and finally shows a diffraction pattern of Cr_2O_3. Furthermore, no hexavalent chromium ion is found by chemical analysis in a diluted sulfuric acid solution dissolving the surface film. Therefore, it is believed that the film consists essentially of hydrated chromic oxide containing no hexavalent chromium. Accordingly, there are no problems of toxicity due to the presence of hexavalent chromium compounds such as chromate and dichromate.

The surface film is transparent, and is light blue or light bluish purple, the color being a function of the electrolysis conditions and of the electrolyte composition.

The chemical property of the surface film was thoroughly checked by using a plate experimentally made in the electrolyte solution containing radioisotopic ^{51}Cr ion. The radioactive plate was immersed in various chemical solutions at 37°C for 60 days. Then, the plate was thoroughly rinsed with water and the radioactivity was measured to find a residual chromium percentage in the film. The results are shown in the table below. In general, the surface film can resist corrosion in alkaline solutions, neutral salts, solvents and oils, but will be gradually attacked with acid media.

Corrosion Resistance

The results of outdoor exposure tests, salt spray tests and porosity tests show that despite the extremely thin surface film, the porosity is very few, so the corrosion resistance is superior to that of No. 25 electrolytic tinplate and is comparable to that of No. 50 electrolytic tinplate in some instances.

The plate tested in the salt spray of 5 per cent sodium chloride solution at 35°C showed few signs of rust after 10 hr and this plate also resisted corrosion for one month in winter or for 10 days in summer in an outdoor exposure test.

Furthermore, it is an interesting phenomenon that no filiform corrosion and no underfilm corrosion have been found on lacquered plate. Blistering of the lacquered film has not been found.

When plate is severely deformed, bent or deeply drawn, the extremely thin surface film of the deformed part is always damaged or scratched enough to cause rusting. To prevent this defect, an application of thin lacquer coating is desirable. Even on lacquered plate, the deformed part is comparatively sensitive to rusting.

Immersion test on experimentally made plate in various chemicals at 37° C

Chemicals		Residual chromium % on plate after immersion					
		1 day	7 days	14 days	30 days	45 days	60 days
Sulphuric acid	1%	14·7 ± 1·3	1·4 ± 0·7	—	—	—	—
Hydrochloric acid	1%	14·1 ± 1·2	7·8 ± 1·0	—	—	—	—
Nitric acid	1%	92·7 ± 3·5	78·3 ± 3·2	—	75·1 ± 2·7	58·4 ± 2·1	52·4 ± 1·8
Acetic acid	1%	—	93·8 ± 3·5	90·8 ± 3·3	87·6 ± 2·9	86·5 ± 2·8	37·8 ± 1·5
Citric acid	10%	—	96·7 ± 3·9	89·5 ± 3·6	53·5 ± 2·2	11·4 ± 1·0	5·5 ± 0·7
Lactic acid	10%	—	94·3 ± 3·8	42·2 ± 1·4	35·7 ± 1·7	20·1 ± 1·1	16·9 ± 1·0
Chromic acid	1%	—	99·9 ± 4·0	—	97·4 ± 3·0	98·0 ± 3·2	95·6 ± 3·0
Sodium hydroxide	1%	—	97·2 ± 3·6	96·5 ± 3·4	95·3 ± 3·1	94·9 ± 2·9	90·5 ± 2·6
Ammonium hydroxide	1%	—	99·0 ± 3·7	98·0 ± 3·5	96·4 ± 3·0	94·9 ± 3·1	93·1 ± 2·8
Sodium carbonate	1%	—	99·4 ± 4·0	97·3 ± 3·6	96·2 ± 3·3	93·0 ± 3·0	90·0 ± 2·8
Hydrogen peroxide	1%	—	96·6 ± 3·9	96·1 ± 3·8	96·1 ± 1·4	90·8 ± 3·0	81·1 ± 2·6
Zinc chloride		—	—	98·7 ± 3·4	94·6 ± 3·0	87·7 ± 2·7	83·6 ± 2·5
Sodium chloride	3%	—	99·6 ± 3·7	97·5 ± 3·2	97·1 ± 3·1	93·4 ± 2·8	89·4 ± 2·6
Turbine oil		—	—	101·3 ± 3·5	99·7 ± 3·0	96·2 ± 2·9	95·6 ± 2·6
Cotton seed oil		—	—	98·6 ± 3·6	95·9 ± 3·2	93·5 ± 3·0	92·9 ± 2·8
Whale oil		—	—	98·5 ± 3·2	95·8 ± 2·9	85·6 ± 2·6	82·2 ± 2·3
Trichloroethylene		—	—	103·0 ± 3·9	100·2 ± 3·5	99·1 ± 3·3	96·6 ± 3·1
Ethyl alcohol		—	—	101·9 ± 3·2	97·8 ± 3·2	97·3 ± 3·0	99·4 ± 3·0
Toluene		—	—	102·2 ± 3·9	96·4 ± 3·3	97·8 ± 3·1	96·3 ± 3·3
Acetone		—	—	102·7 ± 3·5	99·4 ± 3·1	98·2 ± 3·0	96·5 ± 2·7
Phenol	1%	—	—	99·6 ± 3·7	92·7 ± 3·2	88·7 ± 3·0	86·0 ± 2·8
Detergent A (neutral)		—	82·9 ± 3·1	76·4 ± 2·9	69·9 ± 2·4	68·5 ± 2·2	67·6 ± 2·1
Detergent B (neutral)		—	93·5 ± 3·6	90·2 ± 3·4	90·6 ± 3·1	87·3 ± 2·8	82·5 ± 2·5
Detergent C (alkaline)		—	95·4 ± 3·4	93·8 ± 3·3	89·4 ± 2·9	90·8 ± 2·7	88·3 ± 2·5

Residual chromium % was calculated from a decrease in radioactivity of ^{51}Cr in the film on the plate.

Lacquering Quality

Eyeholing or lacquer dewetting problems occasionally occurred on tinplate have not been found on this plate when coated with lacquer.

Furthermore, a better base is provided for the adhesion of organic finishes than with tinplate or black plate.

For examples, adhesion tests were made of various lacquers such as epoxy, melamine and alkyd on Hi-Top, black plate, No. 50 electrolytic tinplate and hot-dipped tinplate. The lacquered film on specimens was cross hatched and dipped in boiling water for 30 min., then tested by the scotch tape adhesion method. The result showed that no adhesion loss was found on the lacquer film on this plate in almost all the cases.

Epoxy lacquer coated specimens were also cross hatched and dipped in boiling water for 7 hr, then tested by the scotch tape adhesion method. The results showed that no adhesion loss was found on this plate while 97 per cent of the lacquer film was peeled on No. 50 electrolytic tinplate.

When white enamel coated specimens were deeply drawn to a cup of drawing ratio of 2·2 and the enamel adhesion of the cup side was tested by the scotch tape adhesion method, this plate showed no adhesion loss while black plate showed 35 per cent peeling.

Formability

Hi-Top can be formed as easily as tinplate, either in the case of plain one or in the lacquered one. The surface film remains unpeeled after ordinary bending, curling, seaming and deep drawing operations.

In deep drawing operation, inadequate lubricating causes a trouble such as crack especially in the case of plain plate. The selection and the applying method of a suitable lubricating oil is always necessary for forming operations of plain plate.

For example, plain tinplate, black plate and Hi-Top made of a same material were subjected to deep drawing test and the limiting drawing ratios were measured. Hi-Top and black plate are worse than tinplate in the case of punch side lubricating.

Weldability and Solderability

Unfortunately, this plate can not be soldered in the conventional canmaking line without removal of the surface film, but can be easily spot and seam welded by ordinary methods. The surface film of the welded part is more or less damaged enough to cause rusting under humid or corrosive condition.

Therefore, the side seam parts of cans made of this plate are usually joined by a plastic cement derived from polyamide resin.

Applications

n Japan, the amount of monthly production of this plate is more than 2.000 tons. It is mainly used to make detergent cans, motor oil cans, cigarette lighter fluid cans, lacquer cans, lithographic ink cans, powdered fruit juice cans, dry battery cases, soap cases, film cases, biscuit cases, candy cases, toys, bicycle parts, shutters and stationaries etc.

The reasons why this plate can be used in such fields as above mentioned are quite interesting. In the case of detergent cans and soap cases, the excellent alkali resistance is a main reason. This is clearly shown in the results of storage test on cans of an alkaline detergent (pH, 10·1), as shown in the following table. In the case of dry battery cases, a reason is the feature which no filiform corrosion has been found on lacquered plate. In the case of bicycle parts, the fact that no underfilm corrosion has been found under a highly humid condition is a principal reason. In connection with this fact, the results of storage test on cans of a neutral detergent (pH, 6·8), and the results of storage tests on various kinds of foods packed in inside lacquered Hi-Top cans as shown in the next table are significant.

Storage test on alkaline detergent cans at 50° C

Can stock	Lacquer	Storage period days	Dissolved metal ppm (¹)		
			Sn	Cr	Fe
		0	0	0·66	6·2
No. 25 Electrolytic tinplate	Double coated	14	1·8	—	7·4
Hi-Top	Double coated	14	—	0·95	6·4
Hi-Top	Plain	14	—	1·02	6·6
No. 25 Electrolytic tinplate	Double coated	28	2·0	—	8·1
Hi-Top	Double coated	28	—	1·15	7·5
Hi-Top	Plain	28	—	0·87	6·8
No. 25 Electrolytic tinplate	Double coated	84	4·5	—	14·4
Hi-Top	Double coated	84	—	0·90	12·8
Hi-Top	Plain	84	—	0·94	25·7
No. 25 Electrolytic tinplate	Double coated	140	2·5	—	35·5
Hi-Top	Double coated	140	—	—	21·8
Hi-Top	Plain	140	—	—	30·6
No. 25 Electrolytic tinplate	Double coated	196	5·4	—	37·9
Hi-Top	Double coated	196	—	0·89	31·6
Hi-Top	Plain	196	—	1·21	66·0

(¹) p. million

The results of food pack tests mean a possibility that mildly corrosive foods will be satisfactorily packed in an all inside lacquered Hi-Top can and an inside lacquered composite can made of Hi-Top ends and tinplate body.

Summary

Hi-Top is an electrolytically chromated steel which is a quite new type of chemically treated one.

This plate possesses a fairly good corrosion resistance, especially in neutral and alkaline media, which is superior to that of No. 25 electrolytic tinplate and is comparable to that of No. 50 electrolytic tinplate in some instances.

The fact that filiform corrosion or underfilm corrosion has not been found on lacquered plate is important.

The lacquer adhesion is more excellent than those of tinplate and black plate.

This plate can be formed as easily as tinplate.

This plate cannot be soldered but can be easily spot and seam welded.

The inside lacquered can has a possibility to apply for mildly corrosive food packs.

Storage test on cans packed with various foods at room temperature and at 37° C

Content	Can Stock	Lacquer	Can type	Storage period months	at room temp. Dissolved metal ppm (1) Sn	Cr	Fe	Vacuum cm Hg	at 37° C Dissolved metal ppm (1) Sn	Cr	Fe	Vacuum cm Hg
Mackerel-pick fillet in oil	Tinplate	All inside single	Square	24	8·2	0·02	20·8	18	3·6	0·02	21·8	15
	Hi-Top	coated	Square	24	—	0·03	27·8	18	—	0·05	49·4	10
Horse-mackerel in tomato	Tinplate	All inside single	Oval	24	41·4	0·02	33·5	2	21·0	0·03	178·6	(2)
	Hi-Top	coated	Oval	24	—	0·05	94·1	5	—	0·06	257·9	(2)
Smoked baby clam in oil	Tinplate	All inside single	Square	24	1·9	0·12	84·6	20	3·0	0·14	105·7	17
	Hi-Top	coated	Square	24	—	0·13	77·6	17	—	0·18	76·5	16
Beef cooked in Japanese style	Tinplate	All inside single	Open top	24	7·1	0·05	54·6	3	7·2	0·05	91·8	(2)
	Ends, Hi-Top	coated	Open top	24	3·6	0·06	69·0	21	3·8	0·07	125·2	7
	Body, Tinplate											
Baby clam in brine	Tinplate	All inside single	Open top	24	3·0	0·13	89·9	26	2·3	0·14	101·3	27
	Ends, Hi-Top	coated	Open top	24	3·7	0·15	92·1	26	1·9	0·14	115·7	29
	Body, Tinplate											
Crab in brine	Tinplate	All inside single	Open top	24	1·4	0·02	3·4	37	2·7	0·02	5·9	27
	Ends, Hi-Top	coated	Open top	24	1·1	0·02	5·0	36	4·5	0·02	5·0	32
	Body, Tinplate											
Green peas	Tinplate	All inside single	Open top	18	57·3	0·02	22·4	20	88·0	0·02	29·6	20
	Ends, Hi-Top	coated	Open top	18	56·5	0·02	24·9	25	89·7	0·02	29·1	17
	Body, Tinplate											

(1) p. million.
(2) No vacuum.

H. GOLDSTEIN

The Surface of Steel and Hydrocarbons

(Translated from French)

The adoption of iron and steel products for an increasing variety of uses depends largely on the protective value of the film covering the oxide surface, the natural formation of this depending on the properties of the base material used and on the atmosphere. This film may consist of a metallic or non-metallic, mineral or synthetic coating, forming a protective screen and thereby insulating the base material from contact with the atmosphere, or at least obviating any atmospheric effect which would cause premature destruction of the metal.

The aim of this paper is to emphasize how corrosion protection of metal products, especially of iron and steel products, can be improved by suitable application of a coating with a hydro-carbon base. Really high quality and protective value in such products can help greatly to promote the use of steel and secure for it its rightful place in the international market, especially as far as its use in soil is concerned.

The hydrocarbons may be divided into derivatives of coal (tar from refining the coal) and of petroleum (bitumen specially adapted to its corrosion-protection coating role). Plastic coal tar has long been used as a protective coating both in the United States and in Europe; it has proved extremely useful and is still much used. The use of petroleum bitumen however is now increasing, in consequence of the good results reported in certain countries after a good many years, of the research conducted by an important petroleum company in the Netherlands, and of work by industrial and university laboratories in Belgium. Lastly the investigations and studies by the Benelux Committee of C.E.O.C.O.R. (*Comité Régional — Europe Occidentale de la protection des conduites enterrées* (Western European Regional Committee on Protection of Buried Pipes) on bitumen-protected pipes which have been in service for several decades have added valuable information to our knowledge of this material.

It is a point we in Europe would do well to note that whereas in 1962 North and South America used more than 600 million tons of bitumen, the Near East more than 300 million and the Eastern bloc more than 200 million, all the West European countries together used only 17·4 million. It is true that in 1953 Europe used only 3·9 million so that its growth rate as regards the use of bitumen has been higher; nevertheless, it is incontestably urgent and necessary to encourage the use of this protective product by making it better known.

Quality and possible improvements of petroleum bitumen used as a protective coating

Two main characteristics determine the quality of bitumen—the softening point as a function of temperature (the well-known experiment with the ball and ring and the penetration of an indenter, standardized at a weight of 100 gm. for 5 seconds at 25° C. Other determinations are sometimes added—the ash content, brittleness (for example, as certained by the Fraas process, or by the diameter of a ball falling from a fixed height on to a disc covered with bitumen and held at 0° C), ductility, paraffin content, water absorption, density, property changes after prolonged heating, viscosity, solubility in organic solutions, adhesion, etc.

Important though these characteristics may be, I shall discuss here only the parameters relating to protection against corrosion. In practice bitumen producers are mainly concerned with road surfaces, this sector being the main bitumen consumer. It is thus necessary to look at bitumen quality and bitumen quality control from another aspect.

The choice of grade of bitumen for corrosion protection has been very thoroughly studied. Bitumen like all protective substances is expected to be resistant to ageing, or at any rate to any radical change in properties which would make it unsuitable as a protective coating. Now, bitumens are classed according to production methods; bitumens obtained by distillation, blown (oxidized) bitumens, hard bitumens obtained under vacuum, and bitumens obtained by mixing various qualities. In practice, certain qualities are eliminated: distilled bitumens are insufficiently stable over a period of time, "hard" bitumens are too fragile, mixed bitumens too soft. For purposes of corrosion protection, this leaves the blown bitumens: oxidation gives a certain stability in bitumen, because a better resistance to subsequent oxidation leads to undue impairment of the characteristics of bitumen under the action of a given medium as time goes on. The industrial qualities of this kind of bitumen vary from 70 to 155 and more, and even for the ball and ring, from 3 to 40 for the penetration.

Experience has also eliminated the extreme qualities. This means in practice that qualities with a very high "Ball and Ring" factor are only used in tropical countries. In these countries, resistance to very high temperatures is the prime consideration. Bitumen with 155° B.R. has been used with great success in dry countries (desert and tropical) and with 130° for very hot countries situated a little further from the tropics and less dry (e.g. Near East). Present usage has long hovered between the choice of other qualities; the range of the products applied is between 70 and 115 B.R. and between 10 and 40 penetration.

Nevertheless, there are various points which enable us to define the parameters more closely: when the bitumen is too soft, the roots of some plants are liable to penetrate into the coating, especially if the construction is not buried very deeply; further, the bituminous coating is compressed by the weight of the construction and the earth covering it; if on the other hand, the bitumen is too hard, it becomes fragile, especially in winter, and is less adherent and less tacky. Such are the conclusions from practice experience and laboratory research.

These tests and considerations enable us to eliminate certain qualities and seek the best feasible compromise as regards possible ways of improving quality.

At present it is undecided whether to use:

(a) a relatively soft bitumen (e.g. 85 B.R.), but loaded with a filler for better resistance to compression. Fillers used are talc, lime, slate powder, or even fine-grained sand; or

(b) almost pure bitumen, not loaded but with a higher B.R., e.g. 95 or 115 B.R.

In the Netherlands, the extremely soft qualities used previously are being abandoned, but the trend is towards (a), while in Belgium (b), which has been used for a quarter of a century, is being retained. Only extensive research at university and industrial laboratories will decide the best way to proceed.

Another major consideration in the choice of a bitumen quality is its adhesion to its support. This quality, whilst fundamental to the protective value of the covering, has not been sufficiently studied. Adhesion of course depends partly on the product used, but also on the conditions under which it is applied, the temperature of the product and support during application, and the condition of the surface (clean or rusty, whether already primed to facilitate adhesion, etc.).

In Belgium, I have myself carried out various investigations to determine how to choose the most suitable product and to establish the best code of practice. Measurements of adhesion would appear to be of some help in this connection.

I feel that research in this field is essential if we are to attain better metal protection.

The problem of water absorption by bitumen has been studied by British and Belgian research workers. In Belgium 80,000 hours of tests were carried out using coatings of various thicknesses and various aqueous media (of different hardness, pH and composition), with 95/15-115/15 and 135/10 bitumens.

It was established that the harder the water the less the absorption, while the lower the pH value and the larger the organic material content the greater the absorption.

The most important discovery however is that water absorption above all affects the external layer in direct contact with the electrolyte. Beyond a certain thickness (1 m. or 2 m.), water absorption ceases to be governed by the thickness and becomes constant.

Water absorption, for a sufficient thickness and a carefully chosen bitumen, is always technically low and tolerated and without significant influence on the protective value of the bitumen. In certain countries, bitumen is the best protective product, whereas in others certain difficulties are encountered. This must depend on the quality of the bitumen: certain products not specially prepared for protection may absorb up to 30% water and thus lose their protective value.

With carefully chosen European bitumens tested for 80,000 hours, different test conditions have shown a water absorption worth noting from the researchers' point of view, but technologically within the permissible limits.

This aspect of the problem also merits close study.

Is coating thickness a very important parameter? In the case of bitumen, a thickness of 0·1 to 0·3 mm. has no protective value, because with time the layer becomes porous, permeable and non-insulating. It is necessary therefore to consider greater thickness, e.g. 0·5 mm., 1 mm., 2 or more depending on the service conditions. Greater thicknesses have however, another very important advantage: small film thickness necessitate careful surface preparation, because even very adhesive oxides can give trouble. On the other hand, if use is made of a thick coating completely covering any surface irregularities, including the rolling scale difficult to remove, a clean surface with no dusty rust is quite sufficient. Really thorough surface preparation is a very serious and expensive matter, and the use of bitumen as a protective coating does the job more simply and economically.

I do not propose to deal with other factors of possible relevance, such as the analysis and function of each of the components, interaction between the coating and the electrolyte, the behaviour of the coating when cathodic protection is used, ageing and after characteristics developing over a period in various media, microbiological action, etc.).

I have tried in my remarks to outline the state of knowledge in this field and the aims of current research, and to emphasize in particular how important it is to the increased use of metal products for burial in the soil that research should be conducted more speedily and comprehensively.

In conclusion I would add that this research work cannot be done by one specialist in a given scientific field, but must be carried out by a team comprising chemists, metallurgists, thermodynamicists, electrical engineers, soil agriculture specialists, and microbiologists. Only when the problem is studied from all these angles will it be possible to gain a clearer picture and to make real progress.

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Edmond LECLERC

The Protection of Steel Sheet Used in Large Rotary Equipment

(Translated from French)

An extension of the range of applications of steel may be said to depend on its ability to resist corrosive conditions in the environment in which it is to be used. This resistance may be achieved by metallurgical means, but usually it is essential to find a satisfactory solution by applying adequate coatings.

CEBEDEAU has formed a "corrosion committee" with Mr. O.L. BIHET, director of C.N.R.M. as Chairman, made up of a large number of leading Belgian specialists. A research committee has also been set up jointly with a group of university professors, representatives of research centres and industrialists specializing in these problems.

In spite of the limited facilities at the disposal of this organization, it has been possible to commence investigations into the use of protective materials, such as certain hydrocarbons, epoxide resins and various synthetic products. I propose to outline some aspects of particular problems which have arisen, to give an idea of the lines on which our research has been carried out. and to report on some of the results obtained.

So far as hydrocarbons are concerned, certain corrosion problems have arisen: Investigation of these led us to draw up a study programme comprising the definition of a standard aggressive medium, the choice of conditions in which it is brought in contact with the hydrocarbon, either alone or applied to the metal surface, and finally the choice of tests for assessing changes in the quality of the water.

My colleague, Mr. Goldstein, lecturer at the University of Liège, will deal more specifically with this subject.

Nevertheless, I would like to say something by way of example about another programme covering a large group of Belgian works, namely the protection of steel sheet used in large rotary equipment.

The conditions under which this equipment operates are fairly complex; they involve hot liquids, local additions of corrosive gases, abrasion, etc.

The use of alloy steels raised difficulties because of increase in the initial capital costs involved. However, corrosion became severe in spite of the very thick walls which were exposed to attack, and our research centre, in co-operation with engineers of works having an interest in the problem, set up a study programme on both laboratory and industrial scale.

The Centre and the works directors conducted an enquiry in several foreign countries. A certain lack of order, and even some contradictions were found in the answers to the enquiry, and in the end it was not found possible to read a decision as to the best course to follow.

It was then felt that laboratory experiments would be highly desirable; it was in fact necessary to analyse all the relevant factors, both from the technical and the economic point of view.

The programme of our laboratory-scale experiments, as a preliminary to a works trial, simulated very closely actual manufacturing conditions, i.e. chemical medium, gas injections, temperature conditions, circulation of liquids, and so on.

From the economic point of view it was necessary to form some idea of the service life of the materials by artificial ageing tests.

As a result of all our investigations we have been able to make a critical examination of the various formulae offered as an effective coating for the sheet steel, and to assess the value of some of the constituents of these coatings. The data obtained enabled us to clarify the views held on the subject and to discard certain "mysterious" solutions offered by specialists, which were often technologically unjustifiable.

In particular, it has been possible to establish the number and thickness of the protective coatings required and to justify recommendations for a code of good practice. Finally, rules have been laid down for rigorous surface preparation before applying the coating.

Without going into the details of the full programme, I shall confine myself to listing some of the items of laboratory equipment used in this work:

— apparatus for alternately removing and immersing the workpiece in a corrosive liquid into which gas is injected. A temperature of 70° C was deliberately chosen as being higher than that encountered under service conditions. In addition, loamy sand was kept moving continuously in the liquid to simulate conditions of industrial abrasion;

— apparatus for producing a brine spray.

Other experiments were carried out alongside this investigation, such as tests in sprayed acid and in a heated atmosphere, adhesion on coated plates; special abrasion and bending tests, etc.

Finally, ageing tests were applied successively according to a cycle to investigate the action of waters similar to industrial liquids, the action of controlled atmospheres and of infra-red rays, various types of spray, etc.

These tests have already enabled some of the proposed products to be eliminated; by taking into account such factors as economy, ease of application on an industrial scale, etc., it has finally been possible to select a process which offers the maximum advantages.

Applied on a limited scale, this process is now being tested industrially before a final decision is made.

In this way we believe we have helped the industry in its endeavour to combat corrosion, and at the same time have avoided some of the troubles arising in connection with the use of steel.

Finally, we hope we have been instrumental in introducing a greater degree of order into the methods of investigation employed by research centres.

All this has encouraged us to extend still further our co-operation with the many groups engaged on similar work, i.e. research centres, industry and universities.

DISCUSSION

Paul ROCQUET

(Translated from French)

Mr. Nepper's paper has given us an account of present methods of producing tinplate.

What he has said however is principally concerned with tinplate production in Belgium. In other E.C.S.C. countries, though some basic Bessemer steel is employed, it has always been the practice in the case of qualities requiring this to use open-hearth steel, or more recently the oxygen steels — LD, LD-AC, Kaldo or oxygen vapour— which give either very high ductilities or an extremely pure metal.

As Mr. Nepper says, we must remember that for the ordinary T4 and T3 qualities improved basic Bessemer—which can have a low phosphorus content—(it is possible nowadays regularly to turn out steels with less than 0·017% P) enables the rigidities desired by the consumer to be obtained without difficulty thanks to the nitrogen content. Using LD steel it is necessary to step up the carbon content or even to renitride in order to make the tinplate sufficiently rigid.

After all, we are not called upon to produce only steels of tempers 1 and 2 quality L, which represent only a small section of the market.

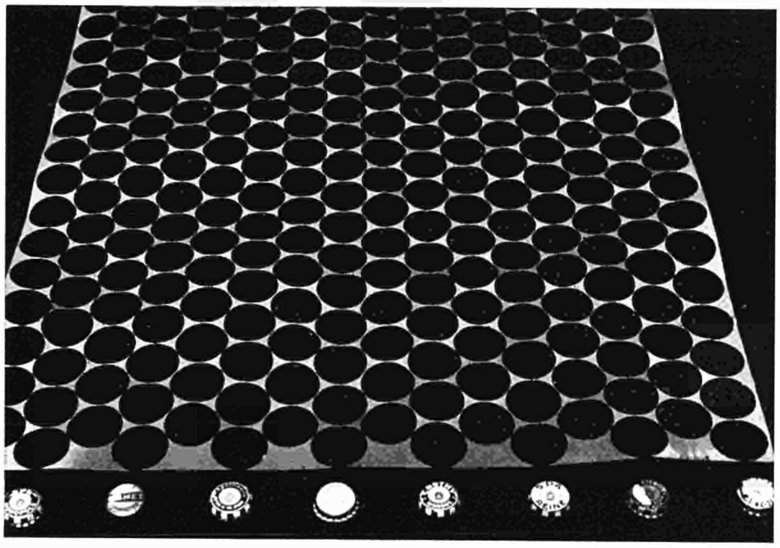
As for the effects of the alloy layer on corrosion-resistance, they have to be considered only to the extent that the tin coating helps to produce the resistance, and the only reason that one tries to make the layer as compact as possible is in order to make electrolytic tinplate as corrosion-resistant as hot-dipped tinplate. Before we dismiss hot-dipping as obsolete, it is as well to concede that the method does at any rate have this advantage as regards corrosion-resistance.

Marcel NEPPER

(Translated from French)

I absolutely agree with Mr. Rocquet. I should be the last to suggest that I think poorly of basic Bessemer steel, when we still make most of our tinplate from it. All the same, I did obviously have to emphasize particularly the new potentialities of the radical changes we are witnessing in steelmaking processes.

List of illustrations



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WORKING PARTY III

Cold Forming of Steel

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Introduction

Working Party III on the cold-forming of steel, was mainly concerned, along with such conventional processes as stamping or rolling, with high-energy forming processes; these have made such advances over recent years that we considered it desirable to review these different processes in an endeavour to ascertain the limits of their application.

High-energy forming embraces all those processes in which forming is carried out at extremely high speeds, i.e. at speeds which are not normally used in the conventional processes. They include

- — forming by explosive detonation;
- — forming by ultra-high-speed discharge of electrical energy;
- — forming by high-energy drop-hammers;
- — forming by magnetic pulses;
- — forming by expansion of compressed gases.

Similarly, the progress achieved in the more conventional processes have been described, in particular hydro-mechanical deep drawing or forming by continuous bending in two directions, at right-angles to each other.

The particular feature of cold-forming operations lies in subjecting the material to a wide variety of stresses depending on the shapes, sizes, tools, speeds and working methods involved, any increase in the range of forming processes creates serious problems for the manufacturers and the steelmakers. One of these has shown the considerable progress made, in recent years, in the fabrication of sheet by cold-forming, as a result of increasingly efficient control of the factors involved in fabrication.

Moreover, discussions have brought to light a number of unresolved problems, such as the increase in embrittlement with explosive forming and the welding of the products after forming.

Between them, manufacturers and steelmakers comparing requirements and production potentialities respectively, should be able to discover the cheapest quality of the product and forming technique for a specific application.

Following the papers on the techniques proper, another very significant aspect of cold forming was discussed — the use of cold-formed structural components and the savings gained on account of their lightness and their increased strength as a result of cold working; the possibilities of raising performance and improving calculation methods ought to enable the structural steelworks industry to catch up on its competitors, provided that out-of-date regulations do not hamstring the new possibilities.

Karl Eugen BECKER

Outline of the Various Shockwave Processes and their Fields of Application

(Translated from German)

In consequence of the rapid development in the field of supersonic aircraft and rockets, new manufacturing processes have had to be sought for the production of components having highly complicated shapes, for which in many instances very high-temperature materials have been used on account of the stresses arising. Since the nineteenth century one of these processes, high-rate forming, has been known through patent letters. This was followed by developments in cladding, hardening and compacting of materials.

The far-reaching expectations, strengthened by the first initial successes with explosive forming of sheets, partly carried out with brittle materials such as titanium alloys, molybdenum, tungsten etc., were only partially achieved, as the later statements will show.

The fields of application of high-rate forming lie principally in the shaping of sheet blanks, in the bulging of hollow bodies and in the sizing of preformed bodies. Apart from high-rate forming with explosives, mention should be made of the underwater high electrical discharge method, for which the energy is produced by a surge generator. Mr. Mürtz will go into the method of operation of this process in detail. As by both these methods the transfer of energy to the workpiece takes place through a transfer medium, they both differ from the contact method, which is used for explosive cladding, explosive hardening and explosive compacting.

In these processes the explosive charge is laid directly on to the material as the source of energy, and the highly intensive shock waves carry out the desired cladding, hardening or compacting process.

Not least in this connection, mention should be made of the pneumatic high-pressure-gas forming machines, which differ from the conventional forming machines principally in connection with their sources of energy and their higher rate of forming.

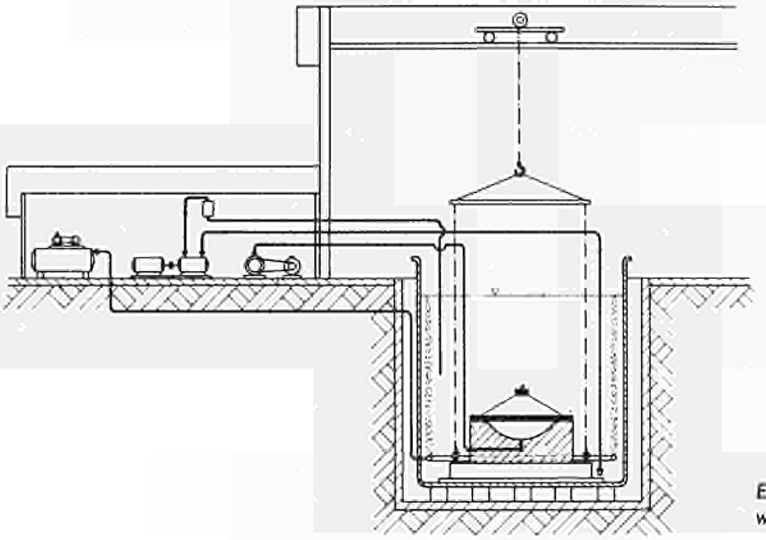
In the following remarks I should like to present a brief review covering the present state of development of the processes, together with the experimental results of our company, which will demonstrate the advantages and disadvantages of these processes. Of the high-rate forming processes mention will first be made of forming with explosives as the source of energy. Four factors are of particular importance here:— the die (for open systems only the bottom half die) the workpiece to be formed, the explosive charge which must always be accurately placed and adjusted, and finally the energy transfer medium, e.g. water, air, oil, etc. Among the dies being employed, a distinction will be drawn between closed and open die systems; the differences lie on the one hand in the fundamental necessity for, and on the other hand in the practical design of, the bottom and top halves of the die.

Without doubt, the efficiency of the energy expended on the forming process is greatest with closed dies. In consequence of the expensive manufacture of the upper half of the die in addition to the bottom half, die costs are high compared with the open system. At the same time the two halves of the die must be held in the closed position during the forming process by means of the bearing surfaces of a clamping device, for example a press. In the closed form of die, air can also be used as the energy transfer medium, and this again has a favourable effect on the assembly time.

The open die system is more commonly used—especially for all the forming operations carried out at our firm with explosives as the sources of energy. Figure 1 (page 439) shows the bottom half die with the formed workpiece during withdrawal from the water tank. Here we have a segment of the Saturn rocket from the U.S.A., which has a length of 6·5 m. Due to the order of size it is already clearly indicated, that high-rate forming is entirely suitable for the shaping of components of such large dimensions, for which no comparable production process is known. These fields of application were of advantage for the further development of the process itself, but not for the economic assessment of the production potentialities.

The design of such a plant should be clear from the next figure, while it is assumed that its operation is known.

The diameter of the steel tank is 4 m. its depth 5 m. Water was chosen as the transfer medium, since it has considerably lower compressibility than air, and is the cheapest fluid. Rapid die changing, and thereby shortening of costly assembly time can be achieved with this plant, through the construction of several similar tanks alongside each other under a crane track or by means of a lift platform.



Explosively formed component and die during withdrawal from the water tank.

The workpiece to be formed, as will be explained more precisely in the following text, either lies loose on the rim of the die, or is fixed by means of a clamping device to avoid skew drawing and formation of folds. It is vital in view of the dimensional accuracy of the workpiece to be formed, to expel the air from the die cavity, which cannot escape at high forming rates (vacuum up to 10^{-2} torr).

For explosive forming detonating explosives are normally used as the source of energy; these liberate large quantities of gas and heat as a result of a dissociation reaction of short duration. After the ignition of the explosive, the shock waves spread outwards at high velocity, and are propogated in the medium surrounding the explosive at supersonic velocity. As they spread outwards, the intensity of the shock waves is attenuated. Through the impulsive nature of the load on the workpiece to be formed it receives an impulse corresponding to a definite kinetic energy, which is to a large extent converted into work done in deformation.

After these short introductory remarks on the construction of an experimental plant, examples will be quoted to describe the design of the dies for explosive forming.

The die material must be chosen according to the shape and size of the workpiece to be formed, its material, and the required tolerances, and also the number of pieces to be produced. For simple forming processes, densified wood dies can be provided, while their working surfaces are reinforced with epoxy resin or with metal inserts. Difficulties occur here mainly during evacuation of the die cavity due to the porosity of the material. The immersion of the die for forming into the water containing steel tank increases these difficulties from forming operation to forming operation. A high degree of dimensional accuracy is mainly uanttainable during the forming of thin sheet blanks.

Similar limitations must be taken into account when using ice—the cheapest material—which could be used during the winter months. The relatively expensive production on the actual site, however, is costly by comparison with the materials mentioned in the following text. At the same time considerable difficulties are presented by gas tightness, preservation of dimensional accuracy, and reproducibility of the workpieces being formed.

In forming smaller numbers of components a mixture of concrete and synthetic resin, with or without glass fibre reinforcement of the working layer, is normally used for the die. Apart from the inconveniently long hardening times of about 30 days, this is one of the cheapest tool materials.

The WIG, welded stainless steel ball socket shown in figure 2 (page 439) was filled with water, and inserted into a steel lined concrete mould for sizing. Reinforcement of the interior of the die was obtained by leaving the first blank formed in the two halves of the die, and for exact location it was then welded to the steel shell of the outer ring. This reinforcement was necessary to ensure dimensional accuracy of the part being formed. The explosive charge was placed in the centre of the two truncated cones, in order to obtain uniform loading and therefore sizing of the two WIG weld seams, completed longitudinally and laterally, which were elongated up to 25%. In the die which was open upwards about 60 workpieces of X12 CrNi 18 8 steel (sheet-blank thickness 1·5 mm.) were formed, without the occurrence of appreciable damage to the shape of the die. Particularly with large numbers of pieces, greater sheet thicknesses and narrower tolerances this design of tool must be adopted, since cracks occurred on the working surfaces of concrete painted with "Araldite". In addition to the inadequate dimensional accuracy of the workpiece, these cracks also entailed difficulties in relation to the required vacuum.

For rapid insertion and removal of the blanks and formed parts between the blank-holder and the die plate, mechanical or pneumatic clamping devices are used. In order to maintain constant the forming rate of the workpieces over the cross-section in accordance with the degree of deformation of the individual parts of the material, and thereby to avoid the occurrence of fold formation, on flat blanks straight pins were fixed on the long sides for location of the blanks to be formed, as figure 3 (page 439) shows. The material used was X 12 CrNi 18 8 steel (sheet thickness 2·5 mm., and dimensions 800 × 1000 mm.). On this child's bath allowances had to be made in relation to the larger inlet radius and the rounded design of the base, but this had no effect on the function of the component. Just as for this child's bath, a similar method was adopted for the production of a flanged plate. Precisely on this component with a firmly clamped round sheet blank the forming processes and the behaviour of the material could be readily followed, as opposed to slow deformation in a hydraulic press, during which spherosymmetrical bulging of the component takes place, through the shock wave the whole surface of the sheet was approximately equally stressed. The forming times for this flanged plate of vanadium steel (sheet thickness 5 mm., dia 950 mm.) were of the order of 1·7 milliseconds, and Nitropenta was used as the explosive with a detonation velocity of 8400 m./sec. At a ratio of the diameter of the die to the sheet thickness of $d : s = 190$ forming of the flanged plate with a blank holder had to be chosen. Apart from vanadium steel, in this die blanks of X 12 CrNi 18 8 steel and various aluminium alloys were formed. In the central area the round blanks were elongated with a thickness reduction of about 5%, in the peripheral area upsetting of the material took place as a result of afterflow with an increase in thickness of about 6%.

At a ratio of d : s = 33 free forming proved possible for the die shown in figure 4 (page 440), i.e. no blank-holder was necessary. This gearshift cap of St 34 steel, 15 mm. thick, dia. 500 mm. was shaped over a steel ring (internal diameter 380 mm.) with tractrix inlet radius.

The base of the die was completed as a simple welded structure, to which the steel ring was welded. Evacuation of the die cavity was thereby unnecessary, and it was possible greatly to reduce the assembly time. A simple plastic tank was fitted over the round blank located on the steel ring; in this tank were placed the explosive charge and water serving as the transfer medium. With such free forming it is difficult to maintain dimensional accuracy of the workpiece to be formed and the reproducibility which is mainly required.

Apart from the production of flanged plates, hemispheres and gear-shift caps experiments were also conducted in the bulging of welded hollow bodies of X12 CrNi 18 8 steel and AlMgSi alloy with a wall thickness of 2-3 mm. The length of the piece, in this instance a beer barrel, shown in figure 5 (page 440), was 600 mm., with a top and bottom diameter of 350 mm. The inert gas welded hollow body was shaped with a rod-shaped charge in the die filled with water. Between the die, which was again made of concrete, and the hollow body to be shaped was a 2-mm. thick steel lining. For more rational production of the beer barrel the bunghole flange and also one end were additionally produced in the same forming operation. Here, again to reduce the assembly times, mechanical, hydraulically and pneumatically operated tools were used and the part to be formed was placed on a rail track to achieve continuous production without immersion into a water tank.

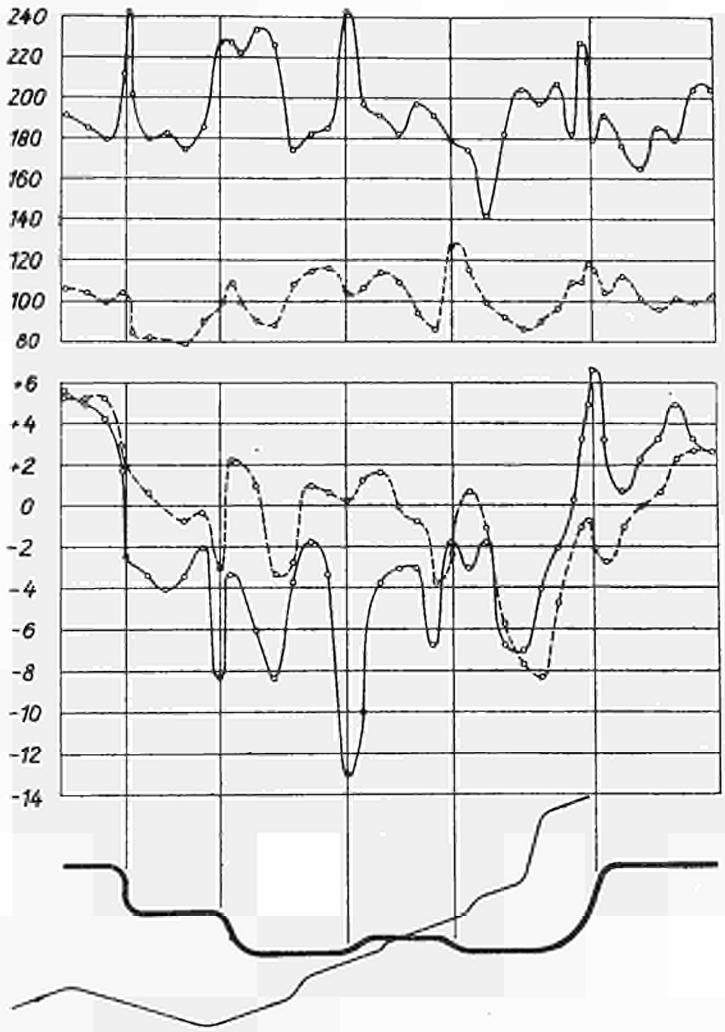
If after the forming process the component is to be perforated in the same operation and divided into individual components, steel rings must be built on the highly stressed cutting edges of dies produced from concrete or soft metal alloys. It is often worth-while, particularly on small components, to make steel dies, figure 6 (page 440) where the procedure corresponds to that for the beer barrel. It was found possible to obtain the best results in respect of working life of the dies and dimensional accuracy of the workpiece by using a zinc alloy ("Zamak"). This alloy has a specific gravity of 6·7 Kg./dm.^{3}, a tensile strength of 22 kg./mm.^{2} and an elongation at fracture of about 1%. Since the melting point is relatively low (390°C), it has the advantage that wood and plaster patterns can be moulded directly in sand and a die then cast (additions 4% Al, 3% Cu, 1% Mg), while the material can be used again by melting down to decrease tool costs.

The automobile component shown in figure 7 (page 441) (vanadium steel or X 12 CrNi 18 8 steel) started from a blank having a basic length of 600 mm., a height of 520 mm. and a sheet thickness of 3 mm. First of all, as figure 7 left, shows, a die was made from concrete with a working layer of epoxy resin. After only a few forming operations the working surface began to have cracks at the exposed points and partly to break away. The evacuation of the die cavity necessary for precision forming and the dimensional accuracy of the component could no longer be achieved. On the die shown in the middle of this illustration a preformed steel component was bedded into the layer of epoxy resin reinforced with glass fibres as an additional reinforcement. Here concrete formed the outer shell of the die, but after only a few experiments the piece of steel worked loose from the synthetic resin layer. As a third attempt the die shown on the right was made from Zamak, which produced the desired result. For the dies shown in the following figures Zamak was exclusively used as the die material. Figure 8 (page 441) shows a die and steel blank-holder, which were made for forming a clutch component. The component was made from St 4 steel, 3·5 mm. thick, dia. 335 mm. Since with these components currently conventional processes have in general already been introduced in production, the designer and experimental engineer are not very amenable to changes in the components in respect of an increase in the inlet radius, a change in the thickness of the material or even an increase in the angle of taper of the die, although in the manufacture of these components it could only be a matter of prototyped or short runs, and through these changes the function of the component could not in most instances be impaired.

Initial thickness in both instances 3 mm.

vanadium steel with initial hardness 78 H_V

X 12 *CrNi* 18 8 *steel with initial hardness* 160 H_V[1]



Change in hardness and thickness of an explosively formed component.

The above figure gives an indication of the change in blank thickness and the hardness sequence of the automobile component shown in figure 7 (page 441) (Vanadium or X 12 CrNi 18 8 steel, initial thickness 3 mm. in both instances). As would be expected, at points of a high degree of deformation the maximum elongations (13%) and degrees of cold strain hardening (50%) occur, while the quantity of explosive charge and the stand-off distance of the charge from the die have a considerable influence.

By changing the nature, shape and quantity of the explosive material, and also its stand-off distance from, and location in relation to, the part to be formed, pressures and velocities can be varied within wide limits. Explosives having high brisance such as Nitropenta, which during high-rate forming are placed in water for detonation, develop about 1400 kilocal/kg., which at a reaction time of about 8×10^{-6} sec, assuming a 1 kg., charge in spherical form, has a corresponding output of 10^9 H.P. During experiments it should be observed, that during the course of the forming process the resultant pressure can under certain conditions be negative, so that tensile forces operate on the water in the vicinity of the sheet; only to a limited extent can these forces be transmitted in the water and lead to cavitation. In accordance with an energy balance compiled by Nemitz, during explosive forming of round blanks in water as the transfer medium about 45% is lost in compression energy, 38% in reflection, 7% in impact loss, so that only 10% remains for the actual deformation energy. Forming temperature and forming rate affect to a decisive degree the processes taking place in the interior of the material in the form of dislocation, while lattice structure, density and arrangement of the dislocations and impurities play an important part. Principally during the winter months a tendency to brittle fracture may be observed. Measurements have shown that as a result of the stress imparted by the shock wave the yield point can be raised to double its original value, while at the same time the elongation falls by half, which naturally entails increased brittleness of the material subjected to stress caused by the explosion.

Theoretical considerations lead to the clear conclusion that it is more economic, for the attainment of a higher peak pressure, to decrease the stand-off distance between the explosive and the tool, while at the same time attention should be paid to the even distribution of pressure over the whole surface of the piece being worked.

Above all, for the manufacture of small components with medium and longer runs explosive forming is uneconomic on account of the relatively high assembly times. Here the underwater spark discharge method, which is similar to the explosive method, offers better prospects. Since safety measures applicable to explosive forming do not apply, it is also possible to work in closed buildings. Experiments have been conducted on a spark discharge plant with an energy storage capacity of 18 kilojoules, and a capacitance of about 100 F. By reason of the low inductance of about 180 normal Henries it is also suitable for magnetic forming. Only brief mention will be made here of some typical examples from the experimental programme of our firm. For the cocktail shaker shown in figure 9 (page 441) a comparative calculation was made with the conventional manufacturing process. During conventional production the sheet blank first undergoes 4 deep-drawing operations are eliminated as well as expensive annealing and pickling. The result is a labour saving method a start is made from a 63 brass tube, dia. 68 mm., 0·8 mm. thick and 250 mm. long, and at once 4 deep drawing operations are eliminated as well as expensive annealing and pickling. The result is a labour saving of about 30% accompanied by smaller material input. The dies for bulging such components are split axially. Steel or a metal alloy was used as the die material. The price comparison was similar for a cream jug; here by comparison with conventional manufacture seven deep-drawing operations and also rubber die pressing could be saved.

Cladding of titanium to steel and tantalum to steel.

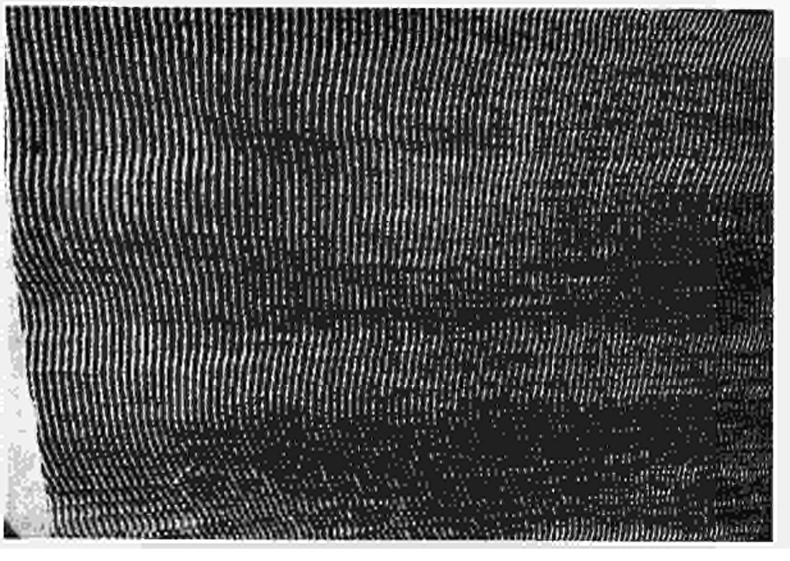
Great importance is attributed to explosive cladding. This production method has within wide limits no comparable conventional process. The above figure shows one of the many possibilities, by which pairs of metals can be joined by means of explosives. Such cladding cannot be achieved by any other process described in the literature. The figure shows polished sections of titanium/steel and steel/titanium. By means of explosive cladding it is possible to unite metals, the melting points of which differ by more than 2000° C, for example aluminium and tantalum or tantalum and steel. The waviness visible here is dependent on the setting angle of the sheets, which was mainly 5° during the experiments conducted on the experimental site. With increasing setting angle the wave lines become greater, while the shape of the wave itself is dependent on the detonation energy and velocity, and also understandably on the pair of materials. Also the attainable adhesion is connected with the setting angle. Clearly visible is the evenness of the wave formation over the area in the figure below, which presents the necessary condition for generally even adhesion of the combination of metals. The adhesion is not comparable with conventional rolled clad products, since any subsequent separation of the metals is impossible. During the shear test on a Cu - X 12 CrNi 18 8 steel combination for example, parting takes place at all events within the layer of copper. Here mention will be made only of some claddings which have been succesfully completed:

Cu/X 12 CrNi 18 8 steel; Cu/Ag; Cu/cu; Cu/AlMgSi; Cu/steel; Al/X 12 CrNi 18 8 steel; Brass/steel; steel/Ti; steel/Ta; Ag/Brass;

in addition, the following double claddings were tried out:

Al/X 12 CrNi 18 8 steel/Al; X 12 CrNi 18 8 steel/Al/X 12 CrNi 18 8 steel; X 12 CrNi 18 8 steel/Cu/X 12 CrNi 18 8 steel.

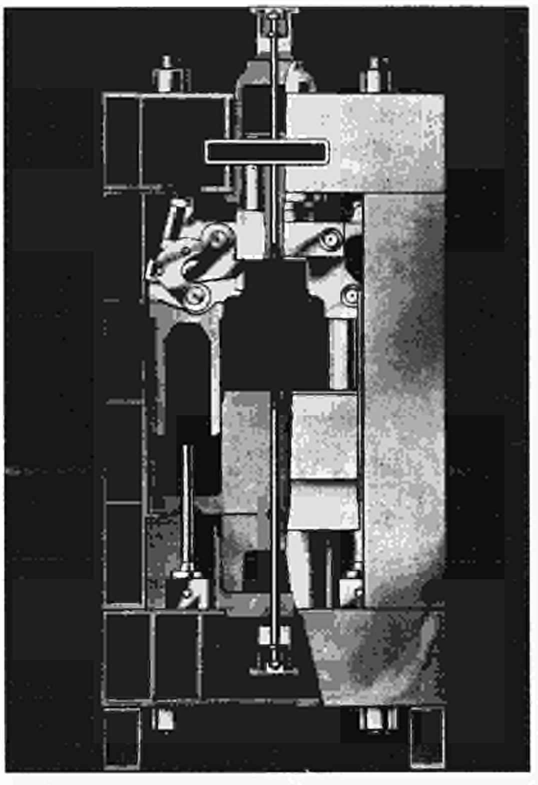
Secondly by this process there is also the possibility of partial cladding.



Wave formation in the cladding zone. Appearance of chromium nickel after etching away the copper.

In connection with explosive cladding, explosive hardening should also be mentioned. In addition to the kinetic impulse used for forming, the shock wave also has a compressive impulse which is utilised for the hardening of metals. Experiments have been carried out principally in the USA to increase the hardness of metals. The hardness of a Hadfield steel, for example, increases from an initial Brinell hardness of $H_B = 225$ to 350, 365 and 385 kg./mm.^{2} respectively after the first, second and third shots. At each shot the depth of penetration of the hardening effect increases up to 37·5 mm. after the third shot. Since we have here a metastable austenitic material, the hardening is attributable to a transformation into a martensitic structure. By this method there is also the possibility of partial hardening.

For short-term production of very high pressures the high-energy process has been applied in powder metallurgy. Single-column and double-column presses for compacting powder into a solid body have been described by Pearson. During the process, difficulties appeared on the one hand in the design of the dies for such high pressures, and on the other in the attainment of an explosive detonation which would proceed uniformly. Within the field of high-rate processes mention must also be made of pneumatic, high-pressure-gas



Section through a high-rate forming machine.

forming machines, such as are shown in the above figure. The problem of the working life of the die is here very closely connected with the possibility of cold or warm working of the materials to be formed. The working life is favourably affected by the short deformation and contact times, but on the other hand is closely connected with the high specific pressures occurring during massive deformations. Only repetition products will in future be able to give an accurate picture of the economic potentialities of the application of these high-pressure gas machines as opposed to conventional methods.

Summary

To sum up, it can be said that for high-rate forming, the essential advantage of high-rate processes lies mainly in the even application of the pressures necessary for forming, in the avoidance of fold formation, skew drawing etc., and in the possibility of local concentration of the energy to be applied to components of complicated shape. This, for instance, is of importance during the bulging and parting of asymmetrical bodies, and also for the sizing of preshaped bodies. In general, it can be established that the application of explosive forming for the production of large workpieces is advantageous for short runs. The die costs can be considerably lowered through the use of cheap materials such as resin, concrete or metal alloys which can be melted down for re-use quite regardless of the elimination of the need for an upper die and punch and the associated assembly and adjustment operations.

The often difficult decision over the installation of expensive forming machines can thereby be overcome without high investment costs until the number of pieces to be worked is finally clarified.

Difficulties and costs arise by this method principally because of the lack of theoretical bases and the necessity for costly and time-consuming experiments.

The forming of small components in smaller and medium runs is possible with an electric current discharge plant, closer details of which will be given later in the proceedings. Here there are difficulties still to be overcome on the mechanical side of the plant, e.g. in the design of suitable workpiece delivery mechanisms, such as rotary tables, wire delivery mechanisms for the electrodes, etc.

Entirely new fields will fall within the scope of explosive cladding where partial cladding of components is possible, since this makes possible a bond between pairs of materials with melting points separated by up to 2000° C, which is of particular importance for fields of application in reactor and heavy engineering construction. Closely connected with explosive cladding is hardening'with explosives. Here also partial hardening occupies a special place.

The advantages of high-rate processes lie, in short, in the low investment and die costs, in the saving in finishing costs, and not least in the ability to form asymmetrical workpieces of complicated shape from materials which are in part highly heat-resistant and which can only be formed with difficulty by conventional methods or indeed cannot be formed at all. In future it is to be expected that these methods will rationally supplement and complete conventional working processes over a wide field, and in addition help to arrive at new production possibilities.

J. L. REMMERSWAAL

and

F. E. VAN WELY

Cold-Forming by Explosive Shockwaves

(Translated from Dutch)

In 1959 the Metalworking Centre of the Metaalinstituut T.N O. reinstituted research on the application of explosive shockwaves to the forming of metal plate, being probably the first organisation in Europe to do so, although work in this field had already been done in America. We say "reinstituted" advisedly since the idea was not new; it had already been described and documented in Europe in the 19th century but its use since that time had been confined mainly to the testing of explosives.

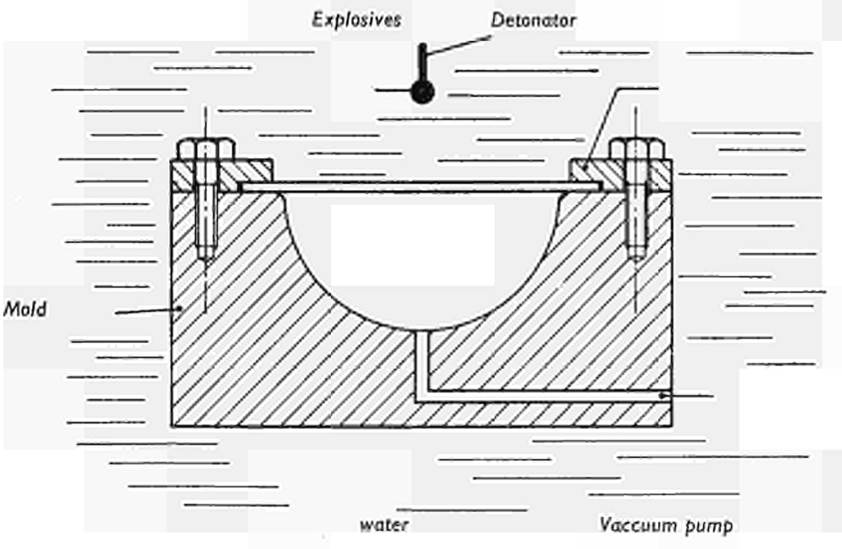
It was left to the carefully planned and comprehensive investigations of the last few years to define more clearly the possibilities of this technique and at the same time to extend its scope of application. Naturally, modern research facilities, so much better than those available to earlier investigators, contributed largely to the success of this work.

As is so often the case with new techniques, work forged ahead principally on an empirical basis without awaiting the results of the investigatory programmes. As a result of this, the economic advantages of the method are not everywhere fully appreciated and less use is made of the technique than in our view would seem to be justified. We therefore welcome the decision to include this method of forming among the subjects to be discussed at this present Congress.

The shapes of shockwaves

It may be assumed that the principles of explosive forming are generally known but for ease of reference we shall here include a diagrammatic illustration of the basic form of the process.

An explosive charge is detonated under water and this action generates a shockwave which, depending on the type and amount of explosive, will have a peak pressure of 1-5 kbar and a duration of 10-1000 μsec.



Schematic showing method of explosive forming

This wave, propagating at a speed greater than that of sound in water, strikes the target workpiece and transfers part of its impulse to it. The result will be a displacement of the workpiece at a rate dependent on the impulse received.

Assuming a good vacuum between workpiece and die, the former will be shaped against the mould wall with a degree of dimensional accuracy and trueness of shape depending on the amount of energy input. If there is not a good vacuum in the mould, a mounting resistance must be allowed for and the process adapted accordingly.

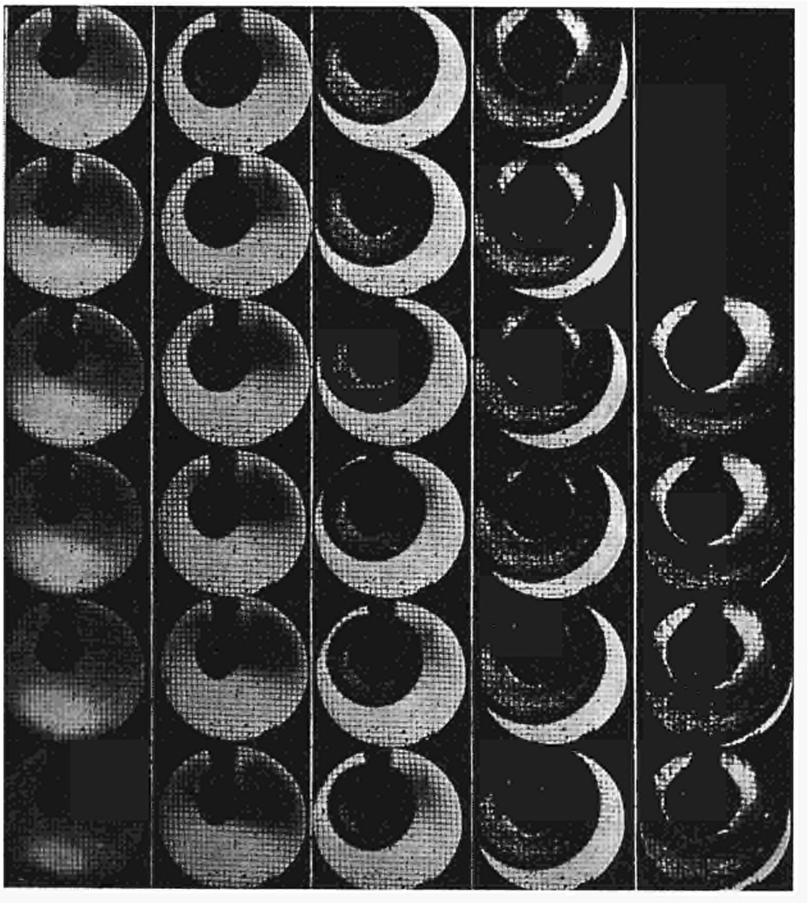
Clearly, the shape of the charge must influence that of the shockfront and it is for this reason chosen as suitably as possible for the target and forming operation considered.

The principle charge shapes are as follows :

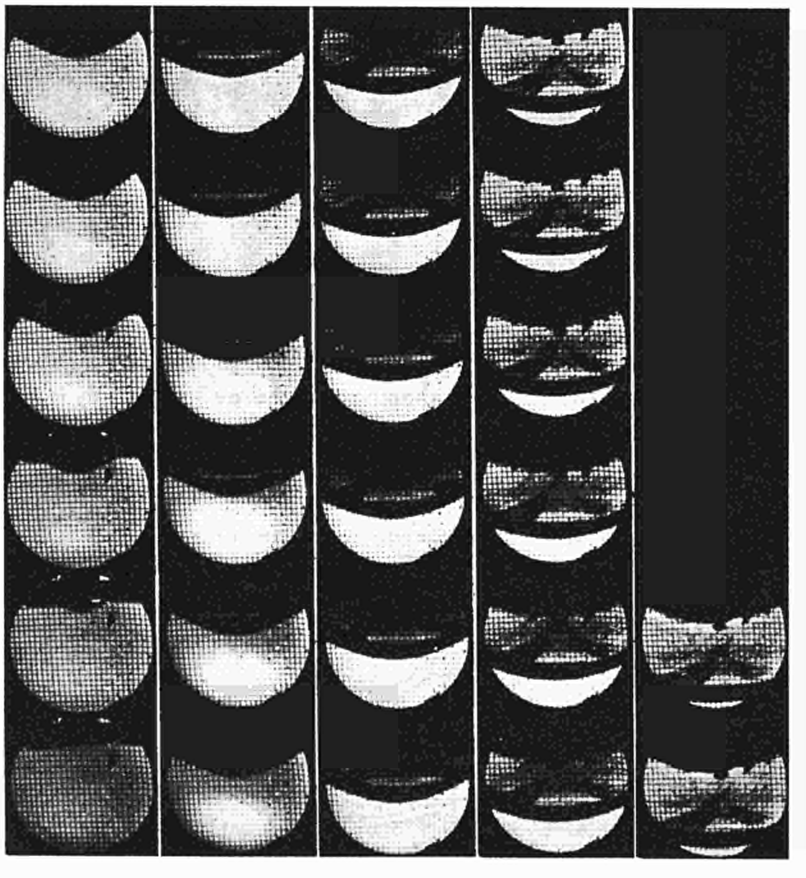
(a) A spherical charge

This shape is suitable for all products the form of which is basically not far removed from the spherical. In the figure below we show the pictorial history of a shockwave in water produced by a spherical charge.

The black band indicates the shockwave whose appearance in this guise is due to the increase in diffusion of the compressed water. The interval between photographs is 2 μsec.



Successive shock-front stages originating from a spherical detonating charge



Successive shock-front stages originating from a centrally detonated, plate-shaped charge

(b) A cylindrical charge

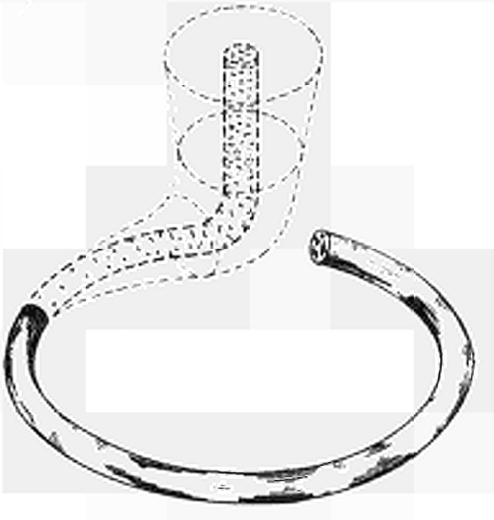
This type of charge can be used for products of more elliptical section and in its extreme shape of a line charge is suitable *inter alia* for expanding tubes. For the *in-situ* expansion of tubes spherical charges are naturally used.

(c) A conical charge

A conical charge transmits a partly flat shockfront. It is not much used as the explosive force generated for an adequate charge size is usually too great. A flat shockfront can also be reasonably approximated by using a sheet charge (see above figure).

(d) Annular charges

These charges, which evidently transmit a toroidal shockfront, can be used amongst other things for forming boiler fronts and they afford a particularly economic method where heavy scantling shells are concerned. In the case of thin material, or when the ring charge is fitted in or around a tube, difficulties due to circumduction of the detonation can arise whereby the shockwave will not impinge uniformly and simultaneously on the target (see figure below). Wrinkling may be caused when reducing tube diameters.

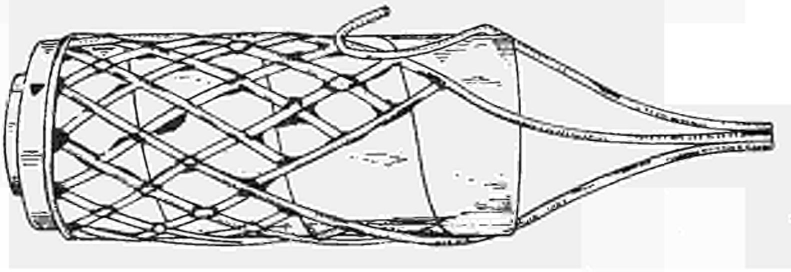


A stage in a shock front originating from an annular charge

(e) Network charges

In general these are less used for ordinary products but may prove expedient in special cases. As in the case of the ring charge the main difficulty is to decide on the right form of ignition. The somewhat fancy example of successful adaption shown in the figure below is probably the best arrangement for this kind of charge. The result of shaping the charge in this way is to produce a more or less conical shockfront with axial displacement.

Combinations of the above charge types can also be used.

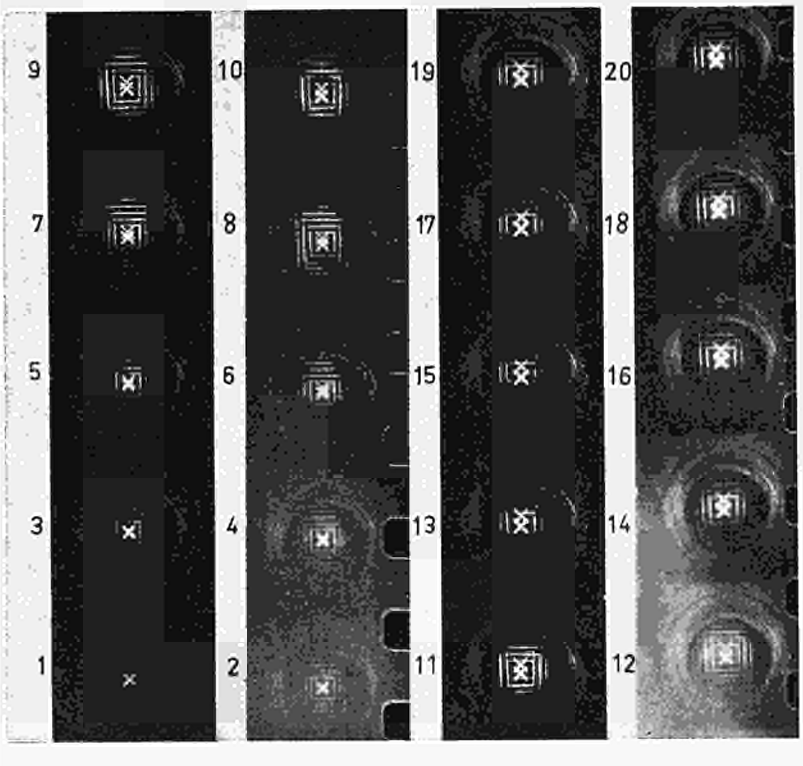


Reticular charge for producing an axial shock front

Forming the blank

To obtain greater insight into the possibilities of this process requires knowledge of the deformation time-history of the target plate. Measurements are carried out to this end through an observation window fitted in the mould. A reference line is printed on the underside of the plate and the displacement of this is recorded by high-speed stereophotography (20.000 pictures/sec.). A series of such pictures is shown in the figure below. When the plate is deformed and approaches nearer to the camera, duplication of the image results, the principle being similar to that of a stereoscopic rangefinder. Evaluation of these photographs shows a stepped deflection/time curve. Generally two or more steps will appear. The contraints are due to the fact that the plate is undergoing plastic deformation. The subsequent accelerations are caused by the associated collapse of cavitation spaces. These cavitations are induced by the high rate of deflection of the plate which stresses the water in tension. As soon as the plate is constrained, i.e. as the kinetic energy is absorbed in the plastic deformation, the cavitation space closes and in so doing imparts fresh energy to the plate.

This again causes high acceleration and the cycle is repeated. These tests were carried out on deep-drawing products with a charge stand-off distance less than the diameter of the work-blank.



Successive shapes of a moving lattice

Effect on material properties

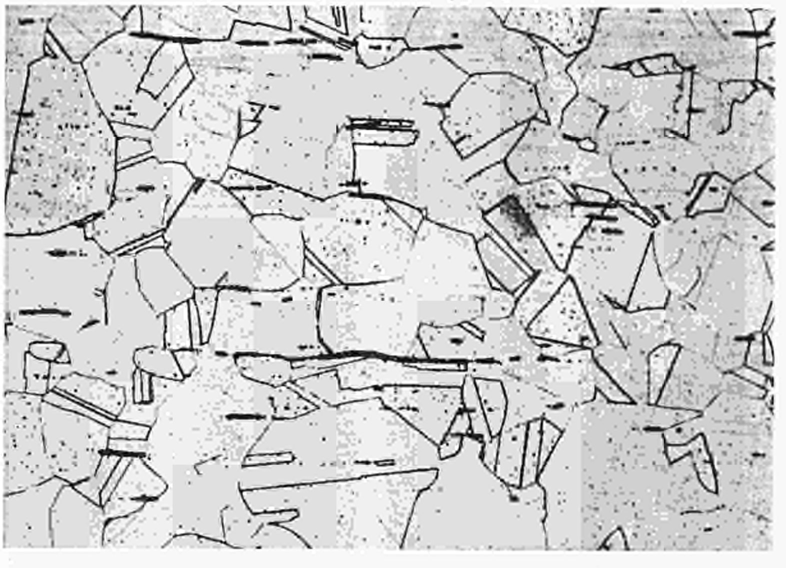
The influence of explosive forming on the properties of the target material is another aspect of the subject which requires to be studied. Two different effects are distinguishable :

(1) A change due to the high strain-rate the relative value of which in explosive deformation is of the order of 100 cm./sec.

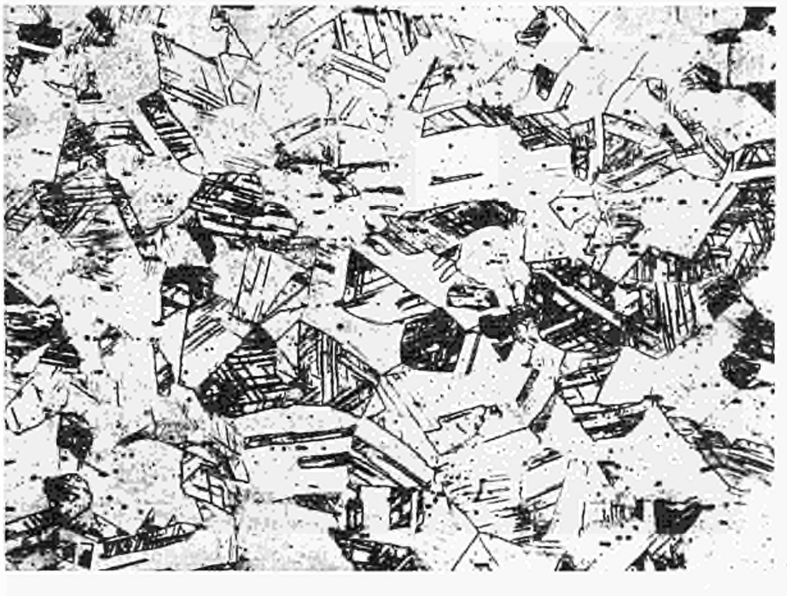
This high strain-rate affects the ductility of the metal during the process. Generally speaking ductility varies in inverse proportion to strain-rate so that whilst molybdenum sheet for example has an entirely acceptable Erichsen value at ambient temperature it proves quite brittle in explosive deformation.

(2) The shockwave effect.
This arises if the plate is forced into contact with the mould. The average velocity of a plate during explosive forming is 200 m./sec. If a flat plate moving at this speed should come up all standing against its mould, peak pressures of 40 kbar (40,000 atm.) can be created. Owing to the short duration of this pressure the permanent plastic set resultant therefrom will be slight. Nevertheless, pressure pulses of this kind may result in structural changes and consequently in changes in the material properties.

An example of change of mechanical properties as a result of explosive forming is offered by the reduction in corrosion-resistance of 18-8 austenitic stainless steel. This comparative investigation was carried out on two stainless steel diaphragms one deformed by conventional means and the other explosively; it was found that the latter corroded appreciably more quickly in an $MgCl_2$ solution than its conventionally worked counterpart. Certainly, a clear difference is observable between the two micrographs (see the figure below) and this is attributable to the greater concentration of twins in the explosively formed product. Alongside this there occur phase transformations in the austenitic steel and the internal stresses associated with the high twinning concentrations lead to an increase in hardness. It is these high internal stresses which are the real cause of the lowering of resistance to stress-corrosion.



Formed by conventional methods

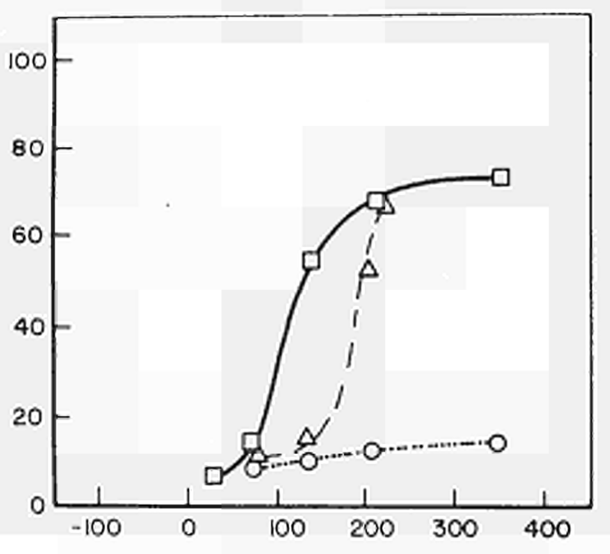


Formed by explosive methods

Structure of 18-8 austenitic stainless steel formed by the conventional method and the explosive method

When studying the effect of shockwaves on the material properties during explosive forming operations, heavy blast-loads are often intentionally imposed. If no deterioration of properties occurs as a result of such heavy loading then obviously no problem will arise on this score in the process. In high-impulse shock tests (> 100 kbar) conducted for this purpose however, phase transformations have been observed to occur. This is demonstrable by way of example from the results obtained with an Fe-30% Ni alloy, an alloy which is austenitically stable at ambient temperature. A shockwave of 100 kbar passing through this material as a compression wave causes twinning. Since the rear wall cannot absorb any stress this compression wave is reflected as a rarefaction wave. It is largely true to say that the influence of the rarefaction wave is such as to promote formation of a less dense structure. This would seem to be borne out by the formation of a body-centered α phase on the underside of the test-piece.

In face-centered materials, twinning and the occurrence of an abnormal slip mechanism appear to be governed by the direction of propagation of the shockwave in relation to the crystal orientation. It is therefore reasonable to suppose that these phenomena could be suppressed by ensuring a suitable material structure. Another precaution might be to subject the material to prior slow deformation. The resulting dislocation structure makes the material tend, during subsequent rapid forming or shocking, to adopt a deformation mechanism similar to that previously activated; a sort of memory effect as it were.



The effect of a shock load ont the transition curve of steel (after Dieter), in "Strengthening mechanisms in solids", ASM 1962)

In steel grades of body-centred type, brittle to tough transition occurs and it is evident that shock-loading affects the transition curve (see figure above). Blast-loading with intensive shockwaves can in fact raise the transition temperature by some 50°C although the permanent plastic deformation resultant from shocking is almost zero. When considering these results it should be remembered that the shockwaves here used are much stronger than those encountered in the explosive forming process.

Conversely, the above-mentioned increment of transition temperature is so great as to be out of the question in explosive formed products.

Applications

For what sort of work is explosive forming most suited ?

At first sight the cheapness and simplicity of the plant make the method seem most attractive. It must be realized however that stringent safety precautions and the need for evacuation and maintenance of vacuum severely reduce production rate. On these grounds the method lends itself best to minor production series of articles which are difficult or impossible to manufacture by conventional means.

In other words it will for instance be very suitable for working heavy plate where expensive machines and/or preheating would normally be needed. The fact that only a female die is required and no punch is also an important advantage. The limiting factor is usually the size of the charge which must be such as not to damage the container. Another important application is for products demanding a high degree of sizing and shaping precision and in this connection significant successes have been reported in the manufacture of radar components, part-sections for spheres, streamlined shapes and suchlike (figure 10, page 442).

Good reproducibility of accurate shape is here of the utmost importance when the product has to be built up of sections.

Finally we should mention the advantage of welding beforehand. The welds appear to be pressed inwards by the die without much difficulty, and this can bring considerable saving in finishing costs. A special application in this same connection is calibration whereby the product simply assumes the surface quality of the die (figure 11, page 442). Thus, by using superfinished moulds or mandrels articles can be produced whose surfaces exhibit an equally high degree of polish. This capability must be particularly valuable when tubular products require to be internally finished.

It is these latter possibilities which give the process its greatest attraction. Unfortunately they are still little known and virtually unexploited.

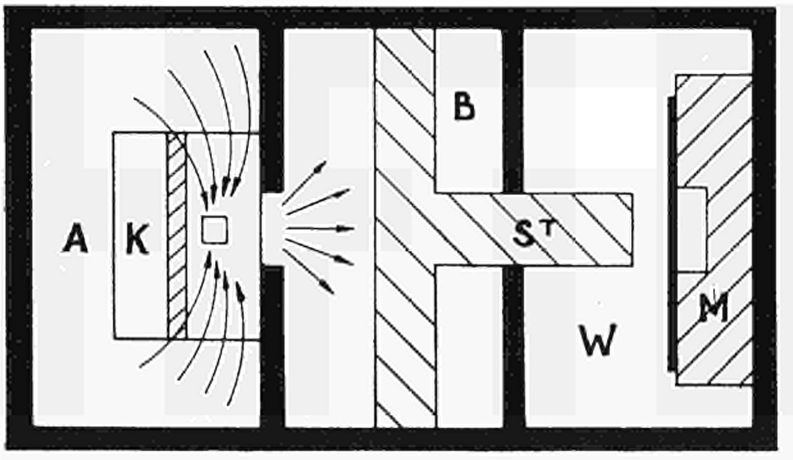
Hans-Josef MÜRTZ

Cold Forming by High-Speed Drop-Hammers and by Shockwaves from Electric Discharges with Special Reference to their Different Modes of Operation

(Translated from German)

In recent years much has been written and said about highspeed working, i.e. the working of materials by means of high impact velocities, but our knowledge in this field is still decidedly limited. Only in the course of the next few years will the fundamental research now in progress reveal where these new processes can be most efficiently used and it is no use expecting them to perform miracles.

Unfortunately the term "high-speed working" or the subordinate term "high-efficiency forming" is still widely used to denote the forming of workpieces by high-speed drop-hammers and by shockwaves, although these consist of two entirely different techniques. The high-speed hammer is in fact only a more advanced form of the conventional hammer, and would be more accurately described as a high-pressure hammer. Explosive forming is, however, an entirely new method of operation, as a comparison of the two processes will show.



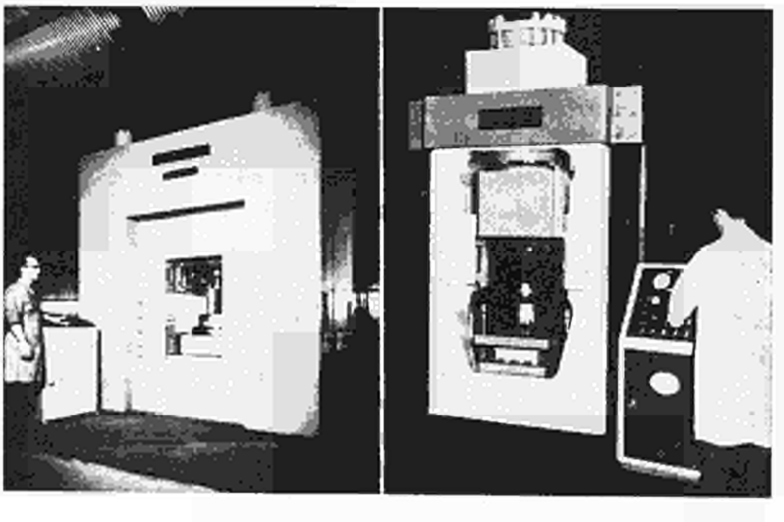
Schematic showing method of hydrodynamic forming

The above figure shows the operation of the high-speed hammers. In contrast to the conventional hammers, the pressure system in self-contained. In the initial state there is a gas pressure of 80-140 kg./cm.² in chamber A, which is closed by piston K; chamber B is pressurized only sufficiently to keep the upper ram St resting against the partition. When the hammer is started, slide K springs back and the gas (commonly N_2) expands and moves the upper ram towards the workpiece. On impact, part of the kinetic energy is converted into forming energy, whilst the remainder is absorbed by the machine parts. By means of oil the ram is returned to its original position and the gas is compressed to its initial pressure. After the exhaust has been closed with piston K, the oil is replaced by a low gas pressure. In the case of one machine the upper ram is mechanically locked.

With this cycle the intervals between blows are relatively long compared with the conventional hammers.

In some machines the die as well as the upper ram are moved so that the impact velocities can be doubled although in fact the velocity of the lower ram is usually lower. The relative speeds so achieved vary between 10 and 30 m.s., affording a considerable saving in weight. Moreover as the inertia forces are compensated within the machine, this often needs no base-plate of its own. Thus high-pressure hammers offer a large working capacity on a small space.

The figure below shows two different types of machine, a Dynapak machine with a working capacity of 32 mt and the CEFF forming machine with a working capacity of 50 mt, which differs from the Dynapak machine principally in the mechanical locking of the ram. Similar high-pressure hammers are manufactured by German and American firms.



Left: 50 mt.
Right: 32 mt.

High-speed drop hammer

So far, the following forming processes have been tested with these machines : waging, hot pressing and cold extrusion, powder pressing, bonding and sheet-metal forming with rubber or liquid cushions. At present however the main field of application is hot die forming where the following advantages are obtained :

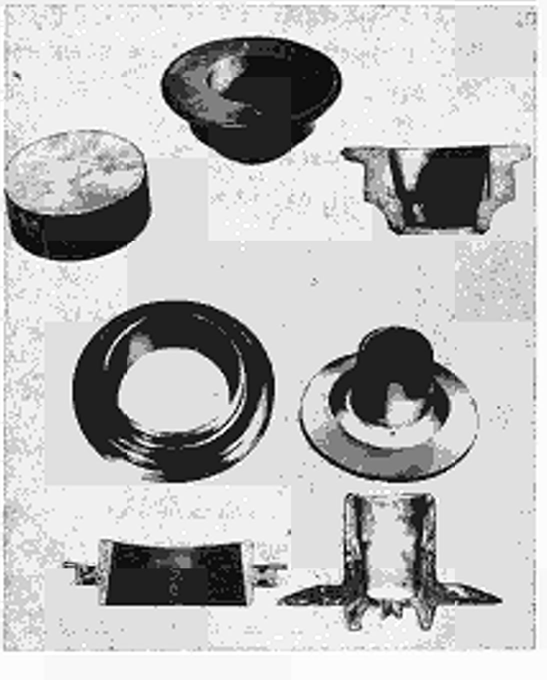
1. even unsymmetrical workpieces can be finish-formed with a single blow;
2. owing to the accuracy of forming, the billet weight is very small;
3. the workpiece tolerances are narrow and the surface quality correspondingly good;
4. the structure is better;
5. even metals which are difficult to form can be handled satisfactorily.

This effects savings in costs of material and working in the case of many workpieces. Some examples are given in the figure below : a roller of 42 Cr Mo 4, a front hub of CK 35 and a flange of X 10 CrNiTi 18·9. (Material No. 1.4541, stainless and acid-resisting steel.). These parts were formed with one blow at a temperature of approximately 1200°C; no subsequent machining being necessary. The same workpieces made of pure aluminium could even be cold-formed with a single blow.

Apart from this little is known about the results of cold-forming processes, and it is probably too early to offer an opinion at this stage.

One problem, however, which is common to all forming processes is that of the exact energy dosage, since any excess energy has to be absorbed by the machine components and/or the tool; extremely careful setting is therefore necessary. Provided this is ensured, the stress on the die should not be greater than in conventional forming, particularly as it has to be taken into account that with the high-pressure hammer the parts are usually formed with one blow. Moreover, it should be noted that this process can most economically be used for the manufacture of complex workpieces, so that an absolute comparison is in any case difficult to achieve.

In this respect the processes of forming with high-speed hammers and with explosives, i.e. shock waves, have much in common : both can at present be profitably used for the manufacture of complex workpieces required in relatively small numbers, so that the longer cycles which at first appeared to be a disadvantage are a minor consideration.



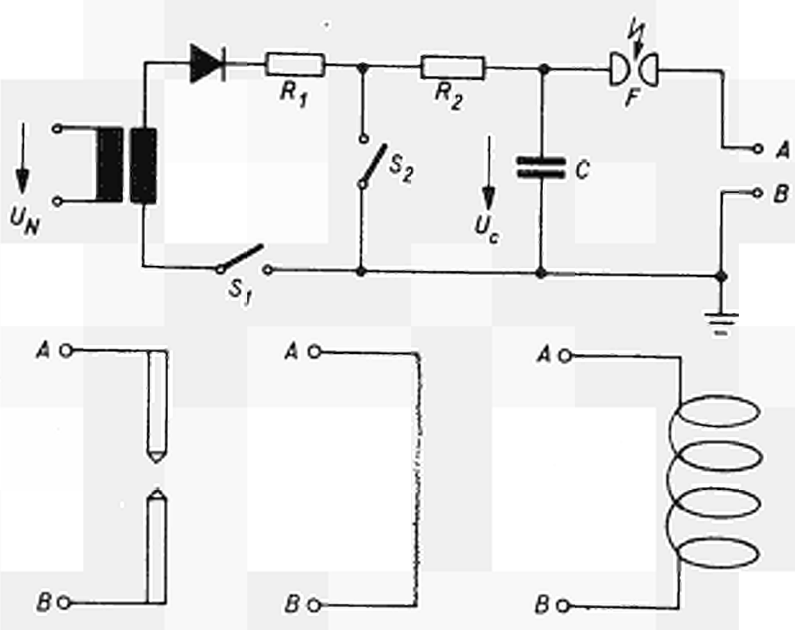
Workpieces produced by a single blow of a high-speed drop hammer

The explosive forming process is, however, entirely different from the technique just described. Here the upper ram can be completely dispensed with; the energy is transmitted by a shockwave which propagates at supersonic speed in a suitable medium (usually plain water) towards the workpiece.

The use of chemical blasting agents in manufacturing involves great difficulties, more especially by reason of the safety regulations to be observed, and it soon became the practice for the necessary shock-waves to be generated electrically by means of a high-voltage discharge. The principle is shown in the figure below.

Energy is stored in capacitors which are charged for a comparatively long time (1 second or more) from the normal system through a H.V. rectifier arrangement, and then discharged into a load through a high-

U_N	*mains voltage*
U_C	*battery voltage*
C	*condenser battery*
$R_1 + R_2$	*charging resistance*
R_2	*discharge resistance*
F	*overload switch*
S_1 kWs	*high-tension-switch*
S_2 kWs	*zero-position separator*
A - B	*load connection*



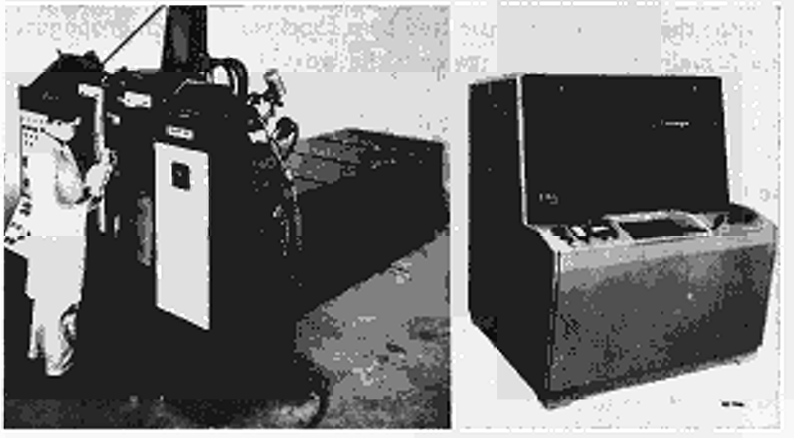
Schematic diagram for hydro-dynamic and electromagnetic transformer

tension switch as soon as the ignition order is given. Up to the connection points A.B. the impulse-current plant is the same both for electrohydraulic and for electromagnetic forming, which is dealt with in another paper. The two processes differ only in the load unit, the energy converter, which in the one case consists of a pair of electrodes or a wire and in the other of a magnetic field coil.

If a pair of electrodes submerged in water is used as a load, this is referred to as an underwater spark discharge. When the capacitors are discharged, a speak jumps from electrode to electrode; this evaporates the water in a fine channel and, as the ambient water acts as a rigid wall, produces a high pressure (up to several thousand atmospheres). As with the shockwaves generated by a blasting agent, this pressure propagates at supersonic speed (several km./s.) through the liquid medium, and if sufficiently high drives the workpiece into the die. To avoid overheating of the air between the workpiece and the die during forming, this space is evacuated.

If the spark gap is replaced by a wire, this is referred to as a wire explosion. The conversion of energy is similar except that the spark track is determined by the ignition wire, which is of particular interest for complex forms. By means of the ignition wire the energy can be converted at specific points if the wire is given a particular form, e.g. a spiral or a specially shaped loop.

In this way it is possible not only to localize the energy but also to produce different shockwave fronts by purely geometrical configurations, and to increase the concentration of energy by reflection of the fronts.



Left : 30 kWs
Right: 7 kWs

Shockwave forming machines

Two special machines are shown in the above figure. On the left we have the 30-kWs EHF machine. The energy is stored in capacitor modules of 6 kWs or 12 kWs which allow an easy extension. The tool, a split and hydraulically compressible die, is in the middle. The electrode holder is also movable. The capacitor voltage can be set continuously between 0 and 8·3 KV; the charging time is 5-10 seconds. The opening, closing and compressing of the die takes less than 15 seconds. The compressive force on the die halves is approximately 100 tons. With this machine parts up to 250 dia. × 250 m. can be formed. The charging of the capacitors and the mechanical movements are not coupled. The connected power is less than 10 KW.

On the right we see the 7-kWs prototype "Megaschock", As this machine shows, processes such as water filling, evacuation and charging of the capacitors, etc, which at first appeared to be complicated, can easily be fully automated. After loading of the part, the machine is started simply by pressing the push-button Start (on the left on the control desk): the tool moves in, the cover closes, the electrodes move in axially and the space of explosion is filled with water by a dosage pump. In the meantime the space between workpiece and die is evacuated, and the capacitors are charged to the present voltage and then disconnected from the system. Upon an automatically controlled ignition order the capacitors are discharged into the spark gap through high-tension switches. The shockwave so generated drives the workpiece into the die. A pump then suctions off the water, the electrodes move out of the tool, the electrical unit of the machine is earthed for safety and the tool together with the formed part returns to its original position. Depending on the setting, this cycle takes 10-30 secs. The capacitor voltage can be set continuously between 0 and 20 KV; the maximum connected power is less than 5 KW. In the tool, which forms a self-contained unit, workpieces up to a maximum size of 150 dia. × 200 mm. can be formed. For the forming of larger workpieces (approximately 400 dia. × 600 mm. or more) with shockwaves, impulse-current units with an energy content of up to 60 kWs are used which are composed of capacitor modules of 6 or 9 kWs.

From this is will be clear that shockwaves from electric discharges offer the following advantages in forming:

(1) advantages similar to those of the high-speed hammer (fewer forming operations and high forming accuracy);

(2) no upper ram and therefore
    (a) reduced tool costs and
    (b) more uniform stress on the material;

(3) simple and precise energy storage and release ensuring high repeatability;

(4) a locally variable concentration of energy;

(5) great versatility.

The application of shockwaves for the working of materials is very versatile and is by no means confined to metals or the forming process only. In cold forming, however, they are at present used mainly for sheet metal forming.

Parts formed by means of high-voltage explosion

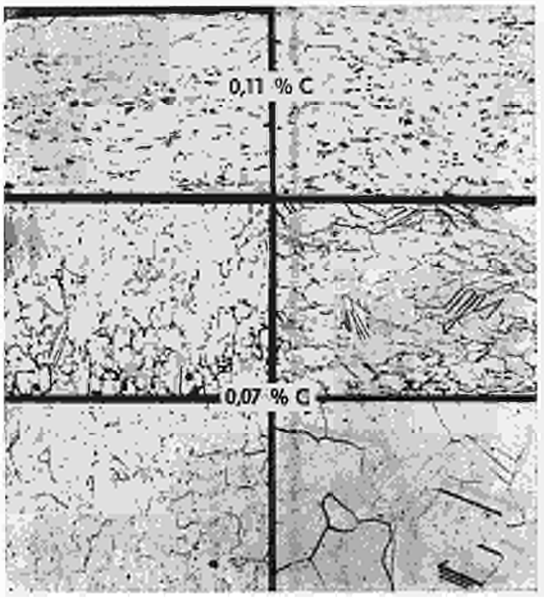
The above figure shows some parts formed by means of high-voltage explosion. In the case of the upper aluminium tube a one-sided bulge of 74% was achieved. For this forming process 3 or 4 discharges are required, but the workpiece need not be taken out. Of special note in the part shown here are the small transition radii which cannot be achieved with conventional processes; in addition, the working time was considerably reduced. — The other workpieces demonstrate that this technique is especially valuable in the manufacture of complex parts, possibly with relief-cuts and recesses, where several forming operations, e.g. bulging, stamping, cutting, punching, etc., can be combined into one. The small hexagon shown at bottom right illustrates a case where conventional manufacture would have been possible but costly, because of the small number of pieces required.

It is obvious from the above examples that these machines are at present used mainly in the aircraft and rocket industries, but are by no means confined to these. The results obtained in high-efficiency forming of circular sheet-metal blanks are unfortunately still far from satisfactory, and it would be premature to say anything about them at this stage.

Although a great deal of experience has been gained in recent years, it is still impossible to establish a generally applicable rule of thumb as to, for example, the ratio between degree of deformation and dimension of workpiece. In most cases it has to be ascertained empirically whether a particular material lends itself to the desired forming or not.

This means that thorough fundamental research must be carried on in parallel. Simple workpieces, such as the steel tube shown in the middle of the above figure, are the most suitable for this purpose: by systematic research the expansion of this tube was doubled.

Some interesting discoveries made in the course of this work may be illustrated by referring to the figure below. In high-efficiency forming changes occur not only in wall thickness and hardness but also in structure. The tubes in this case are made of unalloyed steel with different carbon contents and different tensile strengths the bulge was only 11% and 20%. In the first place it can be seen that, as with chemical blasting agents, there is a marked tendency to twin formation, due to the high impact velocity. The twin lamellas are sometimes superimposed in the form of lattices and the boundary lines are irregular and in places curved. Even in the area which is unformed but subject to the shockwave, twin formation and slip bands occur in places. It is interesting here to note that with higher carbon contents and tensile strength but constant stress, twin formation ceased to occur. Research is being planned into the relationship between tensile strength and twin formation.



Undeformed and deformed area

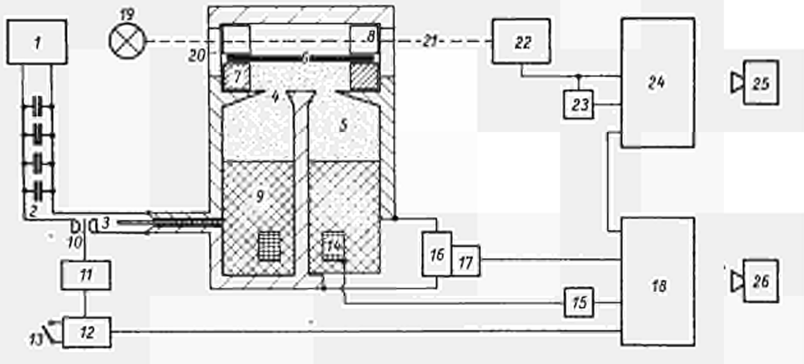
Another notable discovery was made in the case of the tube shown in the lower part of the figure. The sheet metal used was of a special deep-drawn quality but nevertheless some cracks occurred although the expansion was less than 20%; owing to shockwave stress the yield strength had doubled and the expansion had decreased to half of the original value. These cracks may have been caused by compression shockwaves being reflected as tension shockwaves and thus producing an inappropriate area of tension. The same phenomena were observed by C.A. Verbraak using chemical blasting agents.

This research, on such aspects as the influence of the degree of deformation on structure and mechanical properties, has still some way to go so that no general conclusions can be suggested at present.

In the meantime, however it has been found possible to expand steel up to 35% without cracks by selecting a particular amplitude, duration and direction of the shockwave, and suitable lubricants.

Several hypotheses have been put forward in recent years concerning shockwave working, none of which unfortunately so far having been substantiated. Thus it was contended that the disturbing spring-back observed in the conventional method does not occur in explosive forming. This has however proved to be untrue. Drs. Bodenseher and Schmied of the 1. Physikalisches Institut of the University of Vienna have shown that in free sheet-metal forming there can be not only a distinct spring-back but sometimes even vibration of the sheet. A parallel test showed that spring-back is smaller in shockwave working than in the conventional method but that it is by no means negligible.

1. *High-voltage charger*
2. *Capacity energy-storage battery*
3. *Ignition-spark gap*
4. *Coaxial load-spark gap*
5. *Transfer medium*
6. *Round metal workpiece*
7. *Spacer ring*
8. *Hold-down cylinder*
9. *Insulator*
10. *Ignition electrode*
11. *Ignition coil*
12. *Release*
13. *Release switch*
14. *Rogowski coil*
15. *Integrator*
16. *Potentiometer*
17. *Cathode follower*
18/24 *Oscillograph*
19. *Mercury vapour lamp*
20. *Adjustable gap*
21. *Light beam*
22. *Photomultiplier*
23. *Differential amplifier*
25-6 *Camera*



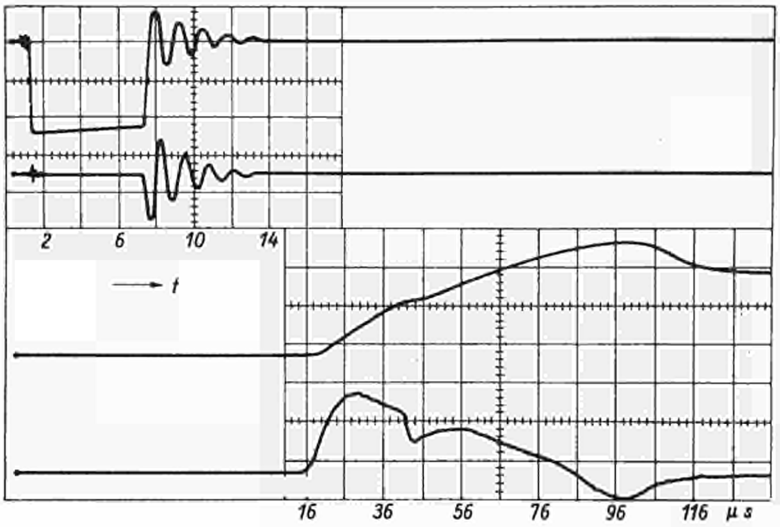
Free forming of steel sheet through underwater ignition

Tests have been carried out on circular blanks of aluminium, zinc, brass, copper, steel and lead sheets of 0-1-1 mm. in thickness freely formed by means of an underwater spark discharge. The clear diameter of the circular blank was 20 mm.

The schematic set-up can be seen in the above figure. The energy storage (condenser capacity 0.5 μF, max. condenser voltage 25 KV) was discharged through a coaxial spark gap. The natural frequency of the total circuit was 800 kilocycles. For each discharge recordings were made of the voltage characteristics on the spark gap, the current characteristic in the discharge circuit, the distances in terms of time of the sheet metal from its original position in the course of the forming process, and the resulting sheet-metal speed. The voltage was measured by means of an impulse voltage divider and the current by means of a Rogowski coil. The forming process was optically sensed in such a way, that the light gliding over the circular sheet blank through a gap was converted into electric current in a photo-multiplier and the current recorded by an oscillograph. Any movement of the sheet metal changes the light intensity, which is directly visible on the screen. Electrical differentiation of the path-time curve gives the sheet speed during forming.

Such an oscillogram is shown in the figure below. At the upper left the voltage and the current are plotted. About 1 μs after release the voltage appears across the load spark gap, which after about 7 μs ignites, and within the next 6 μs the capacitors discharge through the spark gap. On the right are shown the phases of forming and the sheet speeds. Owing to the propagation time of the shockwave and the inertia of the sheet metal, forming starts only some microseconds after the discharge has been completed. At approximately 45 μs a small dent can be observed, presumably caused by a reflected shockwave front which gives the material a new pulse. After the sheet has reached the maximum distance from its original position a distinct spring-back can be observed. The figure below shows that even vibrations of the sheet metal may occur. This is particularly clear from the diagram at the lower left. The diagram at bottom right even shows an overswing, possibly caused by the steam bubble following the shockwave.

Spring-back was observed on all materials except for lead sheet; in spring steel (0·2 mm. thick) it was even 75%. The effects of spring-back and vibration at higher energies will not be known until the completion of the current experiments.



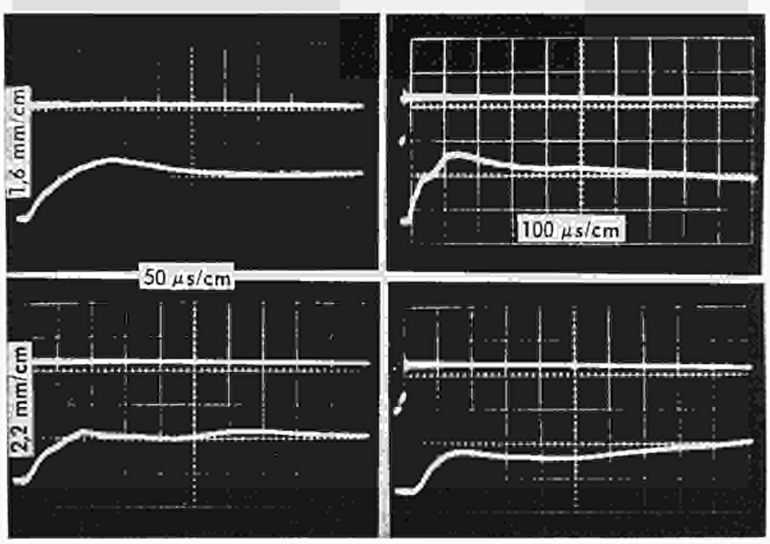
U (t) on the load-spark gap (6 kV/cm) discharge-current path (30 kA/cm) trajectory (1 mm./cm.)
— during forming
Speed of travel of the metal (60 ms⁻¹/cm.)

Measurements of free forming of steel sheet through underwater ignition

An evaluation of the measurements described also showed that the maximum speed of deformation v_{max} of the sheet metal can be expressed as follows:

$$v_{max} \sim \sqrt[3]{E^2} \; / \; (r^2 . \sqrt{a \, . \, \rho}),$$

where E is the stored electric energy, r the distance of the sheet from the spark gap, a the sheet thickness and ρ the sheet metal density. It should be noted, however, that the above formula applies to this particular arrangement only. It remains to be investigated how far it is generally applicable and how far dependent on the natural frequency of the plant.



Optical measurements speed/time of free forming of steel sheet through underwater ignition

These few examples will have shown that while in the present state of knowledge high-efficiency forming can be economically employed only for special workpieces, research during the next few years should not only clarify the mode of operation but also widen the range of application. Moreover, application will become more economical when workpieces appropriate for this technique are designed; this no designer so far ventured to undertake.

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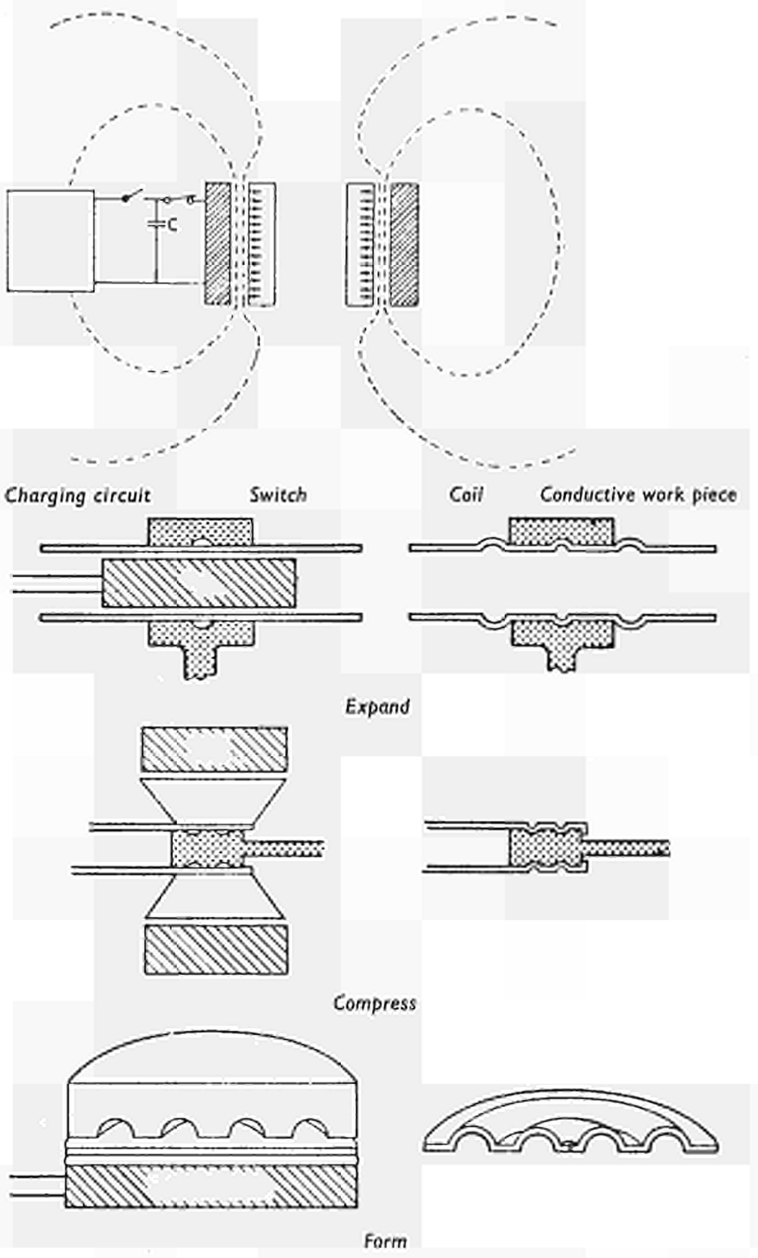
David F. BROWER

Magnetic Pulse Cold Forming

Magnetic pulse forming machines are being used for a growing variety of industrial metal-forming and assembly applications. These machines operate by generating an intense magnetic field adjacent to the workpiece. The interaction of the field with electrical eddy currents induced in the work produces a high pressure impulse. Depending upon the intended application, the duration of the pulse might range from one to perhaps 100 microseconds.

The magnetic field is generated by discharging energy stored in a bank of capacitors through an electrical coil. The figure below shows schematically how this is done. By the use of suitable coils the magnetic impulse can expand or compress tubular parts or form flat sheets of metal. Metals having relatively high electrical conductivity such as copper, aluminium, carbon steel, and brass are easily formed by the process. Metals with lower conductivity, such as stainless steel-alloys can be formed by using an intermediate "driver" of aluminium sheet or tube which responds well to the magnetic pulse.



Simplified schematic diagram of the magnetic impulse forming process, showing the three main steps

Key characteristics

The novel characteristics of the magnetic pulse forming technique present the metal fabricator several new capabilities which he can apply to his metal forming and assembly problems.

(1) Pressure is applied directly to the workpiece through the medium of the magnetic field so that forming can be accomplished with no physical contact. Since the magnetic field will pass through materials which are electrical non-conductors it is possible to work through a non-metallic coating or container.

(2) Unlike the usual metal forming processes, most of the metal forming takes place after the pressure impulse has ended. The metal is rapidly accelerated, gaining a large amount of kinetic energy but moving only a short distance during the impulse. This kinetic energy subsequently does the actual work of forming.

(3) The ratio of the masses of pieces involved in assembly operations may be much more significant than their relative strength or elastic properties. Since no static forces are involved in the process relatively light structures may be used for the support of dies.

(4) The magnetic field behaves very much like a compressed gas. It exerts a uniform pressure which is relatively independent of spacing variations between the workpiece and the magnetic work coil. In swaging and expanding operations no torque is applied to the work such as would be encountered in spinning and rolling operations.

(5) The contact between the magnetic field and workpiece is frictionless so that lubricants are not required.

(6) Being purely electromagnetic in nature the process is not limited in speed by the mechanical inertia of moving parts. The timing of the magnetic impulse can be synchronized with microsecond precision and machines can be designed to function at repetition rates of thousands of operations per minute. The strength of the magnetic impulse can be controlled electrically with high precision.

Limitations

The magnetic field cannot be easily "shaped" to fit all workpiece contours. For example, it may be very difficult to apply uniform pressure to a slotted workpiece. It is not possible, in general, to apply a high pressure in an arbitrarily chosen area while applying a low pressure in adjacent areas.

Although the pressure which can be applied by the magnetic impulse can be very high compared with the average pressures that are usually applied in forming operations the peak pressures are limited by the strength of work coil materials to much lower values than are commonly encountered in shearing, punching, and upsetting operations. About 50,000 psi is the maximum pressure that can be exerted repetitively by the strongest work coils. At higher levels of pressure the coils will deteriorate rapidly. Because of the limitations on pressure and pulse length the process is not useful for most forging applications.

Equipment

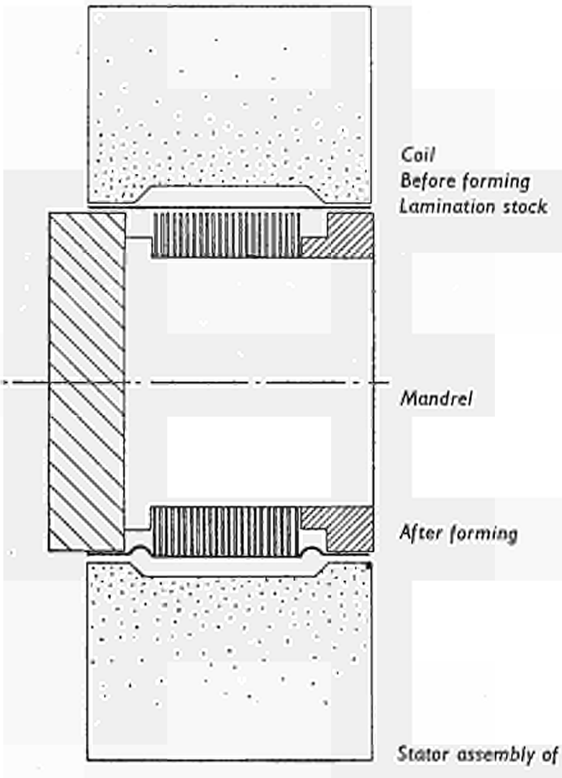
The machine illustrated in Figure 12 (page 442) is a six kilojoule "Magneform" magnetic pulse forming machine being used to bind rubber boots to ball joints by compressing a metal band in place. The 84 kilojoule machine of (figure 13 (page 443) is being used to compress 3-inch diameter steel tubing on to an end fitting with a 50 kilojoule impulse to make an automotive drive shaft assembly. This photograph was taken in the laboratory during the equipment and process development program.

"Standard" magnetic pulse forming machines operate at a maximum rate of ten operations per minute at maximum energy and use ordinary plant 50/60 cycle power. Having no moving parts (except, of course, for feed and holding devices) the machines have few maintenance problems. Although such machines have been used in production only a few years, several have each produced over five million parts without a major component failure.

Applications

Forming

The stator assembly of an electrical machine is shown in the figure below, and in figure 14 (page 443). The steel outer band was compressed into the stacked laminations and shaped to conform to the supporting mandrel in a single magnetic pulse operation. The laminations are bound rigidly in place without the use of rivets or bolts and, simultaneously, shoulders for end bell housings are formed which are precisely concentric with the inner surface of the stator laminations. About 40 kilojoules of energy were needed to form and assemble this part. In this application, it was necessary to apply high pressure to form the shoulders. Such a high pressure would have deformed the laminations.



Stator assembly of an electrical machine

For this reason, the work coil was contoured as shown in the above figure. The pressure along the length of the workpiece in this configuration varies (to a close approximation) in inverse proportion to the square of the radial spacing. Such control of the pressure along the length of a workpiece is easily done; however, control of pressure around the circumference is not always possible.

The grooved hoop-shaped part shown on the right of figure 15 (page 443) was formed by expanding a ·030-inch thick band of steel into the ring die shown at the left. Because of the high velocity of the band when it struck the die it conformed very accurately to the die contour. However, since the die was not subjected to static pressure there was no need for the massive construction which would have been necessary had hydraulic pressure been used. Using the magnetic pulse technique it was merely necessary that the die be many times as massive as the workpiece. About 40 kilojoules of energy were used in this operation.

Joining

Torque joints are commonly made by welding, pinning or riveting. These processes are often satisfactory but like all techniques have certain disadvantages. Because of the heat involved, welding may distort the part. Heat may damage critical materials in the assembly. It is sometimes difficult to attain sufficient strength in pinned or riveted joints, and the drilling of the necessary holes, particularly in precision assemblies, is not always an easy job.

Figure 16 (page 444) shows a torque joint made by magnetic pulse forming. The carbon steel tube, 3-inch diameter by 0·070 inch wall, was swaged onto a slotted end fitting at an energy level of 48 kilojoules. No measurable relative movement was observed in joints subjected to torque sufficient to cause the tube to fail. Such joints can be made which are equally strong in tension.

In some applications the ability to apply uniform accurately metered pressure is of paramount importance as in the joining operation shown in figure 17 (page 444). Here a stainless steel fitting is compressed onto a contoured graphite rod. Although the graphite was an unusually tough variety, a slight increase of pressure above that required for forming would have crushed the rod. Since the electrical resistivity of the stainless steel was too high for efficient magnetic pulse forming, an aluminium sheath which transmitted the pressure was placed between the steel and work coil. The sheath was removed before the photo was taken.

Compressing Rings Into Grooves

Figure 18 (page 444) shows an artillery shell sectioned in the region of the "rotating band". This band is made of a copper alloy, swaged firmly to completely fill the undercut groove by a single magnetic impulse. The technique is of particular value here because it can swage pre-formed rings into place, thus eliminating a postswaging machining operation as well as saving considerable material. In a similar manner slip rings and retaining bands can be swaged into place on rotating components for electrical machinery.

Assembly by heat shrinking

Magnetic pulse forming can be used to extend the usefulness of the heat-shrinking technique.

To heat shrink one part into another, the two components are normally machined to an interference fit. If the outer part is heated or the inner part is cooled (or both), both parts may be slipped together. Because the dimensional change that can be accomplished by this method is small, difficulty in assembling the parts is usually experienced if the length-to-diameter ratio of the components is large.

If the initial clearance could be increased by some means and the heat transfer could be reduced enough so that temperature equalization is slowed, the process could be used in applications which would otherwise not be feasible. This can be accomplished by simply machining the parts to a „loose" fit to start. Then after the usual thermal expansion and assembly, the hot outer part is compressed to contact the inner part. After temperature equalization, the parts will be firmly shrunk together.

To be successful, the mechanical compression must be uniform, the part must not be cooled through conduction to the compressing device and the process must be fast enough so that the temperature difference between parts has insufficient time to equalize through conduction and radiation to each other. Magnetic pulse forming is admirably suited to this operation since the compressive force is applied through a magnetic field, heat conduction is small and the cycle can be completed in microseconds.

Compressing a fluted cylinder

Figure 19 (page 445) is a finned aluminium sleeve swaged onto a nuclear reactor fuel rod. It is fabricated by placing the fluted sleeve over the fuel rod with ample clearance between the two parts and then inserting the assembly into a work coil where a magnetic impulse is applied. Distributed uniformly over the surface of the fluted sleeve, the magnetic field exerts a uniform pressure over the entire surface and compresses it onto the fuel rod without damaging the flutes. The same technique is used to attach radiators and heat sinks to a variety of electrical components. Thermal contact at the interface is good.

Future possibilities in applications and machines

There are several promising specialized applications for the magnetic pulse forming of flat sheet material, but, on the basis of equipment costs and some technical considerations it appears unlikely that magnetic pulse forming machines will be developed in the next few years that will compete with stamping presses in most high production stamping applications. On the other hand, there appears to be a bright future for forming and assembly of tubular parts. Very large machines (over 100 kilojoules) are quite feasible technically and are being considered for several industrial applications.

Low energy, high speed, automatically fed machines for such applications as the forming of threads, trimming, and embossing of light gage tubular pieces of aluminium are an interesting development. We have in our laboratory in San Diego, developmental low energy equipment which has to date operated continuously at the rate of 1,000 impulses per minute for over 100 million operations with only minor maintenance. We have not yet designed the feed mechanisms for this equipment. Two of the major advantages offered by the magnetic pulse technique in high speed operations are the ease with which the forming impulse can be synchronized with the feed equipment and the relatively simple holding and positioning mechanisms which may be employed.

I have discussed only a sample of the growing number of applications for this new technique and have emphasized particularly the forming of steel. Although a sizable number of machines are now being used in production, the development of the many potential applications has barely begun. Magnetic pulse forming has been occasionally substituted to advantage in place of conventional techniques to form or assemble parts of current design; however; the greatest advantage can be gained if the part is designed with the process in mind.

Jean DAUBERSY

Recent Progress Concerning The Manufacture of Steel-Plate for Cold-Forming

(Translated from French)

The highly interesting papers presented to this section of the Congress deal with new steel-forming processes based generally either on a considerable increase in the speed of deformation of the metal or on the hydrostatic pressures used in the deformation process.

It was undoubtedly essential to draw the attention of steel-consumers to these new techniques with their very high speeds and pressures, which considerably assist the plastic deformation of the metal.

Nevertheless, it should not be forgotten that most of the sheet steel currently used is formed in presses where high speeds and pressures are not required, and that the traditional method of drawing and pressing will continue to be very much preferred.

The delegates from the Benelux plate and sheet manufacturers felt that in the section dealing with the working of steel, attention should be drawn to the fact that considerable progress has also been made in the traditional method of drawing and pressing and in the production of steel—which is their business—in order to improve performance under the press at the minimum cost.

I propose, therefore, to outline the progress made and to describe several novel techniques.

The guiding principle behind this progress has been the analysis of the stresses in the drawing process and the systematic efforts made to achieve correlations between the capacity of the sheet to withstand higher stresses in practice and the various properties that can be measured in the laboratory.

For many years, sheets have been chosen and accepted for drawing and pressing almost entirely on the basis of the elastic limit and the Erichsen index. These criteria however do not provide all the required information; in fact in industrial drawing and pressing operations it is necessary to distinguish between two different types of stress :

first, the shrinkage which accompanies the movement of the metal under the blankholders ;

second, the bi-axial stretching which accompanies the formation of a surface under the punch, when this surface is deformed without the addition of metal as the result of flow.

These two stresses affect every industrial drawing and pressing operation in different degrees.

It is now a well-established fact that the capacity of a sheet to withstand shrinkage, for instance its suitability for the deep-drawing of cylindrical cups, is a function of neither the elastic limit nor the Erichsen index.

What principally is involved is that tension in the plane of a sheet causes it to become narrower rather than thinner.

The greater its normal anisotropy, the better will a sheet be able to withstand deformation. This anisotropy is linked with preferential crystal orientations brought about by rolling, annealing, and the presence in the steel of certain addition elements.

The capacity of the steel to withstand bi-axial stretching appears to be linked with the "coefficient of consolidations," which in turn depends on the elastic limit, the elastic limit/strength ratio, and the elongation. But the correlations found are of little value, which proves that there are other factors operating. (See the figures below.)

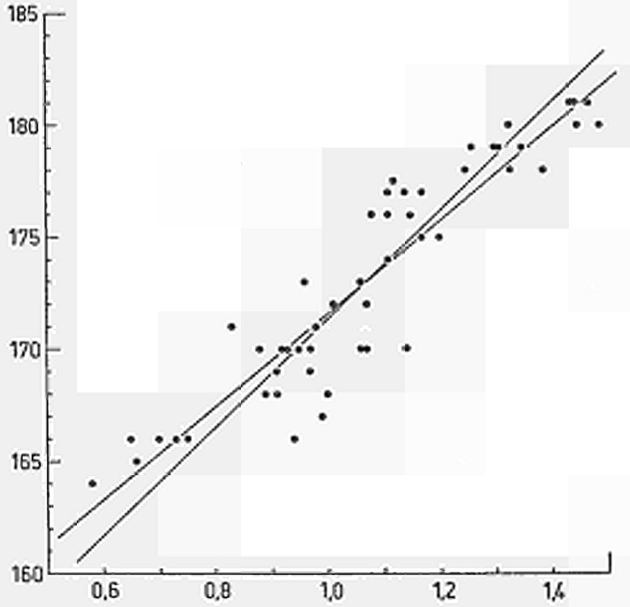
Thus, while there are true correlations between certain measurable criteria and the capacity for certain kinds of deformation, one fundamental difficulty remains, namely to assess the relative extent of circumferential shrinkage and stretching in a given drawing operation. Great caution therefore is necessary in judging whether a sheet is suitable for a given purpose.

In addition, other factors must be taken into account such as ageing, stretcher straining, surface roughness, the capacity to undergo bending, uniformity and regularity of supply, all of these being factors which may at times assume predominant importance.

A priori judgments on the basis of the chemical analysis or the steel-making process are often proved wrong by the facts. The only fully valid critirion is direct trial on the press. This moreover, must be done under technological conditions appropriate to the properties of the sheet.

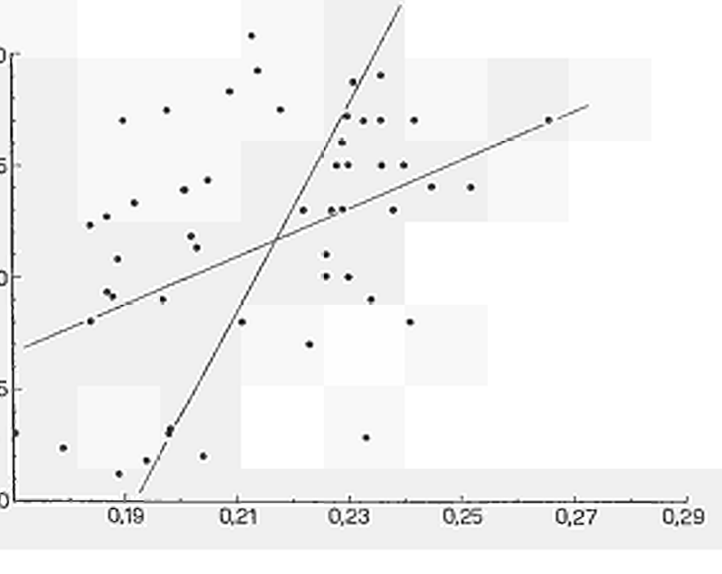
Today, the buyer will find on the market unkilled steel sheets and sheets made of steel killed with aluminium.

— ∅ Critical (mm.)
— r Minimum

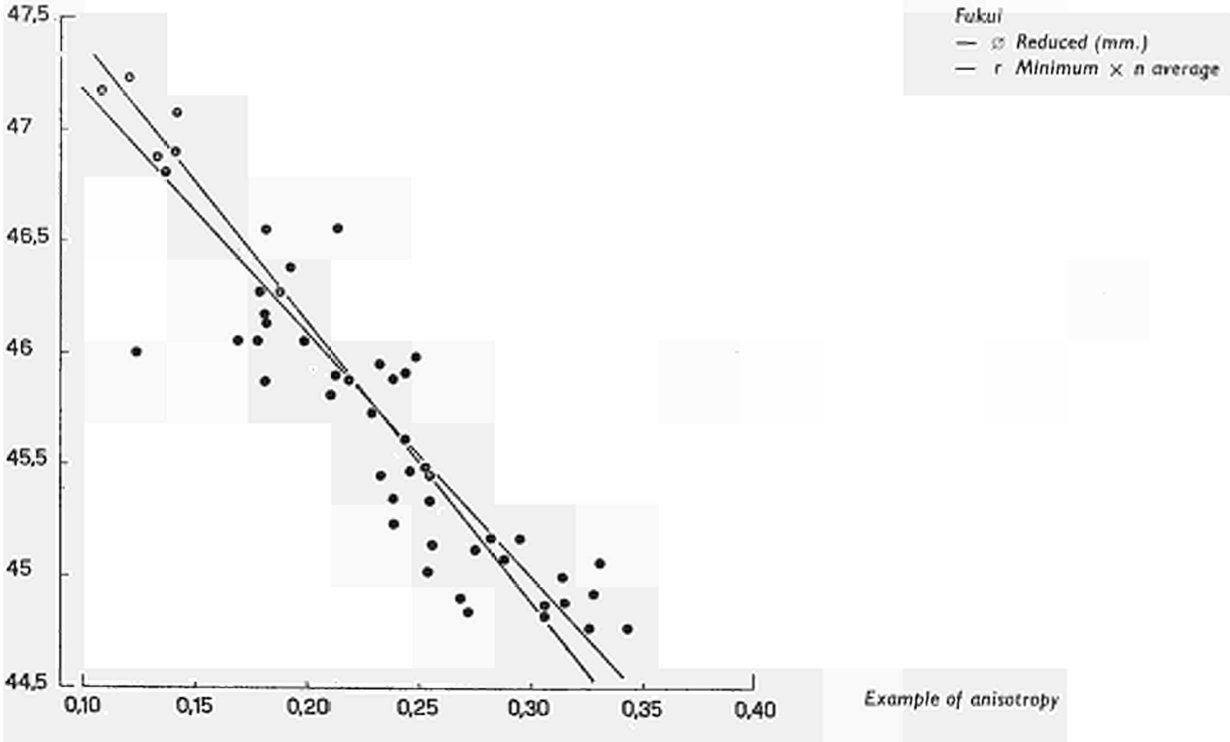


Examples of anisotropy

Bulge test
— n average



Examples of anisotropy



Unkilled sheet steel

This is the most commonly produced quality, because its cost is lower and because the ingot has a very clean rim, so that the surface of the rolled sheet will have no inclusions.

This type of steel sheet, however, age-hardens. Thus, the main progress achieved by the manufacturers consists in reducing the nitrogen, the impurity which causes rapid ageing. There is now a range of new refining methods (blowing with oxygen and steam or with pure oxygen) designed to reduce this proneness to ageing.

Sheet-manufacturers have made every effort to produce a steel with the lowest possible content of sulphur, phosphorus, and residual metals. This makes the steels very mild and so improves their capacity to undergo bi-axial stretching.

On the other hand, too low a content of certain elements impairs the ability to withstand deformation by reducing the normal anisotropy.

Thus, in the manufacture of unkilled steels there is a certain conflict between the need for resistance to compression and the need for the capacity to withstand bi-axial stretching. The buyer will find sheets on the market made of steel of relatively low purity and combining a relatively high elastic limit with good normal anisotropy. These sheets are the ideal solution, and are suitable for all present-day applications, whatever the relative magnitudes of the compression and the bi-axial stretching.

The buyer will also find sheets made of steel of the highest attainable purity and a low elastic limit but in general of poorer normal anisotropy. These sheets can withstand rather more stretching, at the expense of their ability to withstand compression.

Sheet steel killed with aluminium

This type of steel combines to a remarkable degree good behaviour under compression and under bi-axial stretching.

The normal anisotropy necessary for its good performance under compression is connected with the fact that it contains a slight excess of metallic aluminium. This consists of aluminium nitrides, which orientate the crystals and produce a grain that is elongated in the plane of the sheet and is called a "pan-cake".

Sheet steel killed with aluminium is non-ageing. In practice, aluminium-killed steel is used whenever the conditions are so difficult as to exceed the capacities of unkilled steel, or when ageing due to storage and operating time is unacceptable, either because of the problem of stretcher straining or because of the loss of the mechanical properties.

Killed steels are of cause more expensive than unkilled ones, not only because the processes by which they are treated are more costly, but also because the manufacturer has to make a more careful selection of sheets in order to ensure a higher quality surface. While killed steel has better internal homogeneity than unkilled steel, it is without the advantages conferred by the rim of very pure iron that is characteristic of the surfaces of sheet of unkilled steel.

Some manufacturers get round the difficulty by adding aluminium in the ingot mould, if the skin of the ingot is sufficiently thick. Steels killed in the ingot mould cannot be expected to give the same outstanding performance in deep drawing as steels killed in the ladle.

I have brought along a number of slides which will show you the performances currently obtainable with both unkilled and killed steels. The parts shown were made from sheets supplied by the different Benelux manufacturers.

It will be seen that it is already possible to carry out quite difficult deep-drawing operations with unkilled steels (figures 20 and 21, page 445).

In conclusion I would mention some points in connection with the very latest advances, the commercial exploitation of which is still in its very early stages.

I am referring to the fundamental changes in the properties of the sheet brought about by special forms of heat-treatment. Thus, open-coil heat treatment allows wet hydrogen to act on the surface of the sheet and remove from it the carbon and nitrogen which are the main causes of ageing.

The removal of the carbon considerably affects the mechanical properties, mainly improving the behaviour under bi-axial stretching.

By removing. the carbon and nitrogen simultaneously it is possible, if this treatment is carried out with sufficient thoroughness, to produce sheet that will not age.

Furthermore, sheets that have been given open-coil treatment have exceptionally clean surfaces.

Properties of sheets freed of carbon and nitrogen

	Behaviour on expansion			Behaviour on deep swaging		
	I kgm./m.²	R kgm./m.²	A %	H kgm./m.²	R kgm./m.²	A %
			Natural state			
1/8 P	18-5	31-1	44-2	19-2	30-6	44-4
1/4 P	18-8	31-0	44-0	19-9	30-9	41-0
3/8 P	18-7	31-1	45-6	20-5	31-3	42-0
M	19-1	31-2	44-4	20-5	31-6	41-0
5/8 T	19-6	31-3	46-0	20-1	31-3	41-0
3/4 T	19-8	31-1	45-8	20-5	51-5	40-0
7/8 T	20-5	30-9	44-8	19-8	30-9	42-0
			After ageing for 1 hour at 100°			
1/8 P	19-0	31-4	43-0	19-2	30-4	44-0
1/4 P	19-2	31-5	44-0	18-9	30-7	42-0
3/8 P	19-1	31-8	44-0	19-9	31-5	42-0
M	19-8	31-4	44-0	20-4	31-4	40-4
5/8 T	19-7	31-1	43-0	20-0	31-2	43-0
3/4 T	20-1	31-5	47-0	20-4	31-4	40-0
7/8 T	20-5	31-2	45-0	19-9	31-1	44-0

P = taken at the foot M = taken in the middle T = taken at the head

As of course you are already aware, carbon-free sheet has been the means of bringing about a revolution in vitreous-enamelling technique, whereby a simple solution has been found to the problem of applying enamel direct to the steel without an undercoat.

There is however still a lack of awareness of the suitability of carbon-free steels, and above all of carbon- and nitrogen-free steels, for the deep-drawing of parts which are subsequently to be enamelled. It is known that killed steel may be the cause of enamelling flaws. Until recently, when unkilled steel could not be used for drawing parts for subsequent enamelling, the enameller was compelled to use aluminium-killed steel, in spite of the greater number of enamelling rejects this involved.

The new qualities of unkilled steel, whose drawing properties are equal to those of the best killed steels, are thus an ideal solution for the enameller, quite apart from the possibility they offer for enamelling in a single coat.

A further important innovation has been the addition of copper to these new qualities of steel. These additions have a considerable effect on the normal anisotropy of the sheet, which it increases in all directions in the plane of the sheet, particularly at an angle of 45 deg. to the direction of rolling. This not only greatly improves the behaviour under compression, but also makes it possible to deep-draw without producing large "ears", thus reducing the amount of waste and ensuring greater accuracy of thickness (figures 22 and 23, page 446).

While the addition of copper entails a certain loss of performance under bi-axial stretching, due to the removal of carbon and nitrogen, it produces sheets which give excellent performance under both compression and bi-axial stretching, so that it is possible to produce from them the most intricate motorcar body parts.

There is one point which car manufacturers must bear in mind. It is well known that coppered sheets have better resistance to corrosion by the atmosphere. At a time when motor transport has reached such a stage of development that an ever-increasing number of cars are regularly parked in the open and the manufacturer cannot afford the luxury of using thick sheets, a comparatively inexpensive improvement in the corrosion-resistance of sheet should be very welcome. Furthermore, special sheets would be necessary only for difficult drawing operations, the simple copper-containing sheets being adequate for the simpler kind of drawing operation.

The problem here is moreover one of corrosion under paint, to be more precise, under a phosphate coating and paint. Salt-spray tests are hardly conclusive, since the essential property of a copper-containing sheet is that it resists slow corrosion.

Another important development is concerned with the forming of galvanized sheet. It is clearly frequently desirable, in order to increase corrosion-resistance, to use this type of sheet.

But galvanized sheet, particularly if continuously annealed in the galvanizing line, has inferior forming properties compared with good-quality deep-drawing sheet.

A first step towards overcoming this drawback was electrolytic galvanizing, which leaves the sheet with all its drawing properties intact. This method has great technical value and is being adopted on an increasing scale all over the world.

Where however thicker layers of zinc such are as used in hot-dip galvanizing, are insisted upon, this has hitherto imposed strict limitations as regards swaging.

By various methods of applying the Sendzimir process, it is possible to produce galvanized sheets which can be drawn just as easily as the best ungalvanized sheets. Obviously, this will entail considerable extra cost. But, as the accompanying table shows, the results are so striking that this extra cost ought to be acceptable to customers (figure 24, page 446).

Mechanical properties of steel sheets for difficult swaging jobs

	Elastic limit E kg./mm.²	Strength R kg./mm.²	Elongation %	Erichsen index (1 mm.) mm.	Critical diameter on F.H. swaged 80 mm.
Uncoated sheet	18 – 22	30 – 34	40 – 48	10·8 – 11·5	180 – 190
Continuous galvanisation	28 – 35	35 – 40	25 – 34	9·0 – 9·5	165 – 170
Continuous galvanisation but by a new process	< 20	30	45	10·6	185

Finally, I would point out to consumers of steel sheet that their suppliers are as conscious as they are, perhaps even more so, of the need to find the solution that will cost the customer least.

It is not very difficult to improve the performance of sheet. What is difficult, is to do so without the user having to pay an inordinately high price for the benefit he derives from the improvement.

Sheets made of unkilled steel already have a considerable market potential. There is no need to use special, more expensive qualities except where the shape to be drawn presents special difficulties.

If such a shape is required, it becomes necessary to use a quality of sheet with which it is possible to achieve the desired result without too many rejects, and to put up with the extra cost. The best way to solve the problem economically is to ensure closer liaison between the designer, the press-shop engineer and the metallurgist.

Stretcher straining is too often the only problem which calls for the use of killed steel. Should not consumers who are anxious to find the most economical solution in this case make more general use of a flex roller at the head of their press lines ?

Nevertheless, consumers should not overlook the merits of special sheets. The manufacturer has studied them, and only recommends them because in his judgment they meet real, though, special requirements, such as improved corrosion-resistance, better pressing performance, reduction in the number of rejects, a better capacity to take a curve, or the elimination of a drawing operation or an annealing treatment.

Technical developments, while enabling the producer to provide the consumer with qualities of material that are coming more and more into line with his requirements, are rendering it more difficult for the consumer to make a judicious choice. There is therefore a need for closer liaison between the two sides to their mutual benefit.

A. SCORTECCI

and

E. STAGNO

Cold Working and a New Method for Revealing the Resulting Changes in the Properties of the Steel

(*Translated from Italian*)

Modern metallurgy has a clear understanding of the changes which the physical and chemical properties of steel undergo as a result of cold working or, to be more precise, of forming at temperatures to a greater or lesser extent below those of recrystallization. In particular, information is available on the changes occurring in the mechanical properties which are of primary importance in connexion with constructional steelwork.

The consequences of certain changes arising from cold working do not become apparent until a long time afterwards, and often occur simultaneously with other phenomena which are not always investigated. This gives such occurrences a random and uncertain appearance which is most misleading and baffling for both designers and constructors.

To add to this uncertaintly, such changes are always very minute at the time of completion of the cold working and are not easily detected. The necessary instrumentation is complicated and costly, and the tests themselves are often of a destructive nature.

I refer to phenomena such as corrosion brittleness, ageing, blue brittleness, notch sensitivity, fatigue and corrosion fatigue.

The long-term effects of our incomplete knowledge and lack of means of inspection are unexpected structural failures in service, sometimes with the gravest consequences to human life, such as boiler-explosions and the fractures in the famous Liberty ships during the last war.

For these reasons, one of my colleagues recently suggested the removal of the causes of the most important losses of properties in mass-produced steels as one of the major objectives in the mass-production of iron and steel (Biblio. 1.)

It is known, qualitatively, that many, if not all, of the changes we are concerned with are caused by the presence of small quantities of impurities, often called "oligo elementi" (trace elements), which are nearly always found in ordinary steels. Their combined influence can, in principle at least, have cumulative or multiplicative effects.

The main defence against these uncertainties in the service behaviour of steels is a return to their state of internal structural equilibrium, disturbed during the cold working, by means of suitable heat treatments. However, apart from the expense, these treatments cannot always be used because cold working is the last stage of construction; examples are riveting and certain drawing operations, etc.

The elimination of these impurities is not, however, practicable in the mass-production iron and steel industry for obvious economic reasons (Biblio. 1.)

The only practical remaining possibility is therefore that of patiently determining the influence of these trace elements, and trying to establish *a priori* the behaviour and performance of the mass-produced materials in respect of particular types of construction, thereby establishing for the various applications an economic relationship between quality and actual requirement.

This is the course indicated, as an economic solution, in the paper already quoted (Biblio. 1.) which outlines a future field of applied research of great and immediate practical value.

The experimental means for these systematic investigations are however complicated, time-consuming and in general, expensive.

At this point, I feel I should mention the results of our research.

A new and very sensitive method reveals a particular steel structure which is related to this change in properties caused by the effect of plastic and elastic deformations resulting from cold working combined with the effect of all the impurities present in the steel.

Here, in brief, are the main points in regard to the origin and possible applications of our method.

In the course of experimental work started in 1955 (Biblio. 2.) at the Metallurgical Laboratory of the University of Genoa, for the development of a special type of metallography (coloured), the presence of an unknown structure was occasionally noted. Collateral research enabled us to establish the conditions in which this structure was formed, and then to develop a working hypothesis for its origin; the hypothesis was then partially confirmed and improved by lengthy experimental work which is still in progress.

The new structure is related to the magnetic field structure established by Weiss. As we know, the magnetic microfields emerging at the surface, and their boundaries (Block walls), were shown experimentally by Bitter, the now classical patterns which bear his name being obtained from colloidal solutions of materials with good magnetic susceptibility.

In our method, the colloidal particles are replaced by complexes of molecular dimensions which possess, in addition to magnetic susceptibility, an aggressive chemical ability with respect to ferrite; thus, the behaviour of the Block walls is permanently revealed by selective corrosion (Biblio. 3.)

When we had fully developed this method, we began to investigate the manner in which the magnetic structure of steels is influenced by physical and chemical factors, and in particular by the states of tension originating in the elastic and plastic deformations, that is to say, in the final analysis, by cold forming.

We observed that changes in the structures can be clearly revealed by permanent tensile deformations of the order of 0·5%.

Experimenting next in the range of elastic deformations, that is with test pieces under tension, we were able to establish:

(1) that comparatively moderate elastic deformations (about 8·5 kg./sq mm.) change the structure considerably;

(2) that, with the stress removed, the magnetic structure does not resume its original form but on the contrary, retains considerable and clearly visible alterations;

(3) that heat treatments allow the original magnetic structure to reform.

It is of course clear, that this contribution to present knowledge on the properties of ferro-magnetic materials has many possibilities, even though they are purely theoretical. Let us consider, for example, the phenomenon of elasticity. The most sensitive strain-gauges give us elastic limits which a knowledge of the mechanism of deformation will classify as approximations valid only for practical purposes.

Our method lowers these limits considerably.

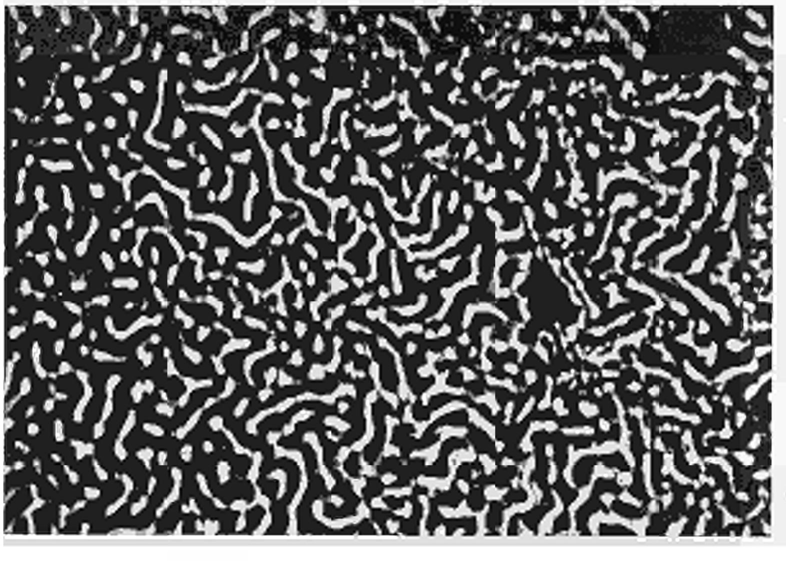
Are we, perhaps, approaching a true limit of elasticity?

What are the relationships with elastic after-effect, elastic hysteresis, corrosion-fatigue and caustic embrittlement?

What is the effect of the various impurities upon the order of magnitude of the truly elastic, i.e. reversible, deformations ?

These are questions that must be asked, and which have indeed been asked. But the replies to them, chiefly because of lack of experimental results, are not as complete and detailed as designers and constructors would want them to be for the safety of their structures in service.

While the experimental work is proceeding, with a certain order of precedence imposed by the availability of funds or by the need to maintain a logical sequence among the results and subsequent tests, we can already confirm that the method is, experimentally, at the stage of establishing economically on structures in service (as soon as a portable apparatus for electrolytic polishing is constructed) :

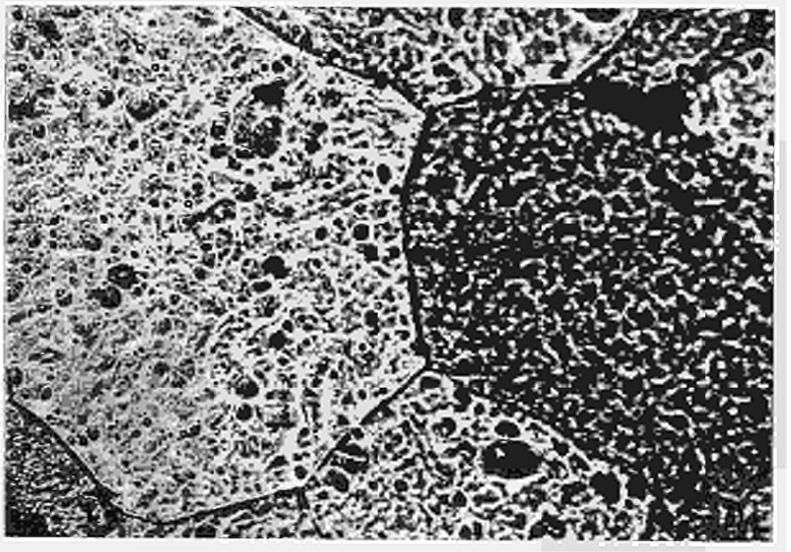


Magnetic structure of ferrite in structural equilibrium.

(1) the presence of tensile forces, even the very smallest (change in the magnetic structure);

(2) whether certain parts of the structure have undergone elastic stresses above a certain limit (reversibility limit of the magnetic structure).

The micrograph in the above figure shows the equilibrium magnetic structure of ferrite ; the figure below shows it for the same material after an elastic deformation, afterwards removed, of the order of about 8·5 kg./sq. mm.



Magnetic structure of the same material after elastic deformation.

I considered it to be of some interest to tell you of this new method and to give an indication of its practical possibilities, economically feasible at the present stage of our experimentation. Besides, as the E.C.S.C. Congress is entitled this year "Progress in Steel Processing," and because of the intrinsic importance of the subject, it seems to us that, thanks to the High Authority which promotes and organises it, the Congress is the most appropriate place, or rather meeting-point, for discussing progress in the fields of both science and application. It is a point from which new developments radiate and have their most effective influence. It stimulates new ideas and thus influences the sum of creative activity and accelerates the propagation of the best existing experimental knowledge; the latter, although mentioned second, is not the least important factor in making progress and achieving results.

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DISCUSSION

J. PIETTEUR

(Translated from French)

Mr. Becker and Mr. Remmerswaal have described to us the technical advantages and scope of methods of forming and cladding by means of solid explosives, but there is one aspect of this problem to which I should like to draw your attention.

There does not seem to be any general "know-how" on these high-energy methods.

Each type of fabrication and each type of workpiece presents a very real problem of research and development. This is very far from being a matter of modifying or adapting technological factors; it is really a new problem each time. Let us take two examples to illustrate this contention:

(1) A good bond between a cladding sheet of tantalum and a parent sheet of carbon steel can be obtained with a layer of solid explosive of constant thickness and an optimum static angle of the order of 6°, if the length to be clad is about 300 mm. However, if this length is 800 to 900 mm., not only the static angle but the nature and even the shape of the explosive charge must be totally different.

The inside of a carbon steel tube with an internal diameter of 30 mm. can be given a stainless steel lining by metal/explosive contact or by using air as the transfer medium. For a pipe with an internal diameter of 700 mm however the most satisfactory technique is to use water as the transfer medium.

(2) The explosive forming of a decimal type dished end with a large knuckled radius, is done with a charge concentrated at a point, provided the diameter does not exceed, say, 600 mm.

For larger sizes, a corona charge must be used, and this is a quite different problem. Even in this case, if, for example, it is necessary to place a 0.5-m. diameter corona charge at about 20 cm. from the blank to enable the two pressure cones, which develop in a diametral plane perpendicular to that of the charge, to meet at the level of the blank and so submit it to a uniform relative pressure, this solution cannot be adapted for use with an corona charge with a diameter of 2 or 2.5 m. A charge of this diameter would have to be placed at such a distance from the blank that the energy released would be completely useless; it is therefore necessary to find a completely new solution.

The point I am trying to make is that there does not seem to be any "know-how" on the general application of these techniques, and that, on the contrary, each application is an entirely new problem in which there is no question of adapting technological factors—a new solution must be found.

This is the context in which the problem arises of disseminating knowledge and of applying these techniques.

How can a manufacturer, interested in the prospect of the technical advantages of using explosive forming for accurate fabrication, make a useful study of the possibility of integrating this production method with this normal methods?

It is understandable that many manufacturers hesitate and even abandon their intention because they cannot reasonably envisage embarking alone on an experimental programme of research work and development tests.

Therefore, to facilitate the dissemination of these new techniques and to avoid the inevitable dispersion of individual efforts, we in Belgium have adopted a policy of co-operation between manufacturers and steel producers, for it must not be forgotten that these techniques always present a metallurgical problem.

To make this co-operation effective, we have jointly set up an experimental station where participating manufacturers can study the feasibility and economic viability of explosive methods of metal forming and cladding in relation to their own particular fabrication work.

At this experimental station, we are producing prototype workpieces for industry and are at the same time studying questions of material quality and the economics of using the processes.

It is only by means of these joint studies and tests that the manufacturer members of the working party can decide upon their attitude towards these new techniques which are being tried and tested at the experimental station.

We believe that, with such a spirit of co-operation, high-energy forming techniques will be able to develop rapidly within the Common Market and that the E.C.S.C. will be able to play a leading role in encouraging contacts and exchanges of information between the four or five specialist units in this field.

Friedrich E. LISTHUBER

(Translated from German)

The interesting papers by Mr. Becker and Mr. Remmerswaal on the use of shock-wave technique give me the opportunity of expressing some additional thoughts, in particular on the question of changes, caused by the shock-wave treatment, in the engineering properties of the materials.

In the forming of thin-walled articles, the associated improvement in strength properties is frequently very desirable, especially as regards the increase in form stability of the parts so produced. The decrease in toughness qualities is not usually of any special significance in this case. Further, according to investigations made in various places, it has been partly confirmed that the loss of toughness in shock-wave forming is less than in a conventional cold-forming producing a similar condition of strength.

But what is the position in respect of the cladding or forming of the larger thicknesses, steel plate for instance?

From my own investigations, there are two factors in particular which should be considered here:

(a) The occurrence of twinning, which calls for particular attention in straight carbon steels.

(b) The rise in transition temperature in the notched-bar impact test.

In Mr. Remmerswaal's presentation on the influence of shock-forming on transition temperature, evidently the steel was unkilled or normally killed. In the case of fine-grained steels—my experience here relates to plate having a thickness of, for example, 35 mm.—the rise in notch-toughness transition temperature has lagged somewhat behind the figures shown.

However, the question arises as to whether parts clad or formed by shock-waves can be used in highly-stressed structures without undergoing post-treatment such as normalizing.

F.E. VAN WELY

(Translated from Dutch)

As far as the influence on the material properties is concerned, a clear distinction should be drawn between the effects of explosive shaping and those of explosive welding and tempering. With the latter methods shock loads with a peak pressure of more than 100 kbar occur while the pressures used for explosive shaping are much lower.

In contrast to what was quoted from Dieter's work (see figure, page 411) we ourselves found during similar investigations that the transition curve shifts to a lower temperature immediately after loading, but that there is a considerable shift to a higher temperature after about three weeks. This indicates that the material exposed to the shock may show significant ageing effects at room temperature. This is probably due to accelerated diffusion occurring in material to which a shock has been applied.

Similar effects may be expected with explosive shaping if the plate collides with the matrix at a high speed. With a plate speed of 200 m/sec a shock wave with a peak pressure of 40 kbar may occur on collision. At these pressures the above-mentioned effects must be taken into account.

It should, however, be noted in this connection that some specific shock-wave effects, such as twinning, do not occur if the material has previously undergone slight (say about 10 %), gradual deformation. At the same time, special textures can be used for this purpose. This means that in many cases the problem of potential shock-wave effects can be solved by the steel manufacturer himself.

ANDRÉ-PAUL FREY

(Translated from French)

Mr. David F. Brower, Mr. Karl Eugen Becker, Mr. Hans-Joseph Mürtz and Mr. J.L. Remmerswaal have painted an informative picture of the many possibilities offered by high-energy techniques utilising electric, electro-magnetic and pyrotechnic processes. If we venture to add to their explanations, it is not because we wish to go more thoroughly into the study which they so brilliantly expounded on these techniques, but because we should like to add the testimony of a user who has already been applying them for several years at the industrial level.

The general trend towards increasing size in storage tanks for food products has led us, as makers of stainless steel tanks and equipment, to look for a comparatively cheap method for the manufacture of large dished plates from relatively thin sheet. To give an indication of their size: these plates are tank ends having a large radius at the crown or having a semi-elliptical profile; their diameters are between 2.5 and 3.8 metres, and their thickness varies from 2 to 4 mm. With these workpieces, it is particularly important to keep the surface in good condition, both inside and out, to allow for eventual polishing. As the making of these parts by conventional means has presented a certain amount of difficulty, we turned to explosive-forming techniques. These have the important advantage, in respect of power requirements and dimensions, of being limited only by the actual tank itself. After much experimental and development work, we had the satisfaction of establishing that the method provided a solution to our problem. Despite the rudimentary nature of the first installation used in the development work, it has enabled us to produce, in the course of the year now ending, some 750 shaped end-plates of the dimensions stated above.

The application of the same techniques has allowed the series production of shaped plates for double casings for heating and refrigeration installations; about 600 have been produced in the current year. These plates, with dimensions of the order of 3·5 m. by 1·5 m., contain a complete system of channels, collectors and baffles.

It has also been possible, with explosive forming, to form light-alloy hulls for outboard motorboats.

The most diverse materials have been used for the tools: concrete, synthetic resins, polyester laminates and zinc alloy. These are the most satisfactory materials for use in the small-series production of medium-size articles. For the larger forms, cast-iron and machine-welded tools have been successfully used.

A number of new series of experiments for developing a procedure for explosive forming without dies are being conducted at present, and promising results have been obtained both in the making of spheres and in tank ends of various shapes.

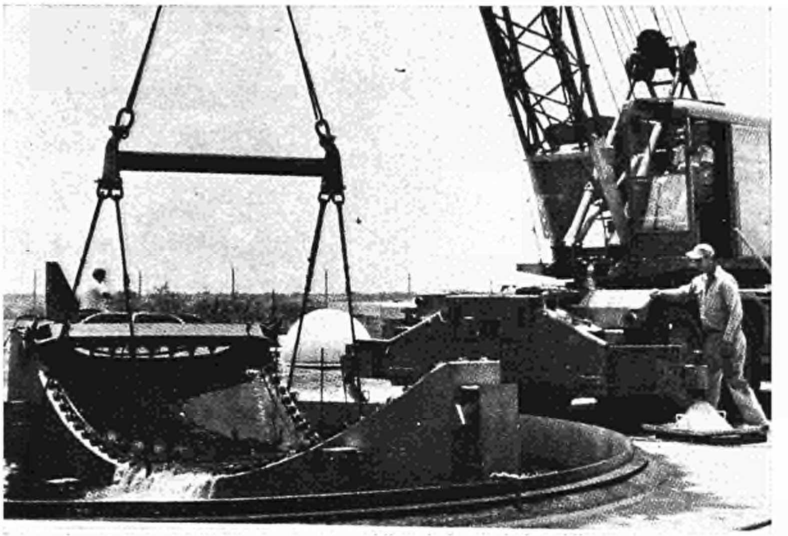
Applications employing the explosive-cladding technique have enabled the most diverse metals to be bonded together: copper on steel, brass on steel, aluminium A3 + A8 on steel, titanium TASE on steel, silver on copper, and stainless on carbon steels.

Finally, a combination of explosive cutting and explosive welding has resulted in the development of a procedure which does the piercing and simultaneously and instantaneously welds a by-pass on to a collector.

Confronted by the variety of all these applications, one might be tempted to believe that high-energy processes are a panacea or magic wand which will solve all the problems of the plate and sheet forming industries. It might also be thought that these processes are going to compete, directly and in all respects, with the conventional manufacturing processes employing the usual mechanical methods. Experience has shown, however, that in practice the new and the old processes complement each other rather than compete. In fact, the application of high-energy techniques is particularly appropriate in the case of work which presents difficulties for conventional methods because the dimensions or thickness of the workpiece, or the nature of certain special metals, is not suitable for ordinary presswork.

Leading French companies engaged in conventional sheet and plate forming have therefore joined with us to establish a specialist factory in France; production is to start there in three weeks' time. The large size of the new firing pit, in which dimensions of up to 9 or 10 metres can be handled, should greatly contribute to the development of explosive-forming techniques; in particular, it will allow those manufacturers who are interested in the advantages here offered, to consider, right from the design stage, products in relation to their means of production.

List of illustrations



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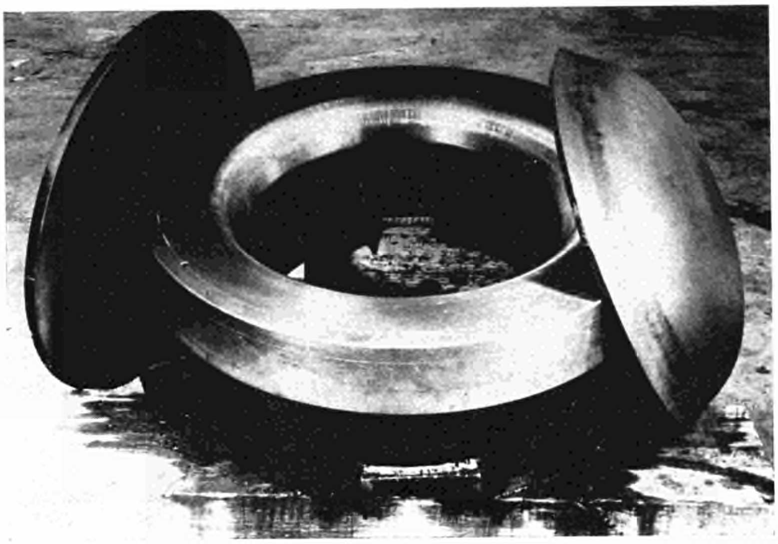

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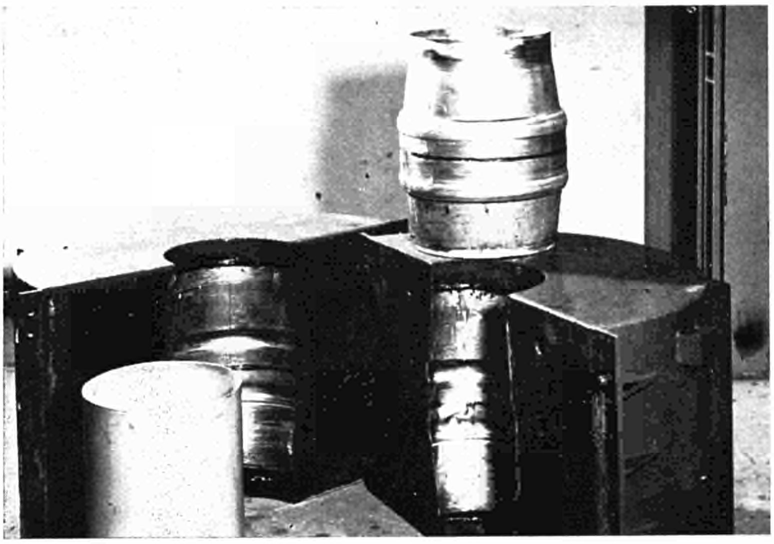

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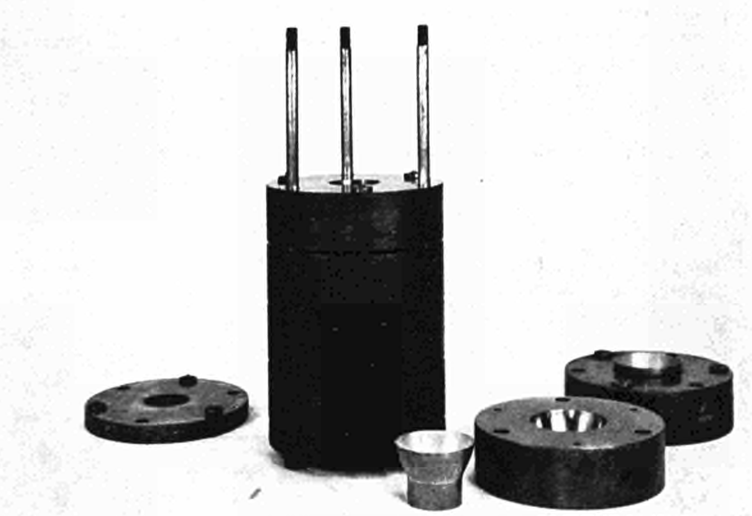

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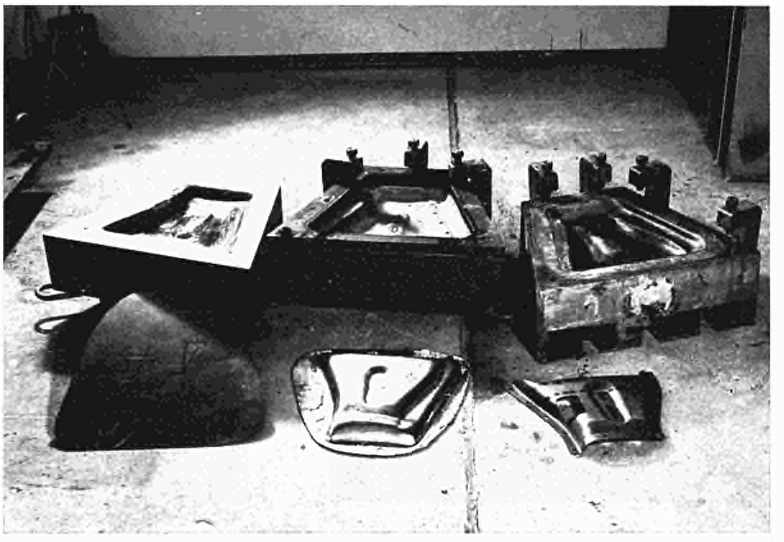

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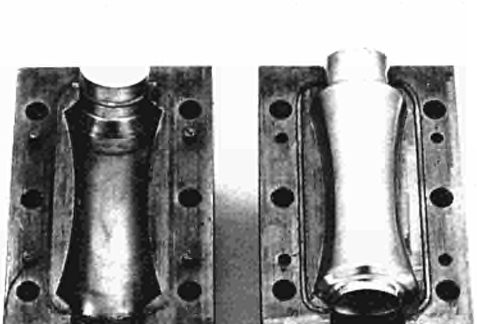

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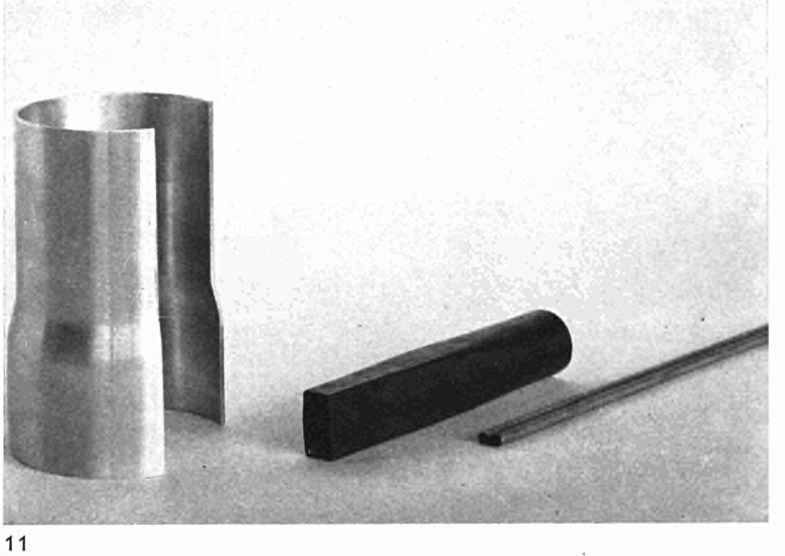

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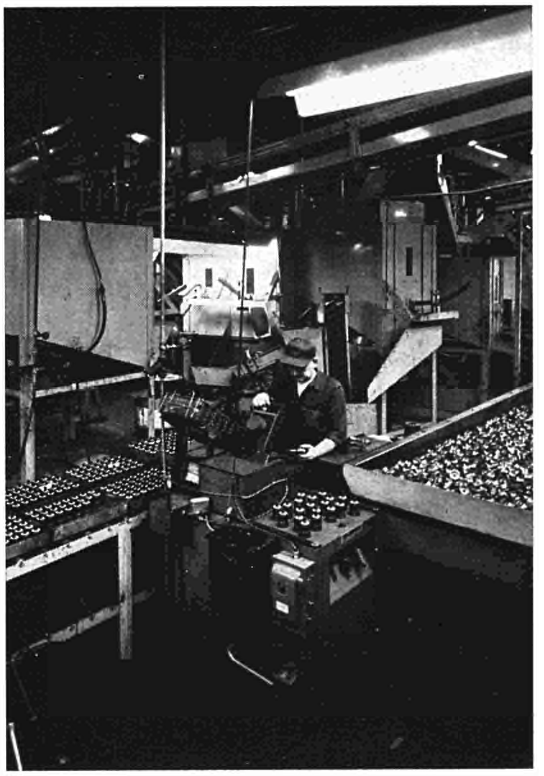

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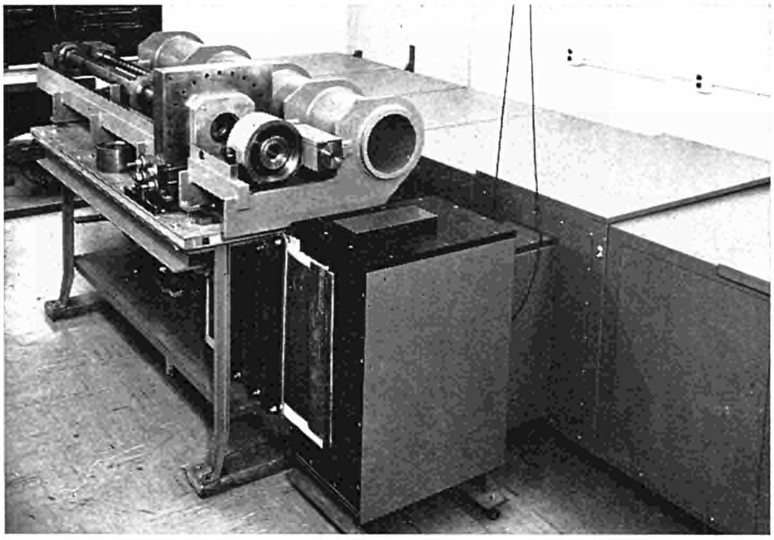

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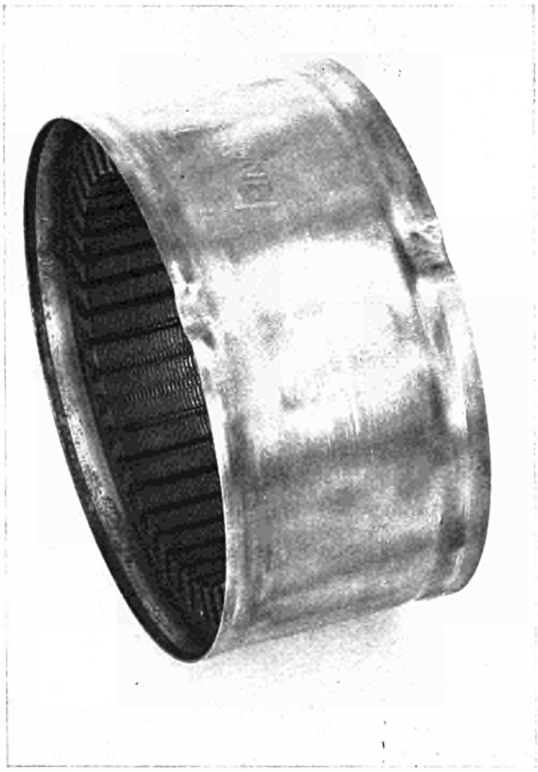

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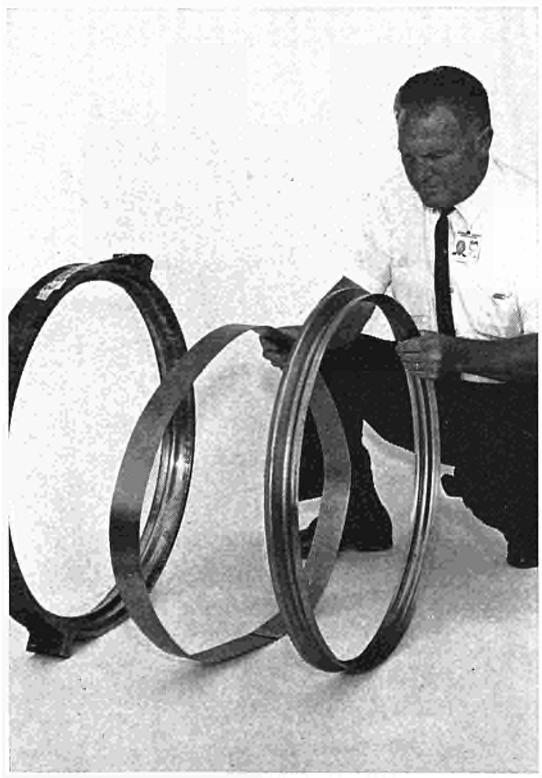

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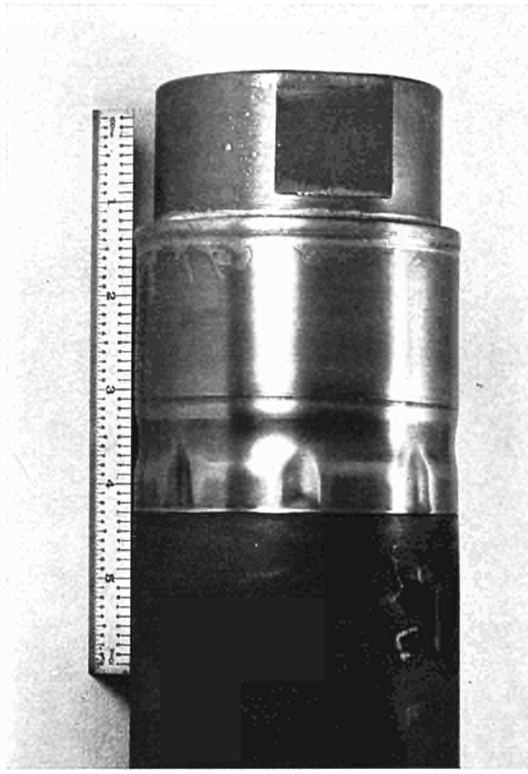

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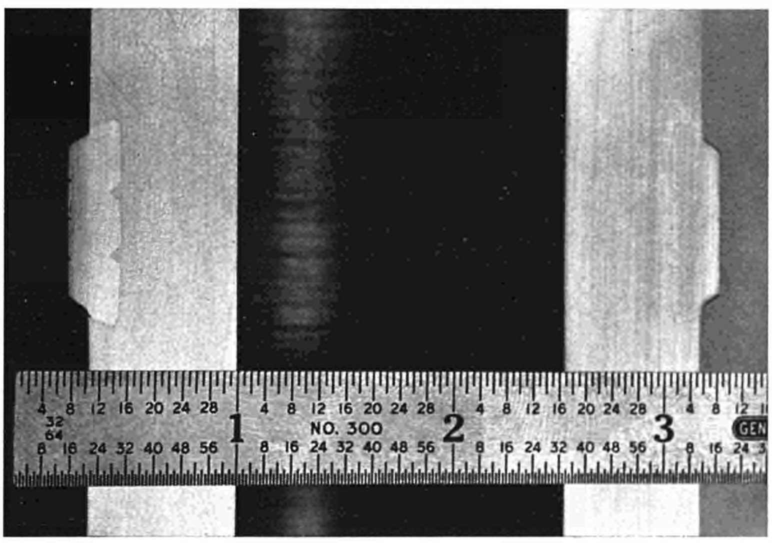

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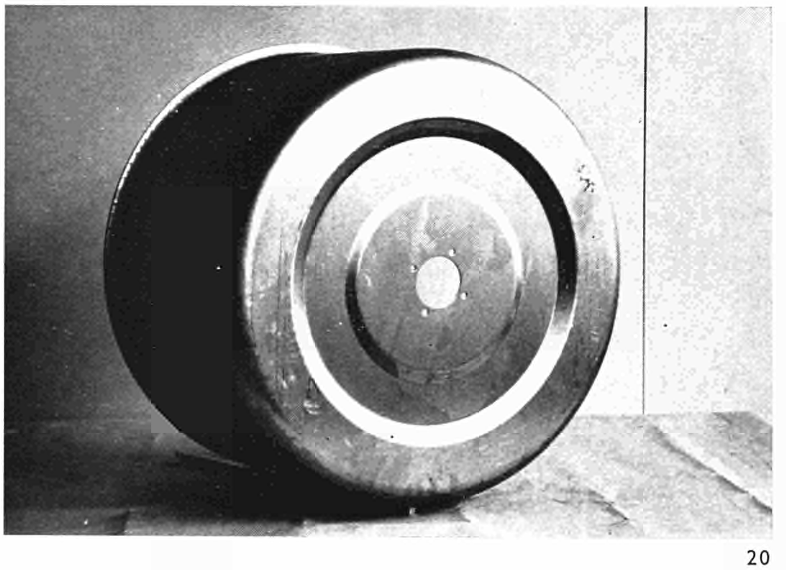

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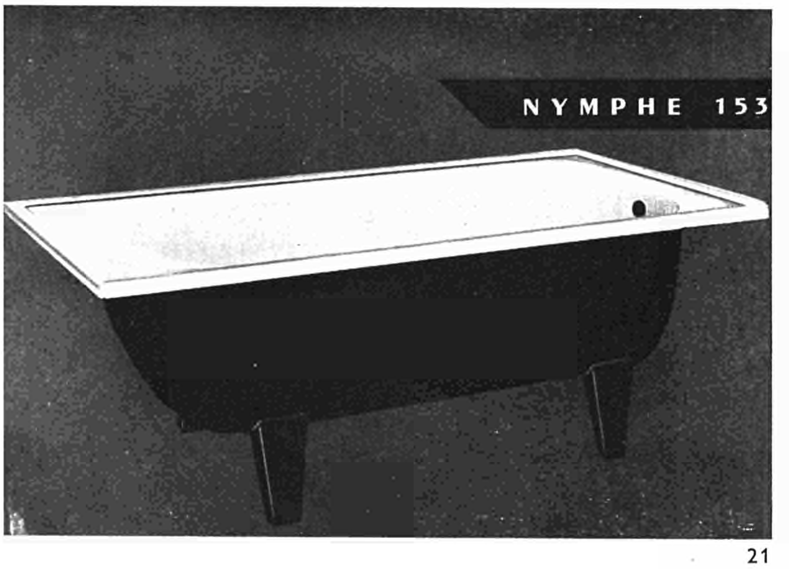

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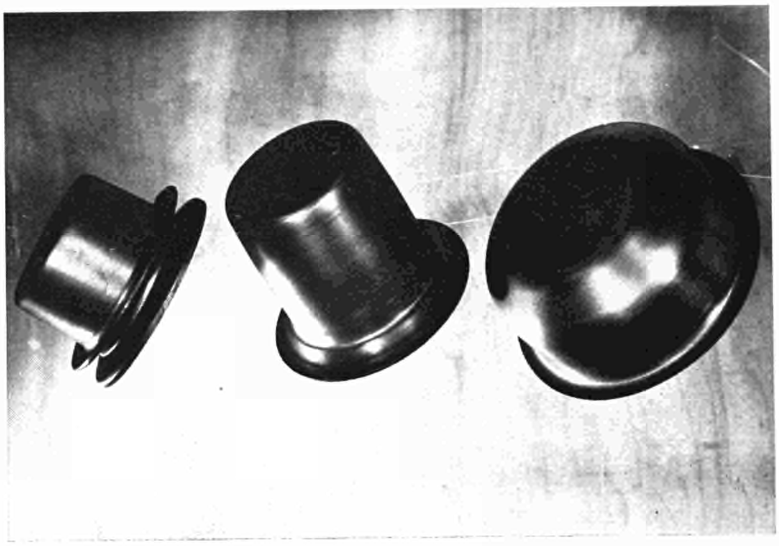

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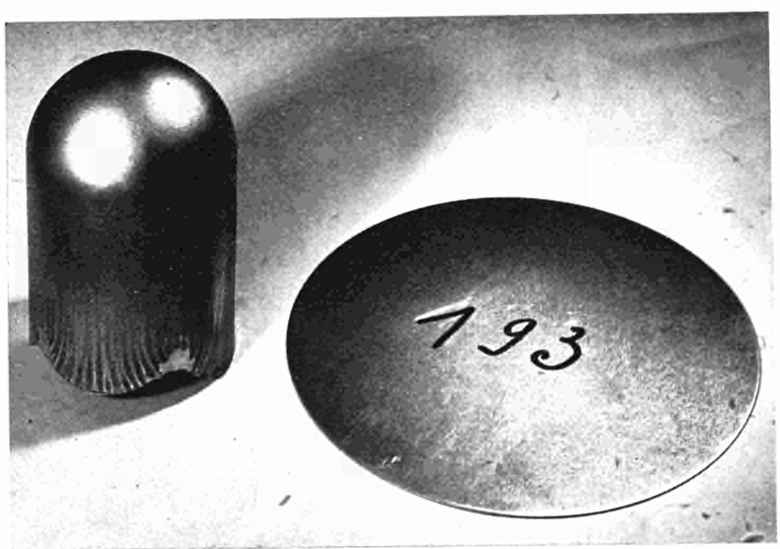

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René-Henri FORESTIER

Modern Methods of Cold Forming other than Stamping and Explosive Forming

(Translated from French)

In order to make this paper quite clear we will first define the meaning of certain terms:

(1) Bend: to deform the axis of an object to a given curve;

(2) Roll: to bend to a circular curve;

(3) Hoop form: to roll a plate to complete closure;

(4) Flange: to bend only the ends of a sheet or section;

(5) Form: to dish a flat object, the surface of which is not "developable";

(6) U-bend or V-bend: to bend a straight piece along a small radius curve so that the rectilinear parts on either side of the bend form an angle or are parallel.

(7) Fold: to bend about a very small radius the flat portions which may bear on a block.

Forming may be effected:

(a) By combined bending in two perpendicular directions. This is effected using a wheel or a roller-bending machine with rolls which are specially shaped and not cylindrical, or a series of forming rolls.

(b) By simultaneously shortening and lengthening the fibres on the concave and convex sides of a sheet (Kraft-forming machine).

(c) By spinning.

(d) By drawing on a mandrel.

(e) By stamping.

The two last methods, which considerably reduce the thickness of the steel, will not be discussed here since stamping alone would require to be dealt with at considerable length.

Combined bending in two perpendicular directions

Wheeling

The end of a horizontal driving shaft carries a forming roll or wheel. An idle shaft which carries a second complementary roll presses the sheet against the first roll.

By passing the edges of a flange or hoop between the rolls and bending it by hand so that the rolls act as a continuous vice, the edges may be "lipped."

The area of mild steel sheet may be increased locally by locally increasing the diameter of the rolls so that the pressure on the sheet calculated according to the Hertz formula exceeds 100 kg/sq.mm.

Using imbricating forming rolls it is possible to form moulded, lipped, beaded edges etc. In this case the sheet is rolled in one direction and bent or even folded at right angles to the direction of rolling.

If these machines are used carefully they are extremely useful in small-scale production runs.

Application: special roller bending machine for forming tori

Starting from a consideration of two combined perpendicular bending processes often along very different radii—such as is carried out using a wheel to transform a welded cylindrical hoop into a ventilator port—and a machine for coldforming (figure 1, page 471) based on a wheel and with four-bearing horizontal shafts used for forming external sections of tori for small-quantity production runs such as lorry wings, a French engineer concluded that it should be possible to produce a special roller-bending machine for forming tori with a large radius of curvature (figure 2, page 471).

The upper central-driven roll is barrel-shaped, while the lower central idle roll is diabolo-shaped; the two oblique idle rolls being of necessity also diabolo-shaped.

The supports (shown in figure 3, page 471) must be so constructed so as to ensure that they support the sheet to definite radii of curvature. They must be of adjustable height and be located as near as possible to the oblique rolls and must form an integral part of the machine (figure 4, page 471).

These supports are reminiscent of the "presentation sheets" shown in figure 1, page 471.

This machine is of the roller-bending type and has four rolls, but various tests have shown that it would probably have been possible to use a roller-bending machine with three asymmetrical rolls.

This latter method corresponds to the arrangement of a single guide on a wheel, while the four-roll machine corresponds to the arrangement of two symmetrical guides on a wheel.

We consider that it is a little easier to use a machine which has four rolls, since on the three-roll machine operating on the roller-bending principle along the whole length of the plate it is important to check the excess thickness at the centre of the sheet most exactly so as not to produce too great a rolling effect at the centre; this would result in falsifying the curve. Also, the plate must be fed into the machine at the same side for each new pass.

It should be noted that the four-roll type machine could probably produce half a large-radius torus at the most.

As for the machine itself, experience shows that calculations carried out in 1958, which considered plate as being in the elastoplastic range, were correct. Thus with a thickness of 20 mm., a plate width of 3.50 metres and a radius of curvature of 27.50 metres, calculations show that the radius of the rolls should be of the order of 17 metres, or at least within a metre of what has been definitely adopted after experiments with a much larger radius.

This is explained by the fact that when a hoop is rolled the rolls must be set to a radius of curvature which is much smaller than the final radius of curvature.

The roller does not realise the extent of this effect since stresses reaching the elastic limit are liberated over the whole of the hoop, except in the zone adjacent to the central rolls.

Our calculations, show that for a cylindrical hoop of a thickness of 20 mm. and radius of 3·50 metres, the rolls must be set to a radius of curvature of 2 metres.

This fact may be confirmed by merely finishing the rolling of a plate using radial clamps; the hoop re-opens when the clamps are removed.

We do not wish to give here the formulae for the force, power, etc. of the rolling and forming machines since these are beyond the scope of this report. We would, however state, from the practical point of view, that any rolling of the plate during the bending operation must be avoided when maximum pressure is maintained only between the central rollers.

In conclusion it is worth mentioning that the radius of curvature of even the central rollers has to be set with an accuracy greater than 5%, since in view of what has been said above, it may be seen that it is sufficient to roll about a smaller radius in the longitudinal direction for the transverse radius of curvature to be increased at the output end of the machine, by elastic straightening of the torus in its longitudinal direction.

Series of forming rolls

If a strip is passed at a speed of between 30 and 60 metres per minute through a machine comprising successive sets of rolls of suitable "complemantary" shapes, causing the strip progressively to assume a desired shape, sections, channels, I's and zeds, girders and reinforcement beams of the most complicated sectional shapes, Tourtelier rails and even the rails of miniature trains (figure 5, page 472), may be produced.

The following principles govern roll design:

(a) The strip must never be subjected to a scuffing action.

(b) Strain-hardening must be avoided.

(c) Forming must be progressive (e.g. angles must be produced in 4 or 5 sets).

(d) Square-edged angles may be produced if folds are prepared using a pre-forming or reducing arrangement.

(e) The first pass serves as a skin pass for steels which are more liable to ageing—which ensures regular curves in subsequent forming.

(f) A number of folds or throughs should not be commenced simultaneously if this would lead to transverse stretching in the zone which separates them (e.g. corrugated plate).

(g) Closed sections are often advantageously produced from a round tube.

Lubrication is effected by spraying each station with a jet of soluble fluid.

Cropping is effected by means of a machine which accompanies the section at the output end of the machine. Speeds must be perfectly synchronized at the moment of cropping. Two strips of different metals may also be passed through simultaneously to produce a composite section (e.g. curtain rods of steel and aluminium).

In order to produce square-angled sections from zinc-coated steel, the material used should preferably be strip which has been continuously zinc-coated by an electrolytic process or continuously hot galvanized (Sendzimir).

The lines of shaping rolls are often preceded by a line of slitters in which the strip is fed from a coil and is slit into strips by means of cutting wheels and then re-coiled on multiple capstans.

Punching may be carried out before forming by slackening the strip beforehand and synchronizing the action of the press with the speed of the line (perforated angles).

Closed sections should be welded at the same speed as the machine:

(a) By resistance welding—after pickling—using rolls with large surfaces of contact located on either side of the joint.

(b) By medium frequency current (60,000 c/s) without previous pickling—by placing brush-contacts towards the front of the melting zone of the joint.

(c) By high-frequency welding (40,000 to 600,000 c/s)—without previous pickling, the flux coil being located below the weld.

(d) By argon arc welding in the case of stainless steel.

These impressive machines are expensive. They have an intake and output of an astonishing tonnage of sheet steel—as much as 20 wagon loads per day. Careful study of the organization of the shop is therefore required to ensure that such machines are put to their best use.

The preparation of the edges of the plate for overlapping is carried out on a machine operating on the same principle (lockformers). If the machine does not carry out this stage itself the overlap is closed on assembly using a rotary pneumatic hammer with a head in the form of a truncated cone (e.g. ventilator ducts).

If the machine allows the longitudinal edge of an open cylindrical part to pass through its rolls and completes the lockjointing, the operation is known as lock-seaming.

Simultaneous shortening and lengthening of the fibres of the two opposite surfaces of a sheet

Universal machines known as Kraft-formers are used (figure 6, page 472).

These machines are of three types and may be used :

(1) for reducing the length of the fibres in one direction on both sides of the sheet, which has the effect of increasing the thickness of the sheet without changing the curvature.

(2) for increasing in one direction the fibres on both surfaces of the sheet or plate, which has the effect of reducing the thickness of the plate without altering the curve;

(3) for extending the fibres of one surface in one direction while shortening the fibres of the opposite surface in the same direction, which has the effect of preserving the thickness while varying the curve.

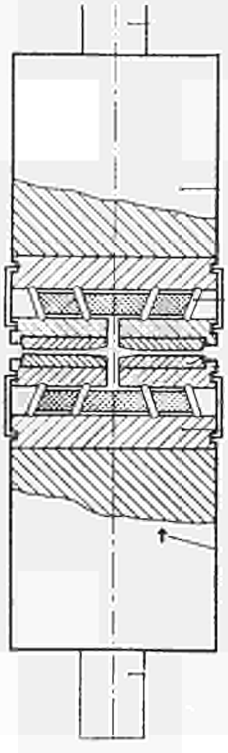
These machines comprise a C-shaped frame, the two ends of which are provided with stocks arranged opposite each other.

An eccentrically mounted rod arrangement vertically displaces a slide by about 9 mm. at the rate of 300 strokes per minute so that the lower stock, which is integral with the slide, presses firmly against, but does not strike, the lower surface of the sheet, the upper surface of which is pressed against the fixed upper stock. The height of this stock is adjustable manually by about 80 mm. by means of a screw thread.

Within the stocks is located a block of hard rubber in whicn inclined strips of steel have been inserted prior to vulcanisation. These strips join the body of the stock to ribbed jaws which are grooved at two locations, the latter being drawn together under the action of the pressure which causes the strips to press inwards, see figure below.

An action is thus obtained which results in the fibres being shortened at each stroke, when the plate is pressed between the two jaws as in the figure.

In order to obtain an extension instead of a shrinkage, it is only necessary to use opposite stocks, the strips of which are inclined in the opposite direction to that in the preceding case so that the action of the pressure tends to urge the jaws apart.



If a shrinkage stock is mounted opposite an extension stock, the plate is considerably bent so that the convex portion is adjacent the extension stock. A machine of this type is able to form pieces of different curves and even lip the edges of large-radius curves.

We should like to make the following points in connexion with the use of these machines :

(1) There are only three sizes of rib and it is necessary to use the largest size permitted by the state of the surface of the plate, although the work may be finished with fine ribs.

(2) Pressure must not be too great (adjust the upper stock).

(3) The metals used must be clean. Any dirt, grease or paint must first be removed.

(4) The ribbed jaws must be frequently cleaned with a steel or nylon brush.

(5) These machines may be used for planishing if the stocks are replaced by smooth tools.

The capacity of these machines is of the order to 2·5 mm. for steel, 1·5 mm. for stainless steel, 3 mm. for copper and 5 mm. for aluminium and its alloys.

Spinning on a lathe

This technique may only be used for shapes of revolutions and is carried out on a lathe known as a spinning lathe which differs only from the normal types of lathe in that the tool does not cut but pushes the material on to a wood or cast-iron mandrel which replaces the face plate.

If the flange does not have a central hole, it is held in place by a rotary plug on the movable stock of the lathe.

The tools or thrust members may be of different shapes—hooks, sabres, spoons, or spheres, or of the polisher or roller type. They must be extremely hard and highly polished. Careful lubrication is a "must."

Hot spinning requires steel mandrels and thrust members of refractory stainless steel mounted on large dimension conical rollers. It is sometimes necessary to keep the flange red-hot using an aero-propane burner set (figure 7, page 472).

Determination of the flanges

As in the case of stamping, it is assumed that thickness and the surfaces remain constant.

For deep objects, spinning requires a number of mandrels as does stamping. In view of the cost, the latter method is generally preferred for large production runs, while the former method of spinning is reserved for polishing operations or for finishing when the part needs de-skinning (spinning mandrel with a number of removable parts).

Special machine for bending large-diameter tubes

We do not wish to conclude this brief discussion of methods of cold forming, without mentioning a new tube-bending machine.

Whereas in conventional machines the tube is bent on rolls which prevent its taking on an oval shape and also require the use of an insert for small radii of bend or for thin-walled tubes, the machine which we are about to describe uses a completely different technique.

The tube is part-rolled by a set of wheels to the right of a spectacle-type support and to the extent which it is fed through this support (figure 8, page 472). The amount of rolling may be regulated and is applied only to the outer part of the hoop. The radius of bend is thus set with accuracy but the tube is slightly thinned after bending—a factor which has a certain detrimental effect on its strength. These machines bend tubes of 100 to 400 mm. diameter and we have made frequent use of them for large-diameter tubes of stainless steel and copper.

Conclusion

The choice between the processes which we have described and the processes not here referred to, particularly stamping, will depend on the mechanical and geometrical characteristics required of the finished product and on the economic efficiency of the machine which clearly depends on the size of the production run.

Works Study and Organization and Methods Departments will have the last word in deciding which machine is to be used.

Eugen BÜRK

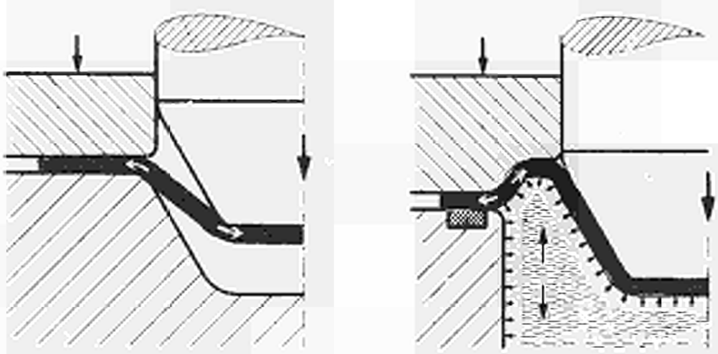
Hydrodynamic Deep-Drawing

(Translated from German)

The hydrodynamic deep-drawing process is used for the plastic shaping of flat sheet or preformed components to cylindrical, prismatic, conical, or paraboloid hollow bodies.

The deformation of the material is effected by expanding, upsetting, and bending it into hollow shapes against the pressure of a liquid.

In order to throw light on the shaping process, the case of "classical" deep-drawing will be considered. (Shown to the left of the figure below).



Schematic of conventional hydrodynamic deep-drawing

The surface area of the sheet that is fed into the press must be the same as that of the portion which is to be drawn. In the process of shaping into a cup, radial extension is coupled with circumferential shrinkage. Prof. Dr. Panknin has described the process clearly and in great detail in an article entitled "Grundlagen des hydraulischen Tiefziehens (hydroform-) und hydraulische Tiefzieheinrichtungen" (Fundamentals of hydraulic deep-drawing (hydroform-) and hydraulic deep-drawing devices).

He describes how, during deformation, a longitudinal stress σ_1 in the drawn part operates from the bottom, is deflected at the die radius, and acts on the flange as a stress radial to the direction of drawing.

This radial stress σ_r releases a compressive hoop stress σ_t which, in order to cause the material to flow, must be less than the radial stress by the amount of the resistance to deformation. The process of flow occurs below the blankholder. Wrinkling takes place if there is insufficient blankholder pressure.

The force that effects the deformation has the following components :

(1) The effective drawing force, i.e. the force that must be applied in order to deform the piece. This depends on the thickness and strength of the material and on the drawing ratio.

(2) The friction loss between the drawing die and the blankholder.

(3) The friction loss at the die radius and the reciprocal loss at the extremity of the drawing edge.

The force required for deformation must be less than the tensile strength of the sheet at the punch nose radius, as the force is transferred solely to the base.

If it is assumed that the tensile strength of the sheet at the punch nose radius is the same as the tensile strength of the sheet in its initial state, then for cylindrical parts the force required to shape the part is

$$P_V = (d + s) \cdot \pi \cdot s \cdot \sigma_{zB} \cdot \alpha$$

If it is in excess of this then the sheet around the punch nose will inevitably rupture. (See the right-hand side of the above figure).

The friction loss between the draw die and the blankholder depends on the qualities of the surfaces of these, or on the draw-bead if provided, the lubrication, and on the limiting drawing ratio β. This is the ratio between the diameter d and the diameter D of the punch nose.

In the above formula, α is a factor that accounts for the drawing ratio. For the limiting drawing ratio it is equal to 1.

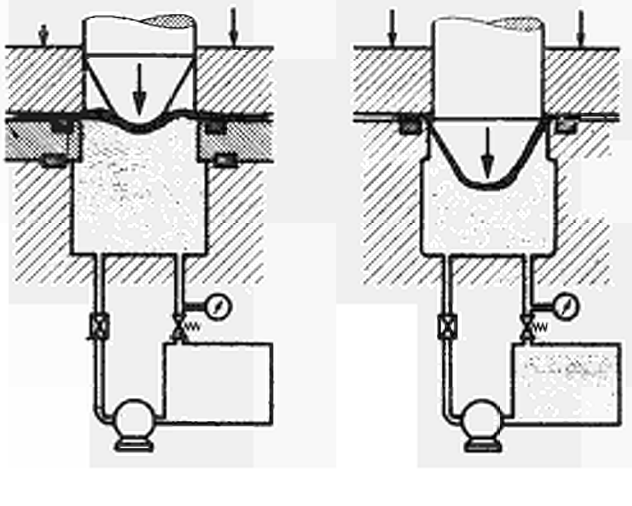
For cylindrical parts it is

$\beta = \frac{D}{d}$ 1.66 on the first impact
1.52 on the succeeding impacts

σ_{zB} = Breaking strain

Let us now consider the conditions of hydrodynamic deep-drawing.

In this process, the lower part of the die is in the form of a pressure chamber. The holder is filled with a liquid and is sealed by the blank itself, and a circular sealing ring. The downward movement of the punch creates a pressure in the pressure chamber which is controlled by a valve. The pressure acts in all directions in the container. As the punch moves downwards the blank is pressed against it. In this way, considerably greater forces can be transferred to the drawn part. The liquid pressure also causes a bending moment to be exerted on the free part of the sheet blank, causing an upwards movement as shown in the diagram. This releases components of stress which act radially and are then converted into tangential stresses, thus causing the material to flow between the drawing die and the blankholder and simultaneously overcoming the friction between the drawing die and the blankholder and allowing the material to move upwards into the shaped blankholder as shown. The force exerted by the punch, by way of the longitudinal stress in the cup, is thus much less than in the normal drawing process. The punch shapes the sheet in the centre portion only. The result is that the hydrodynamic drawing process achieves a much better total drawing ratio than the processes known hitherto viz. $\beta = 3$ or better.



Deep-drawing of conical hollow parts

Standard presses can be used for the process; these can be single-acting, double-acting from above, or double-acting from above and single-acting from below.

Hydraulic presses are more efficient on account of their uniform ram speed. It is better if the individual movements can be controlled separately with these presses. (See above figure).

The devices are constructed as follows :

The lower part is designed as a pressure chamber, which can preferably also act as a drawing die. A drawing die provided with a seal can also be screwed into the pressure chamber. The drawing die has roughly the same shape as the part being drawn. There is a groove in the drawing die, at a suitable distance from the die mouth. Into this groove a sealing ring, which can be made of abrasion-resistant synthetic material is fitted. For very high pressure, it is advisible to apply a coating of copper to the plastic packing. A valve is provided for adjusting the pressure. In most cases it is necessary to raise the pressure in the pressure chamber during actual drawing, and this is particulary so in the case of conical drawing. At constant speed of the punch, the volume of liquid displaced becomes greater because of the natural shape of these parts, and so the pressure in the pressure chamber automatically increases.

The case of highly-sensitive parts, that is, parts made of very thin or soft material, e.g. aluminium, or extremely conical parts, it is necessary to regulate the pressure in the pressure chamber according to the depth of penetration of the punch.

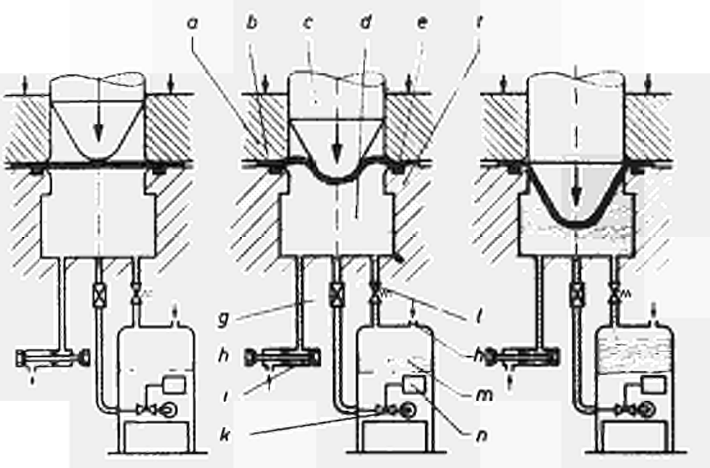
The pressure can also be regulated by varying the downward speed of the ram. This can be controlled according to the position of the ram which can function as a slide valve or by means of a battery of pressure cylinders having varying pressures, which can be brought into operation. It can also be controlled by an electronic valve via a punched card.

The displaced water flows into a storage tank from which it is returned by a pump via a non-return valve to take part in the next drawing process.

It is advisable to introduce a filter between the pressure chamber and the pump in order to retain any solid particles. The volume of recirculated water is regulated by means of a time relay.

The fluid-container can also be pressurized by connecting it to a compressed-air line. (See the figure below.) After each stroke of the press, the water is forced back into the pressure chamber via a time relay and solenoid valve. For relatively small parts it is possible to fit a piston at the bottom of the pressure chamber instead of the installation described above. This piston will be on spring, pneumatic, or hydraulic pads.

(a) Blankholder
(b) Work
(c) Punch
(d) Pressure chamber
(e) Sealing ring
(f) Drawing die
(g) Non-return valve
(h) Compressed air
(i) Pressure cylinder
(k) Magnetic valve
(l) Drain valve
(m) Water container
(n) Time relay



Deep-drawing of conical hollow parts

The pressure in the pressure chamber is then generated by the displacement of the piston, which is interlocked until the blankholder has returned to its starting position.

The piston forces back the displaced liquid in the drawing process. Care must be taken to ensure that the drawing die is always filled up to the brim.

As in the normal drawing devices, the upper part consists of a blankholder and the punch.

With light pressures, form below the blankholder can be held down with springs in the case of single-acting presses. If the pressure from below is higher, an interlock must be built in.

In the case of presses double-acting from above, it is secured to the ram.

The punch is designed as for the classical drawing process, its form being the inverse of that which the part is to have when drawn.

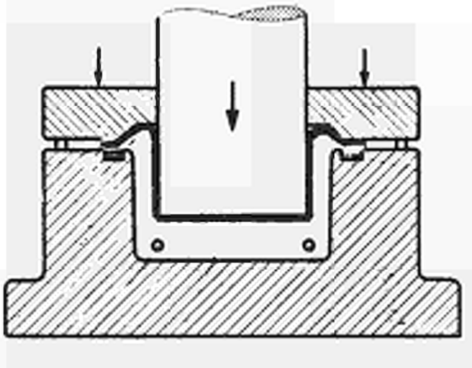
Operating procedure

The operating procedure is as follows :

When the drawing die has been filled to the upper rim with pressure fluid, the sheet to be drawn is laid on it. The press is switched on, the blankholder pressing against the slab which in turn presses against the packing, which is fitted into a groove and thus forms an enclosed pressure chamber in the lower part of the device. As the punch descends the pre-selected pressure builds up in the pressure chamber. The punch contacts the blank and the free portion of the sheet between the face of the punch and the blankholder is thrust upwards by the fluid pressure and that part of the sheet lying between the blankholder and the drawing die is drawn inwards. The part involved in the drawing process, that which contacts the punch, requires only the force that is necessary to shape the part from the centre of the bulge. The actual drawing process occurs, not over the drawing edge of the die, but over this bulge.

In order to adjust the degree of upward thrust, it is necessary in the case of extremely sensitive and sharply conical parts to regulate the pressure according to the depth of penetration of the punch, or to limit the height of the draw by means of the blankholder pressure.

The fluid forced into the container during drawing is forced back into the pressure chamber by a pump or compressed air against a non-return valve. When the pressure chamber is full, the cycle can begin over again.

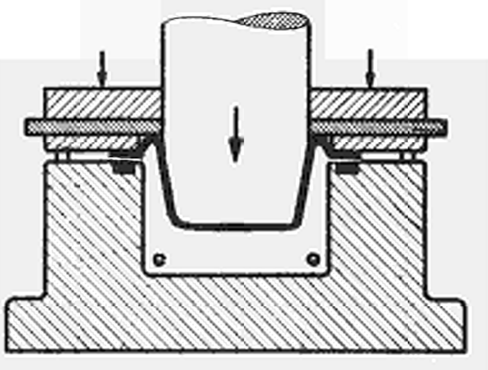


Hydrodynamic deep-drawing with a reverse redraw

With this process it is therefore possible to make the drawing ratio $\beta = \beta_1 \cdot \beta_2$. This is done as follows :

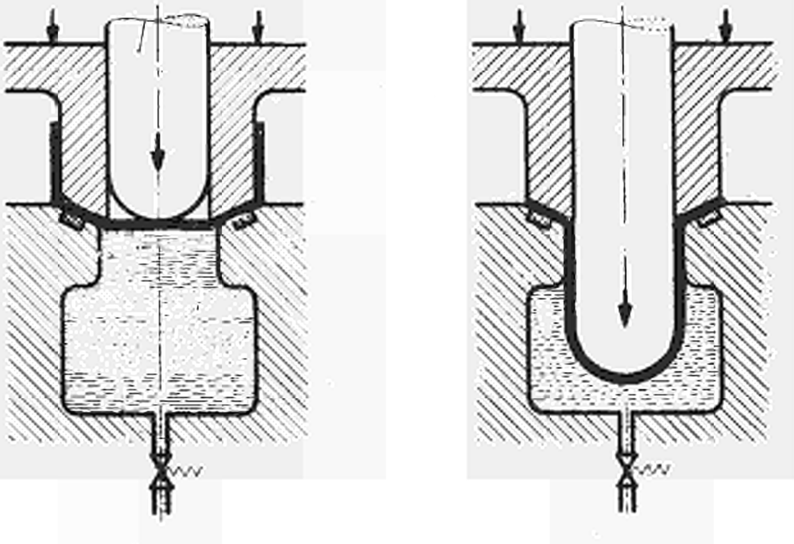
The blankholder is designed to give the ratio β_1. The fluid pressure causes the sheet to enter a recess, and the drawing ratio β_1 results. The punch then draws the projection into the finished part.

Thanks to the recess in the blankholder it is possible to keep the pressure very high, since the height of the upthrust is restricted.



Hydrodynamic deep-drawing with a restricted reverse redraw

In the case of conical parts the height of the upthrust can be limited by means of slide valves built into the blankholder.



Forcing the blank through the die in hydrodynamic deep-drawing

The figure above shows the design of a die for hydrodynamic shaping as a final operation.

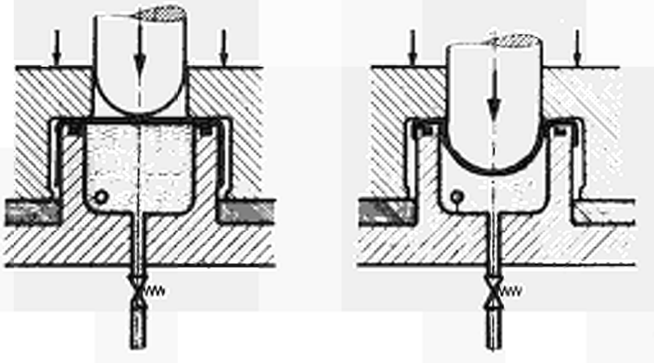
Again, the lower part consists of the pressurized container, the pressure chamber, and the drawing die, which has a seal, and the throttle valve, the non-return valve, a container for the liquid, and a pump.

The upper part consists of a punch and the blankholder which is shaped to the initially drawn component.

The operation is as described above. Instead of a flat blank, the initially drawn component is inserted, or thrust on to the blankholder, and is shaped to the finished part.

The figure below shows in diagrammatic form the design of a hydrodynamic reverse drawing die. The lower part is constructed as follows :

The outer diameter serves as a die for an initial drawing process. The inner diameter is the drawing die proper, and with its seal serves as a pressure chamber for the finished part. On the outside is a blankholder



Hydrodynamic deep-drawing with a reverse redraw

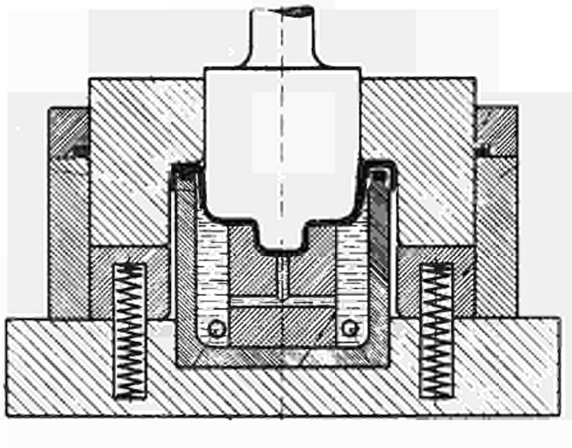
for the initial drawing operation. The blankholder operating from above acts as a pressure plate for the final drawing process. The punch has the inverse form of the drawn part.

The stages of the operation are as follows :

The sheet is laid on the die, the pressure plate operating from above, drawing the sheet against the blankholder operating from below, as in the classical drawing process.

The punch then completes the drawing process, in the reverse direction hydrodynamically.

This die could of course also be used for the finishing of an initially drawn part. In that case the sheet-holder operating from below could be dispensed with. The initially drawn part would simply be placed in position from above and finished hydrodynamically.



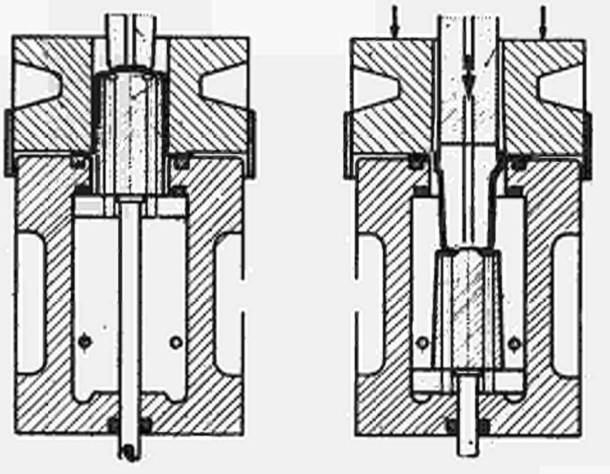
Combined reverse redrawing and cutting

The figure above shows an inverted drawing die which cuts the blank from the strip and shapes it by reverse drawing, as follows :

The blankholder, acting as the blanking and drawing die for the initial drawing process, draws the initially drawn work against a blankholder operating from below and against the pressure chamber, which acts as the punch for the initial drawing process.

When the blankholder lies up against the initially drawn work, the punch comes down and finishes the work by hydrodynamic drawing. In the figure the pressure chamber which is provided with a seal, is shown containing a form die. The punch will stamp or mark out very sharp contours against this.

In order to empty this die during drawing, it is connected to the pressure chamber by ducts. The die and the cutter can of course also be attached to the dies described above.



Hydrodynamic reverse redrawing by means of a filler

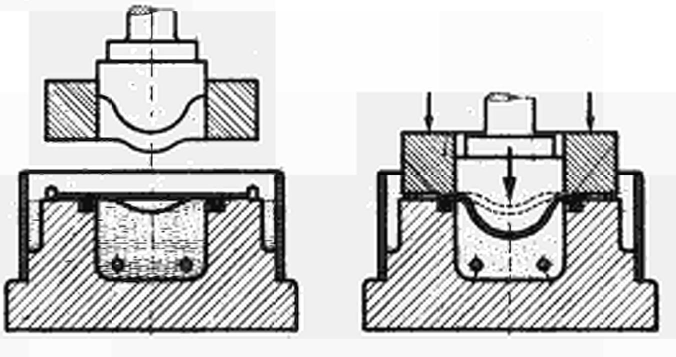
The figure shows a die that has proved highly valuable in practice and with which likewise hydrodynamic reverse drawing of initially drawn parts can be carried out.

The lower part consists of a drawing die, in the form of a pressure chamber, with the usual seal.

There is a "core" (Füllkörper) in the lower part of the body the form of which fits into the outline of the initially drawn part. One or more bolts sealed on the outside secure the "core" to an air cushion in the table. It is sealed against the drawing die and has a number of borings in it.

The upper part consists of a pressure plate made to fit the initially drawn part, and the punch, which has the reverse form of the finished work. The operation is as follows :

The pressure chamber is filled as far as the upper edge of the "core" with pressure fluid, and the initially drawn part with its flange is placed on the filler. The clamp presses the flange against the seal on the drawing die. The punch then draws the part hydrodynamically. The "core" is locked in the lower position until the punch and pressure plate have returned to the upper position.

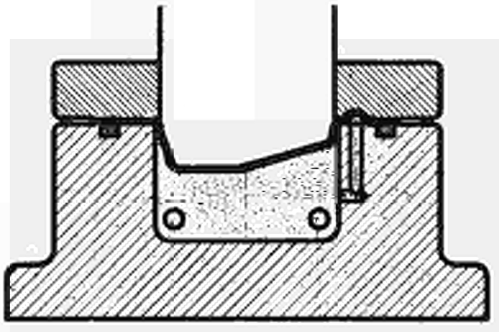


Hydrodynamic deep-drawing with an uneven flange

It is often necessary in industry to draw parts having uneven flanges. The use of the hydrodynamic process is recommended for this purpose also.

The die in constructed in the manner already described. (See the above figure.) The die, blankholder and seal are given the form of the flange. In order to fill the die to the upper edge with pressure fluid, it is advisable to fit a sealed border of sheet metal about the die, into which the water displaced from the clamp can escape. The blankholder shapes the flange and so restores the enclosed pressure chamber.

The rest of the operation is as described already.



Deep-drawing of hollow parts with an additional upward drawn die

A part is to be hydrodynamically drawn to a certain shape. At the same time it is to be flanged upwards. This is done as follows (See the above figure) :

In general, the die is constructed in the same way as described above. The negative of the form that the upward-drawn part is to have, is built into the lower face of the blankholder, and is connected to the pressure chamber by ducts. If the pressure generated in the pressure chamber is insufficient, it is possible to raise it by means of a separately controlled piston.

In this case it is of course advisable to seal specially the surface that is stressed in this way.

Advantages of hydrodynamic deep-drawing

The following are the advantages of hydrodynamic deep-drawing over the other known processes :

(1) The die can be incorporated in standard presses, so that it is not necessary to instal costly special machinery.

(2) The drawing ratio is considerably better than in classical drawing, and better than in the hydraulic deep-drawing processes hitherto known.

(3) Tool costs are relatively low, as fewer drawing operations are necessary (thanks to the better drawing ratio) and so fewer tools are necessary. Moreover, only the punch has a positive contour, the work does not need to have a negative contour.

(4) No diaphragms or membranes are used in hydrodynamic drawing.

(5) It is possible with the hydrodynamic deep-drawing process to finish the drawing of initially-drawn parts.

(6) The hydrodynamic deep-drawing process can be applied to reverse drawing.

(7) In the hydrodynamic deep-drawing process there is virtually no limit to the depth of draw.

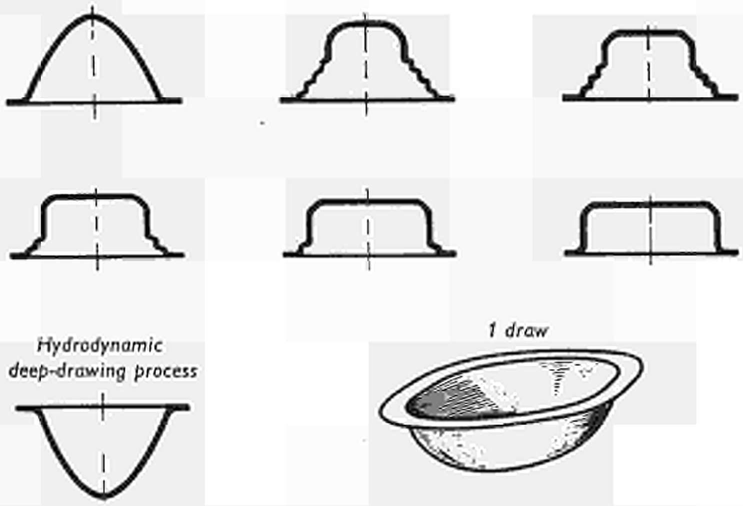
(8) It is a special feature of hydrodynamic deep-drawing that the thickness of the material is kept, broadly speaking, constant.

(9) In the hydrodynamic deep-drawing process the stretching that is characteristic of classical deep-drawing does not occur. Consequently, these parts have good surface quality, which is extremely important for parts the surfaces of which are to receive further treatment.

Disadvantage of the process

A disadvantage of the process is that the presses used for hydrodynamic deep-drawing need greater ramming and clamping force than the classical process.

Advantages of the process



Deep-drawing of conical hollow parts: different methods compared

The above figure shows that the number of draws in the hydrodynamic process can be much less than in the classical process, in the present instance in the ratio of 1 : 6. This reduces tool and finishing costs.

This account was written with the object of showing that hydrodynamic deep-drawing constitutes a significant step forward in deep-drawing technique, and that it should receive serious consideration whenever problems of deep-drawing have to be solved.

W. PANKNIN

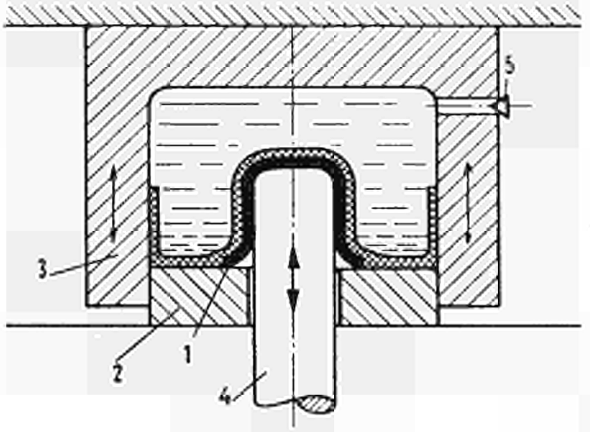
The Hydroforming Process and Hydro-Mechanical Deep-Drawing

(Translated from German)

More than 10 years ago a new deep-drawing process was publicized which differed from the conventional deep-drawing process in that it used a hydraulic cushion instead of a drawing die (see figure below). It operates in the following way: the work is laid on the blank support with the die open. The die is then closed and the support is locked with the hydraulic cushion. The hydraulic cushion is then put under initial pressure.

When the ram penetrates into the cushion, the hydraulic pressure causes the work to lie up against the ram, the pressure in the cushion preventing wrinkling in the flange of the drawn part. The oil expelled by the ram can escape by way of the pressure-control valve which is a means of maintaining the oil pressure as a function of the travel of the ram. Oil pressures of 1000 atm. and over may be necessary. Towards the end of the drawing process the oil pressure is blown off, the support released from the interlock, and the die is opened. The drawn work remains on the support, and can be removed.

This process has advantages from the point of view of both drawing technique and tool design. Since it is the oil pressure that brings the work up against the ram, there is no need for a bottom die. Also, it generally requires several fewer operations that conventional deep-drawing. Taking into



1. *work*
2. *blankholder*
3. *hydraulic cushion (buffer)*
4. *ram (punch)*
5. *pressure-control valve*

Diagram illustrating the hydroforming process.

account the fact that the ram can often be made from easily worked material, it is easy to see that the costs of the die will be considerably less.

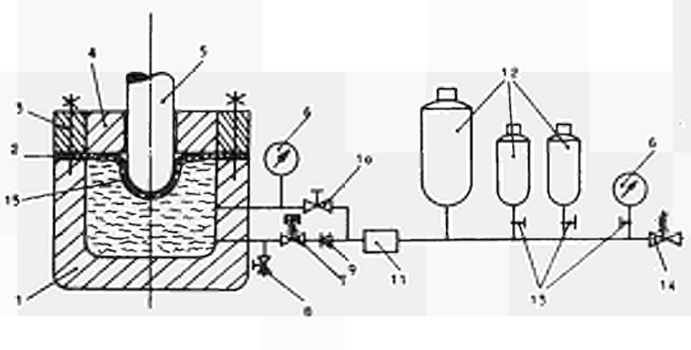
For some drawing dies it is only necessary to make one ram and, where other ram diameters are involved, a blank support. The clearance between the ram and the support is not critical, and can therefore be considerably oversized.

There are economic disadvantages to set against the technical advantages of this process. For instance, the process calls for the use of special equipment which is expensive and has a relatively low output. In their systematic research into the hydroforming process, Professor Siebel and his co-workers tackled the problem of modifying the process so as to retain most of the advantages while avoiding the disadvantages (Biblio. 1-7). Cost being one of the main problems they first endeavoured to ascertain whether it would be possible to carry out the process with dies such as can be fitted to conventional presses. It proved necessary to distinguish between two types of die, one to be used for making samples and for short production runs, the other mainly for mass-production. The following are the requirements for making of samples and or short production runs:

(1) A basic die that can be rapidly converted for use on various jobs.

(2) The die costs for each item of work must be as low as possible.

(3) The capacity of the die need not be high.



1. *Hydraulic cushion with oil filling*
2. *Rubber diaphragm*
3. *Clamping ring*
4. *Support (interlocked with clamping ring)*
5. *Punch*
6. *Pressure gauge*
7. *Pressure-control valve*
8. *Filling line*
9. *Non-return valve*
10. *Valve*
11. *Oil-cooler*
12. *Oil-storage cylinders*
13. *Valve*
14. *Safety valve*
15. *Work*

Hydroforming Die and pressure-control Unit for making samples and for short production runs on simple-acting hydraulic presses.

The reason behind these requirements is that when only a few units are to be produced, die costs and conversion times are important factors influencing the cost of each component.

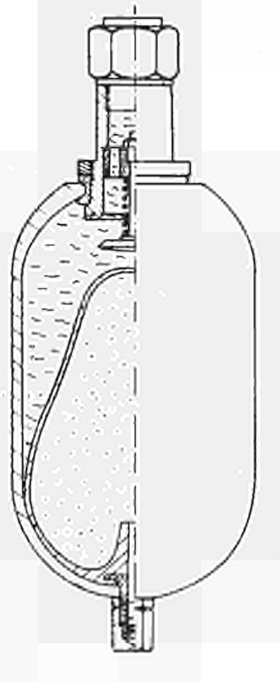
The first requirement for the mass-production die on the other hand, is high output, and die costs and conversion times are of less importance. For a mass-production die therefore:

(1) a basic die is required that can be fitted to rapid conventional presses and imposes no limit as regards operating speed;

(2) higher die costs; and

(3) longer conversion times for the production of different items of work with the basic die can be accepted, in contrast to the case of individual production.

The above figure shows a die for samples and for short production runs, the recovery, by means of a pump, of the liquid expelled during drawing being dispensed with; this type of die is usually built into a single-acting hydraulic press. The die is constructed similarly to the hydraulic cushion of the hydro-forming machine, but the hydraulic circuit is different. The operation is as follows: the die is opened while the oil expelled by the preceding drawing operation is still in the oil cylinders. The work is then inserted into the hydraulic cushion. The punch moves down, closes and locks the blankholder with the hydraulic cushion. When the blankholder is locked, the return valve is opened for a short time, enabling the oil in the cylinders to flow back into the die and regain the required initial pressure. The valve then closes again, so that the oil displaced by the punch in the subsequent drawing operation can escape only via the pressure control valve, the non-return valve which is there for safety, and the oil-cooler, to the storage space. The pressure-control valve controls the pressure in the hydraulic cushion in relation to the travel of the punch by means of a mechanism which can be easily and rapidly converted by means of screws to suit different jobs.



Bosch hydraulic oil-storage cylinder

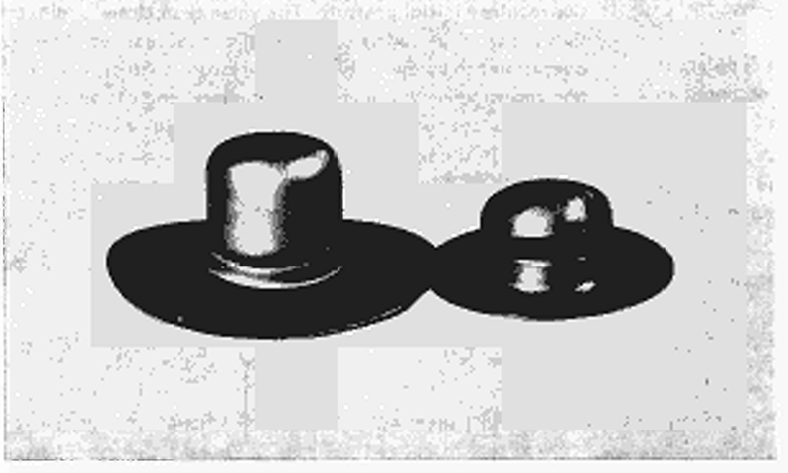
When the drawing process is complete and the punch has returned to its original position, the blankholder is released and the die is opened.

The initial pressure required before the drawing operation begins depends initially on the shape of the work, the thickness of the sheet, and the material. Sensitive pressure control is not normally necessary, so that in general it is possible to make do with a few pressure stages. Three oil cylinders are therefore provided and they are charged so as to have different initial pressures. If a high initial pressure is required, the lower-pressure cylinders are disconnected. In order to prevent pressure-equalization between the oil cylinders, the special type shown in the figure below is used. When empty of oil, these cylinders form a closed system, because the inner container closes the valve.

As the hydraulic pressure in the die can be made up to 1000 atm., there are relatively powerful forces acting on the blank support or blankholder; the interlock on this component must accordingly be very powerful. At low working speeds the interlock gives no trouble, but at the high outputs required for mass-production, the proposed solution is no longer satisfactory. Again, only when the diameter of the blank is small in relation to the diameter of the punch, that is, when the drawing ratio is low, is it possible to use the ram or the cushion to absorb the forces acting on the support direct. For this reason this method is normally not applicable.

In order to arrive at another solution, it is necessary to determine why it is that higher drawing ratios can be reached in hydroforming in one pass than by the conventional method. It is widely believed that the absence of the drawing die, and hence of the friction between the sheet and the die, the die radius and the favourable bending radii at the transition from the flange of the drawn work to the rim are essential factors that make a higher drawing ratio possible.

Closer examination however shows that these factors appear to be of subordinate importance (Biblio. 3, 4). The main reason for the higher drawing ratio is because the area where tearing occurs if the drawing process is carried to excess, is shifted. The figure below shows work torn in the hydroforming process and in normal deep drawing. Whereas in normal deep-drawing the tear is at the transition of the punch nose radius to the flange, in the hydroforming process it appears in the cup wall where the compound has been hardened by previous working. Consequently, greater forces can be transferred there than at the nose of the punch, where the material has only been slightly deformed, so that the strength at this point is about the same as the tensile strength of the original material. The diagram on the next page shows these relationships in the form of a graph.

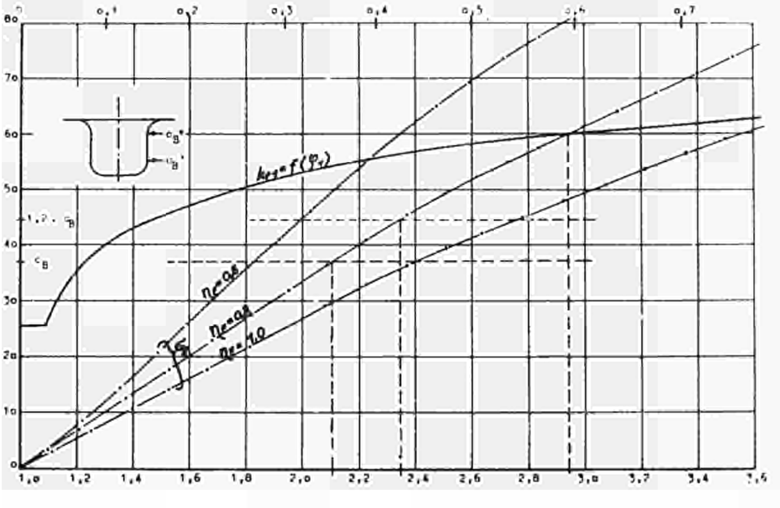


Failure due to tearing in the hydroforming process (left) and in normal deep drawing (right)

The longitudinal stress at the rim for three different values of ηF is plotted against the drawing ratio

$$\beta_0 = D_0/d_0 = \frac{\text{diameter of drawn part}}{\text{diameter of punch}}.$$

If this stress exceeds the strength of the sheet at any point, the sheet will tear at that point. Assume for the sake of simplicity that the tensile strength σ_B of the cup at the radius of the punch is equal to the tensile strength of the material in its original state.

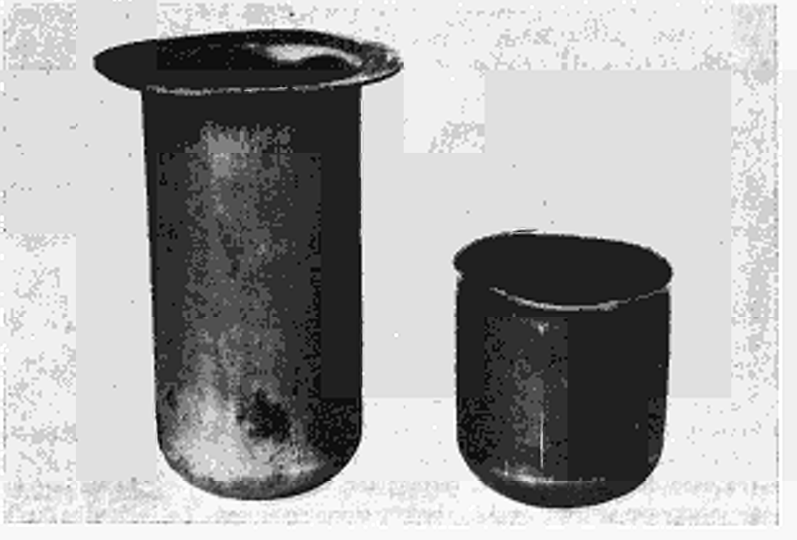


Calculation of limiting drawing ratio in the deep-drawing of work from St 14 2 mm. thick (Tensile strength 37 kp/MM²) by the hydroforming or conventional drawing method for a punch diameter of 100 mm.

If it is assumed that $\eta_F = 0{\cdot}8$ the stress required for deep-drawing will intersect the broken line representing the tensile strength at the drawing ratio $\beta_0 = 2{\cdot}11$. In normal deep-drawing, tearing is to be expected at this drawing ratio when $\eta_F = 0.8$. In the hydroforming process, the pressure acting on the flange from all directions presses the sheet so firmly against the punch that the drawing force is transferred not only from the punch to the bottom or to the "rounding" from the bottom to the flange of the drawn part, but also laterally by friction contact right into the flange. This reduces the stress at the punch nose to such an extent that given proper control of pressure in the hydraulic cushion, tears will occur at the transition from the wall to the flange. The strength of the material at this point, $\delta_{B}\hat{e}$, is the same as the tensile strength of material K_{f_3} at the drawing edge, and is likewise plotted in the above figure. Not until the drawing stress c_1 has reached the tensile strength K_f is tearing of the work to be expected in the hydroforming process. In the case studied in this figure this happens only at drawing ratio 2.95.

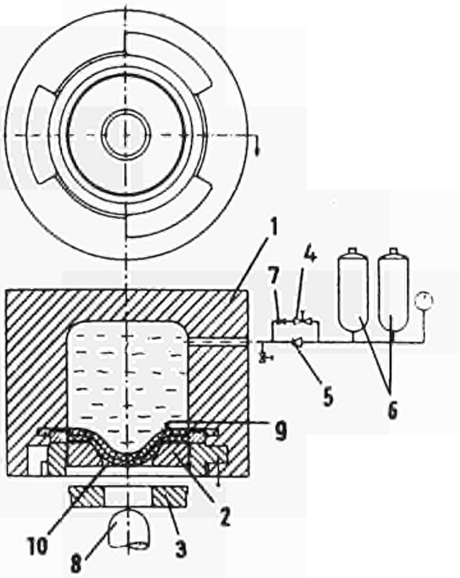
For completeness it is necessary to mention that in relation to convetional deep-drawing two factors, which however more or less cancel each other out with respect to the limiting drawing ratio, have been ignored. In the case considered the efficiency was about $\eta_F = 0.7$ and the rupture strength of the cup was about 20% above the tensile strength of the sheet in its original state. The figure above shows the two cups that can still just be drawn without tearing in the hydroforming process and in conventional deep-drawing with a punch diameter of 100 mm. and sheet 2 mm. thick.

Punch diameter d_0 = 100 mm.
Plate thickness S_0 = 2 mm.
Material St 14



Limiting drawing ratio in the hydroforming process (left) and in normal deep-drawing (right)

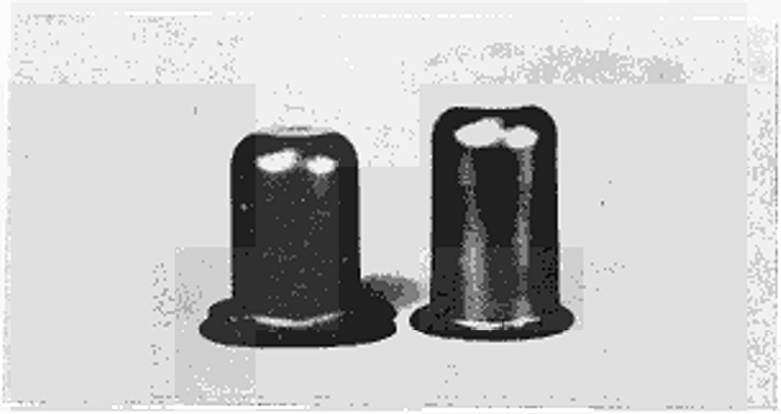
1. *Hydraulic buffer*
2. *Drawing Die*
3. *Support*
4. *Oil return valve*
5. *Non-return valve*
6. *Oil storage cylinders*
7. *Control valves*
8. *Punch*
9. *Sealing diaphragm*
10. *Protective diaphragm*



Hydro-mechanical die and pressure-control device for high outputs, applicable to double-acting presses and single-acting presses with drawing buffers

Once it was appreciated that the lateral pressure of the already deformed material on the ram and the resulting possibility of direct transfer of force from the punch into the rim was the main cause of the increase in the limiting drawing ratio with the hydroforming process, the difficulties due to the powerful forces at the support were solved by fitting an additional drawing die (see the figure above) (Biblio. 1, 2, 6).

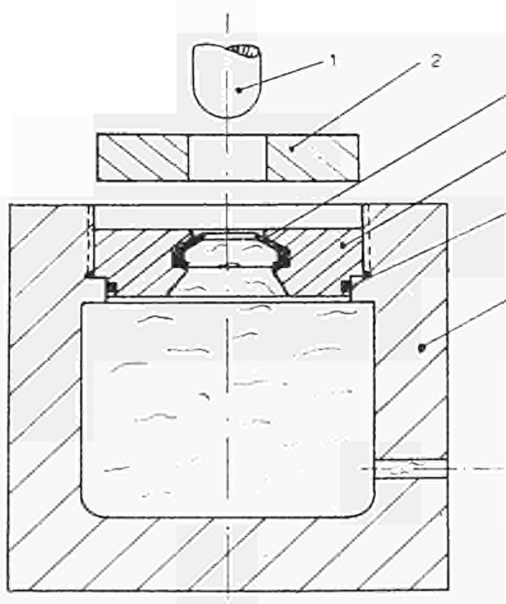
This does not create any greater outward-acting forces and instead of the powerful holding-up forces, only the usual sheet-holder forces are now necessary. The device shown diagrammatically in the above figure can be used for normal single-acting hydraulic or mechanical presses with drawing cushions or for double-acting presses. Despite the drawing die, the advantages of the hydroforming process are not lost. Thus, in this arrangement it is not necessary to construct a complex closed bottom die and yet the high drawing ratios are retained. The figure below compares two pieces of drawn work, one (left) drawn by the hydroforming process, the other (right) by the hydro-mechanical process. In both cases the highest drawing ratio that was possible without rupturing was $\beta_{omax} = 2.8$, whereas the work drawn by the hydroforming process showed distortion and thus could not be drawn any further than shown in the figure without damaging the sealing diaphragm. A greater depth of draw was possible when the same material was drawn hydro-mechanically.



Limiting drawing ratio with normal (left) and hydro-mechanical deep-drawing (right)

in the deep drawing of square, rectangular, and complex non-rotatory symmetrical work by the hydroforming process, wrinkling can easily occur at corners. To prevent this, such high pressures are required that normally only low-strength materials such as aluminium can be drawn to a great depth, and only smaller depths of drawing are attainable even with stronger materials such as steel and brass. Wrinkling in the corners is impossible if hydro-mechanical deep-drawing is applied, and so good work of this kind can be made. A further advantage is that projections can be built into the die. In this way even complex shapes can be accurately drawn by the hydro-mechanical process.

A disadvantage of the hydro-mechanical device is that an additional drawing die has to be made, which is not the case with the normal hydroforming process. Since the pressure in the hydraulic cushion presses the sheet against the punch, a closed bottom die is not needed but only a simple drawing



1. *Punch*
2. *Support*
3. *Sealing sleeve*
4. *Drawing die*
5. *Seal (O-ring)*
6. *Hydraulic buffer*

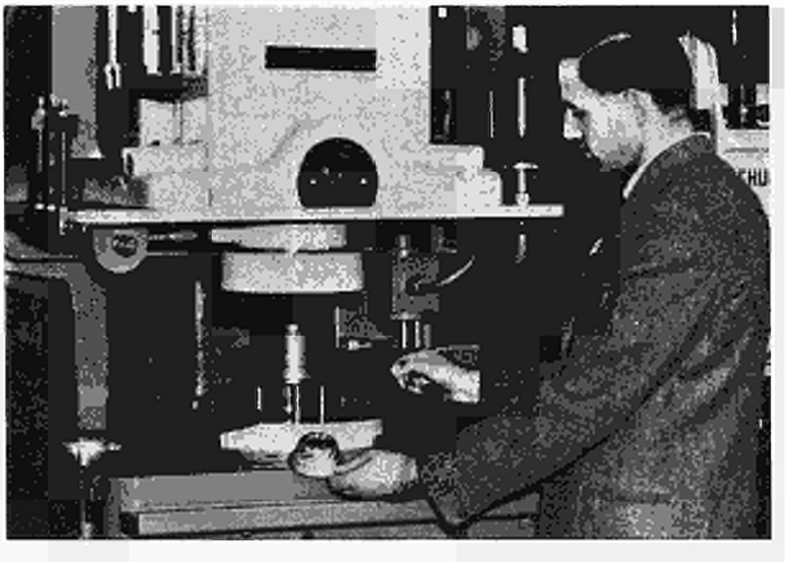
Hydro-mechanical deep-drawing die without sealing container die. Costs of production are therefore low. Moreover, the clearance between the punch and the drawing die is not critical, so that clearances of more than ten times the sheet thickness still produced perfect results, since it is the hydraulic pressure that brings the sheet up against the punch. Consequently, the one drawing die can be used many times and for different diameters of punch. One advantage is that conventional presses can be used and that there is no need to operate interlocks in the tool. This means that the basic equipment is of simple construction, so that in spite of higher tool costs the example shown in the second figure on page 465 can frequently be recommended for the making of samples. It is used in combination with the hydraulic circuit shown in the second figure on page 462. A pump can be used instead of the storage cylinders to circulate the oil and this also serves to create the necessary initial pressure.

A further variant of the hydro-mechanical deep-drawing device dispenses with the troublesome sealing diaphragm (see the figure below) (Biblio. 1, 2, 8). A sealing lip or O-ring provides a seal. In many cases however it is possible to do without sealing altogether, as the sheet provides an adequate seal directly at the radius of the drawing die. As the circuit is open and the pressurizing fluid can escape, it is advisable to use water. In this case the fluid is displaced before the ram is passed via the pressure-control valve into a storage vessel, from whence it returns to the die after the drawing operation. The liquid level is simply adjusted by communicating tubes.

A disadvantage of the open circuit is that the fluid is always escaping, but the pressure in the cushion can generally be controlled via a control valve. But it is also possible in principle to apply the control device described below and used for mass-production to the process of hydro-mechanical deep drawing without a sealing diaphragm. Admittedly in this case the liquid level has to be set very accurately each time, and adequate precautions must be taken in case an inadmissible pressure rise occurs in the oil-storage vessels.

In order to apply to mass production the advantages of the hydroforming process, it will in most cases be best to use the hydromechanical device, which, being without interlocks or similar arrangements, is not tied to a maximum speed of operation. At high speeds of operation of course it is not advisable to control the pressure in the hydraulic buffer by means of control valves. The second figure on page 465 shows a hydraulic unit for high operating speeds combined with a hydro-mechanical device. In the arrangement shown here the die was designed for a standard eccentric press with drawing cushions. The hydraulic cushion with die is secured to the plunger with the hydraulic device. The blankholder acts on the cushion via pins, and the punch is fixed to the table of the press. The operation is as follows: the work is laid on the blankholder and the press is then started. As the plunger moves down, the blankholder first lies up against the die and simultaneously closes the oil return valve. As the punch penetrates the die and displaces oil, the oil escapes via the non-return valve to the storages vessels.

The sizes and initial pressures of the storage vessels are so adapted to the work that the volume of the gas compressed by the expelled oil brings about the required pressure rise as a function of the travel of the ram. Thus there is no need for a valve to control the pressure, and hence no need, as far as pressure-control is concerned, to limit the speed of the drawing process. When the ram of the press has reached the bottom dead-centre and the return stroke begins, the non-return valve immediately closes, so that no oil can return from the storage vessels to the die. Only when the support is lifted clear of the drawing die does the by-pass valve open, enabling the oil to flow from the storage vessels back into the die. The finished work remains on the blankholder. After it has been removed, the die is ready for the next drawing operation. The pressure-control valve in the second figure on page 465 controls the speed at which the oil returns. Once again, the special cylinders shown in the figure on page 463 serve to store the oil.



Eccentric press with built-in hydromechanical deep-drawing die (See Diagram, page 465)

When the basic drawing device is to be adjusted for other drawing work, all that is necessary is to change the ram and, if the ram diameter is different, the drawing die and the blankholder. A nitrogen bottle then puts the oil-storage cylinders under the new initial pressures, and the device is ready for the drawing of the new work.

In order to make the oil-storage volume adaptable, it is always advisable to instal several cylinders of different sizes, which can be connected up or disconnected to suit the work. If higher pressures are needed in the hydraulic cushions than the valves and storage cylinders are suitable for, a pressure-converter is built in after the drawing device. The above figure shows the tool that is illustrated diagrammatically in the figure on page 465 in an eccentric press working at 45 strokes a minute. The circular blank and the complex pattern of the drawn work, which can be finished in one pass, are clearly visible.

In the meantime, hydro-mechanical deep drawing has been used for much more complex shapes, when it was necessary to adopt additional measures to control the flow of the material over projections. Especially favourable features are the accurate shape and the smoothness of the inner contours of the drawn work. Because high drawing ratios are impossible, fine grained steel qualities that are suitable for drawing can be used where a particularly good surface is required. Moreover, purely with a view to the drawing properties, use is often made of sheet that is thicker than the application requires. In such cases, hydro-mechanical deep drawing may be the means to considerable savings in costs of materials.

The sealing diaphragms for the hydraulic device are made of plastics with the highest possible abrasion resistance, such as Vulkollan. A second, thicker diaphragm is laid over the sealing diaphragm to protect it against damage from sharp edges. Sealing diaphragms generally have relatively long lives, provided that no work is drawn to a depth that is great in relation to the diameter. Also, from the point of view of tool design it is best to ensure that it will take only a few minutes to change a diaphragm. The advantage of this will be smooth operation and high output, so that even small parts can be turned out on quick-acting mechanical presses.

Summary

Siebel and co-workers developed hydro-mechanical drawing with and without a sealing diaphragm about 1955, from the hydroforming process. This process can be carried out on normal hydraulic or mechanical presses. The devices for making samples and for short production runs differ from those for mass-production in the manner of pressure control. In the mass-production process, the tool speeds can be adapted to the required press speeds.

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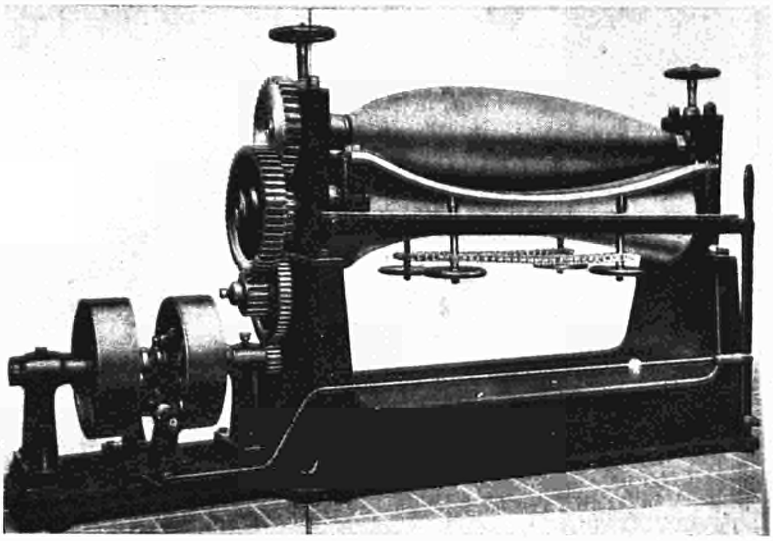

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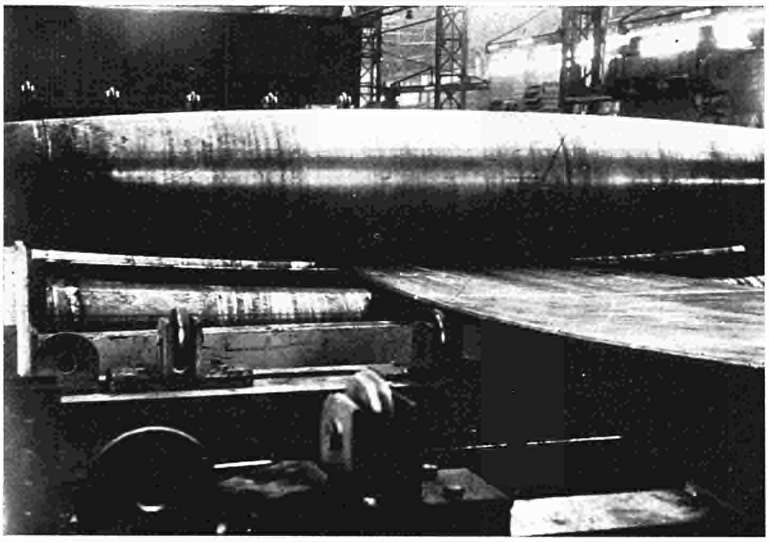

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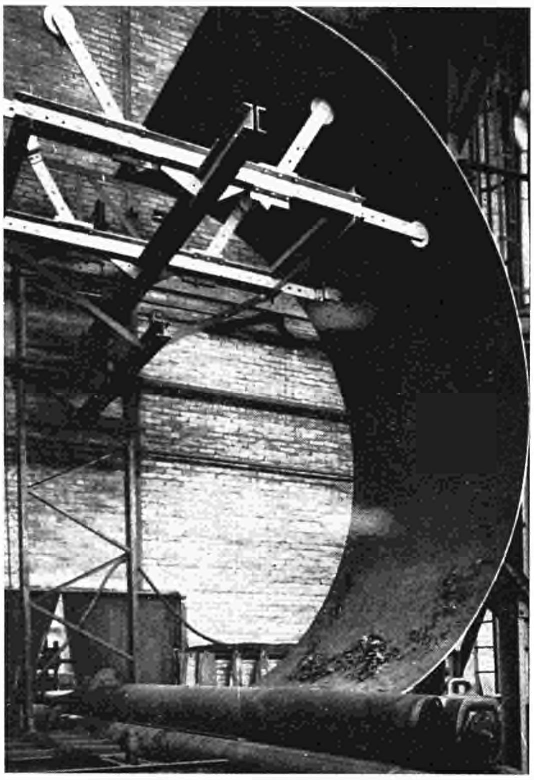

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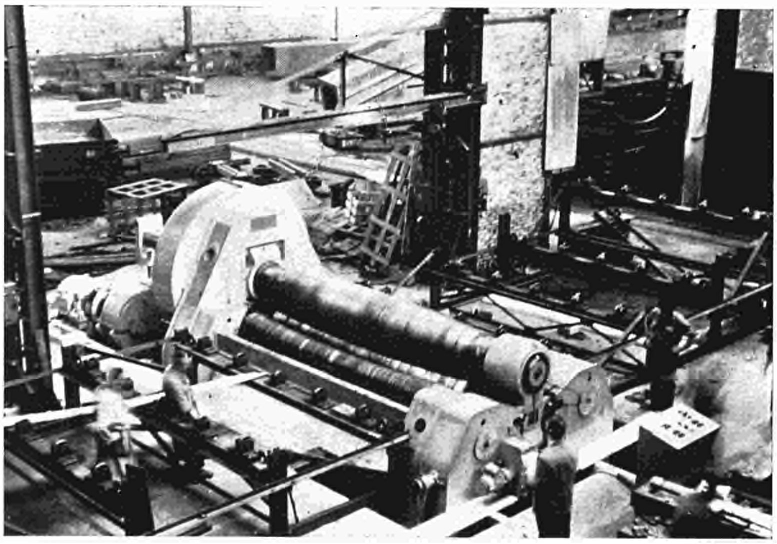

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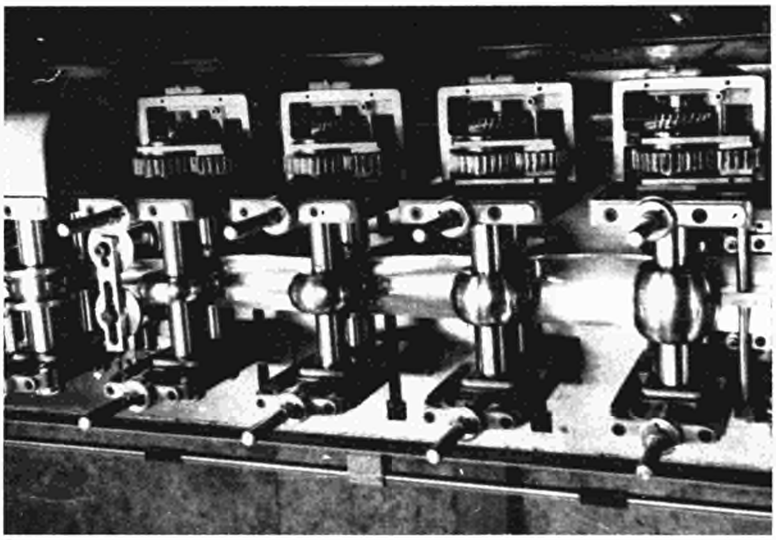

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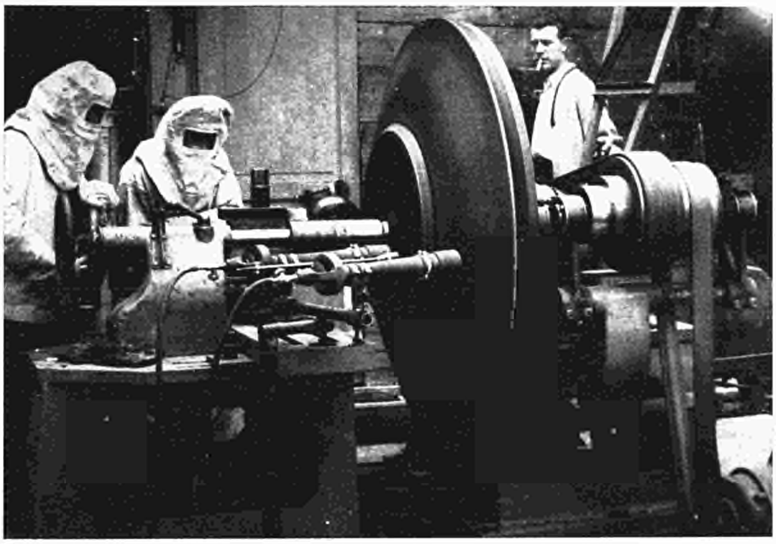

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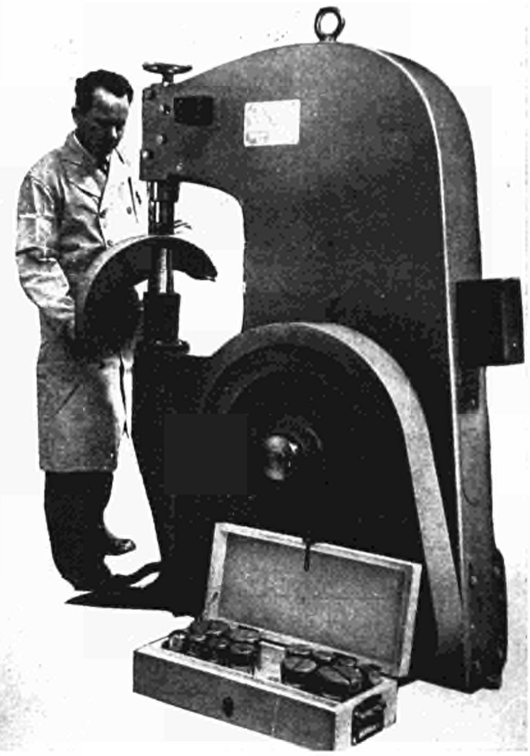

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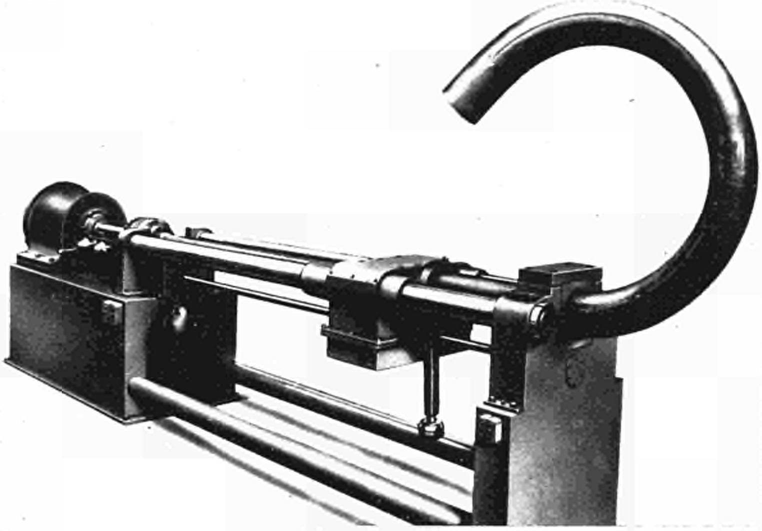

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W. PANKNIN

Systematic Raising of the Yield Point by Cold Deformation in Particular of Cold Rolled Light Sections

(Translated from German)

The dimensions associated with many designs are governed by the allowable stresses of the material. Since a design usually has to satisfy economic requirements, in addition to satisfying technical demands, production costs can frequently be reduced by striving to achieve the lightest possible construction. Such efforts are generally associated with the concept of light construction, though this is not to be considered as an absolute, but rather as a relative, concept. There are, first of all, two fundamentally different methods of achieving the greatest possible saving of weight in a machine or structure of a given material, e.g. steel. One is concerned with shape and therefore design, while the other refers to material. As regards shape, the optimum cross section relative to resistance moments and cross sectional area must be selected. It must also be remembered that the optimum shape is by no means always the most economical. At this point, production engineering requirements must therefore also be considered. As regards material the first priority is maximum tensile strength with adequate ductility. Although the ductility of a material is not normally directly included in calculation equations, it is of considerable importance because of inevitable stress peaks and the consequent possibility of local deformation. In this connection, we need only recall the very thorough and comprehensive research in the field of brittle fracture.

The attempt to attain ever higher tensile figures in a material will naturally be limited by the point at which higher tensile figures cease to be of further economic value. At the same time, material costs must be directly taken into account and questions of production engineering, such as welding, must be considered.

In the manufacture of tools and in mechanical engineering, very high tensile steels are produced by alloying and heat treatment. Because of the alloying elements and the heat treatments required, the cost of such materials is considerable. For larger machine components or structural members, these types of material are frequently out of the question. Their place is taken by ordinary carbon steels. In many structural components, the high tensile strength of alloy steels can frequently not be utilised because of excessive elastic deformation or instability (e.g. buckling). The following discussion will, therefore confine itself to ordinary carbon steels.

The tensile strength of plain carbon steels can be increased by raising the carbon content or the proportion of other elements, by quenching or by cold working. The carbon content can be raised only within relatively narrow limits because weldable materials are often involved and must exhibit adequate ductility. Additional alloying elements increase the cost of the product and quenching is associated with certain difficulties in addition to an increase in cost. From an economic point of view, it is therefore advisable to take advantage of the possibilities associated with strain hardening or cold work hardening. This field will, therefore, be considered in greater detail.

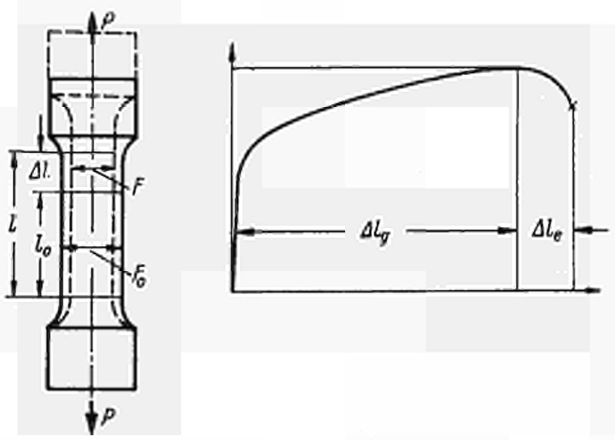
Many metals can be permanently deformed without disturbing the constitution and cohesion of the material. Plastic action will begin when a critical shear stress k is attained in the slip planes. This material flow takes place either by translation or by twinning. In the case of a polycrystalline material, it may be assumed that flow begins when the maximum shearing stress attains the critical value. It follows, therefore, that the material becomes plastic when the maximum principal stress difference ($\sigma_{max} - \sigma_{min}$) reaches some value characteristic of the material, the flow stress k_f (critical shear stress theory).

$$k_f = \sigma_{max} - \sigma_{min} = 2\,k$$

When a material is worked below the recrystallisation temperature, the flow stress depends principally on the material and the deformation. In this case, deformation is best represented by the true strain ε of the greatest magnitude (principal deformation). The relationship between strain and/or compression (upsetting) $\varepsilon = \frac{l - l_o}{l_o} = \frac{\Delta l}{l_o}$ and the true strain is:

$$\varphi = \ln \frac{l}{l_o} = \ln (1 + \varepsilon)$$

The flow stress k_f as a function of the principal true strain, will be represented graphically for the various materials in what is known as the true stress-true strain curve (Biblio. 1). This function is experimentally determined usually in the tensile or compression test. The figure below presents the relationships between the load-extension diagram of the tensile test and the requisite values for the true stress-true strain curve. It should be noted, however, that the simple relationships are valid only so long as there is no necking of the specimen.



$$\sigma = \frac{P}{F_o} \qquad \varepsilon = \Delta l = \frac{l - l_o}{l_o}$$

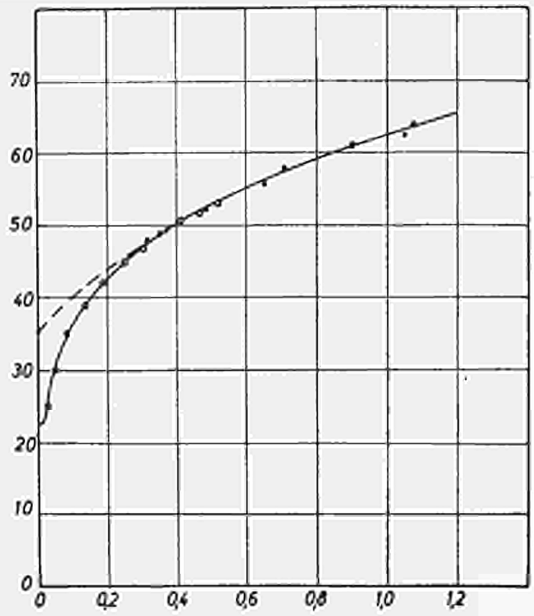
$$k_f \; \frac{P}{F}$$

$$kf = \frac{P}{F_o}(1 + \varepsilon_g) = \sigma (1 + \varepsilon_g)$$

Concepts for Determining the True Stress-True Strain Curve from the Tensile Test.

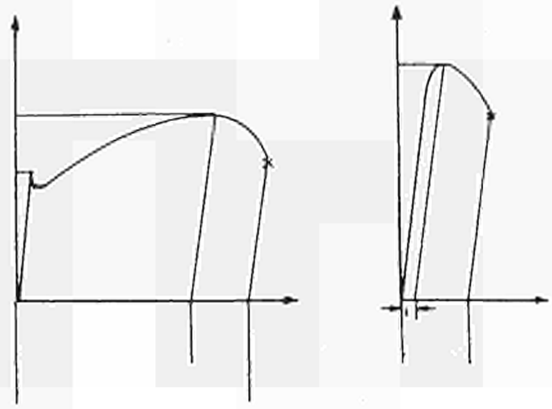
As a first approximation, the flow stress k_f might well be taken as the equivalent of the 0·2% proof stress of a material although they are determined experimentally in a different manner and therefore do not correspond exactly. This statement is, moreover, valid only so long as the yield point is not substantially falsified by internal stresses. This occurs, however, only with materials of higher tensile strength. The flow curve, therefore, indicates the extent to which the flow stress of a material can be raised by cold working. The figure below presents the flow stress k_f and the tensile strength σ_B of a low carbon steel. In this case, the tensile data were determined after various degrees of prior deformation while the flow stress was taken from the compression test.

The diagram shows the great extent to which the flow stress (i.e. proof stress) of the material has been raised by cold working. With deformations of about $\varepsilon = 0{,}2$ the flow stress is almost doubled. The tensile strength does not increase at the same rate, so that, with ordinary steels strained beyond the limit $\varepsilon = 0{\cdot}2$ tensile strength and flow stress roughly coincide. The stress-strain diagrams for a material not subjected to cold work hardening and for one which has been strain-hardened above the 0,2 limit are presented



True Stress-True Strain Curve and Tensile Strength Plotted in the Compression Test after Various Degrees of Prior Deformation by Cold Rolling. Material: deep-drawing sheet of St 12 Grade.

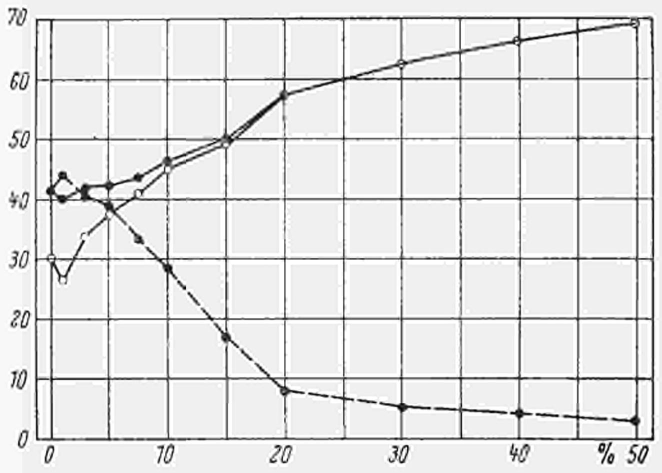
graphically the figure below. It will be seen that, even after small amounts of plastic deformation, the tensile strength of the severely strain-hardened material increases. The elongation before reduction of area (uniform stretch) is, therefore, practically zero.



Stress-strain diagram of a steel which has not been cold worked (left) and of a cold work hardened steel δ_g = elongation before reduction of area (uniform stretch).

The figure below shows the yield point σ_S, tensile strength σ_B, and elongation at fracture γ^2 (on 5 × dia) for an unkilled basic Bessemer (Thomas) steel with a minimum tensile strength of 37 kg./sq mm. (TU St. 37) in relation to prior cold working (Biblio. 2). After 10% cold working, the yield point was raised by about 50% while the elongation at rupture was still adequate. A striking feature of the elongation at fracture is that, with increasing cold working, the curve drops relatively steeply but only so long as tensile strength and yield point differ from each other. When both these coincide, the value of the elongation before reduction of area is about zero and the elongation at fracture covers only the proportion due to the reduction of area. Since the reduction of area is not greatly affected by prior cold working, the elongation at fracture value continues to diminish relatively slowly.

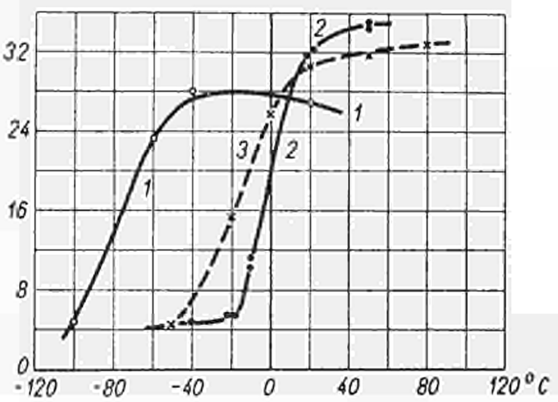
In cases where the stressing of a working part is similar to that associated with the uniaxial tensile test, the low elongation before reduction of area and the coincidence of yield point and tensile strength must be taken into account. With other types of stressing, or with a stress gradient through the cross section, the material can, nevertheless, become plastic locally without any danger of failure by rupture because the elongation before reduction of area and the tensile strength determined in the tensile test result solely from the conditions of stability with uniaxial tensile stressing. If, however, the application of a cold worked material requires a still higher elongation at fracture value, then either the degree of cold working must



Kp./mm.² and %

Influence of cold deformation on the tensile strength (σ_B), yield point (σ_S) and elongation at fracture ($\delta 5$). Material: TU St 37.

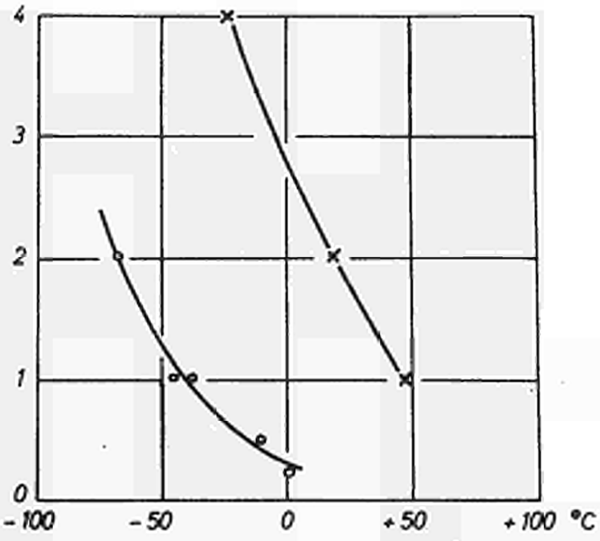
not exceed a certain amount or a subsequent tempering treatment must be used to increase the elongation without substantially lowering the yield point. In such cases, however, the temperature range in which artificial ageing of the material occurs, must be taken into account.



1. *Izett steel*
2. *Mild steel (melting point)*
3. *Mild steel (liquid)*

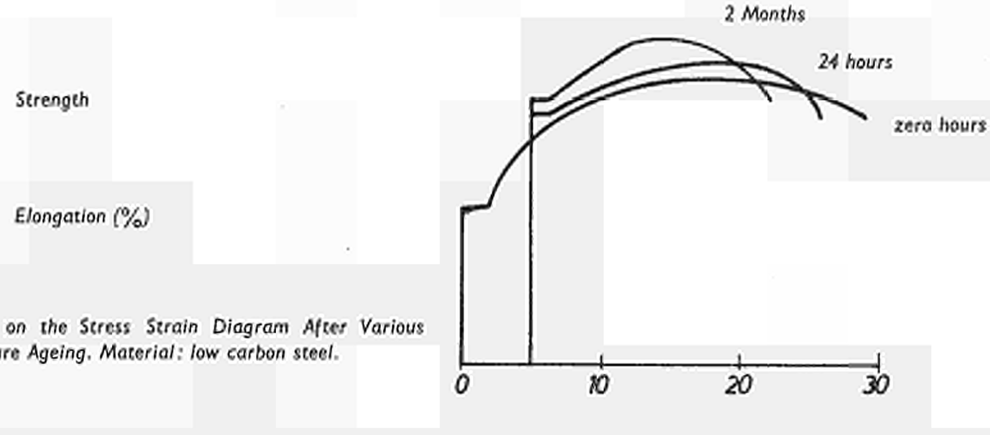
Notch Toughness-Temperature Curves for Various Steels.

The ductility of a material is of special importance at points where multi-axial tensile stresses occur, as for instance at points where forces are introduced, junctions, etc. The greater the multi-axial state of tensile stress or the lower the operational temperatures, the greater will be the danger of brittle fractures. The transition temperature in the notched bar impact test is the criterion. The above figure illustrates the influence of temperature on the notch toughness for various steels (Biblio. 3, 4). The notch toughness passes from the peak to the minimum value within a critical temperature range depending on the state of stress and the rate of loading. This means that, with similar stresses, brittle fracture must be expected at the transition temperature. The transition temperature is displaced toward higher temperatures with a less favourable combination of stresses a higher rate of stressing and a number of other influences. Within these limits it should be born in mind that cold deformation also displaces the transition temperature to higher temperatures. Furthermore, there is an additional displacement of the transition temperature toward higher temperatures because of ageing.



Influence of Ageing and of Notch Radii on the 2 mkg./sq cm. Transition Temperature.

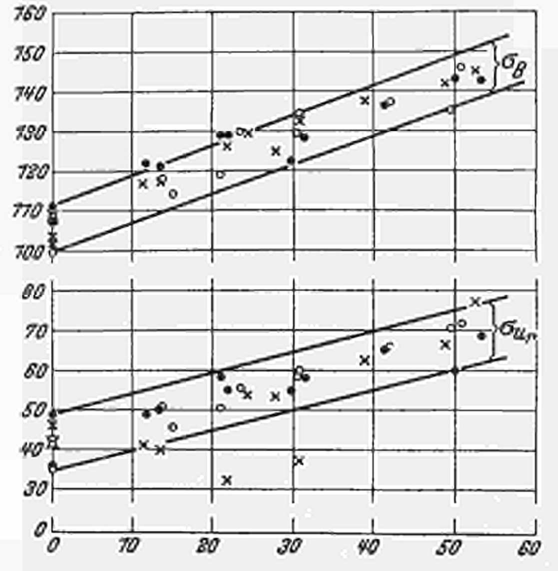
The above figure shows the influence of notch radius and ageing on the transition temperature of a steel containing about 0·16% carbon (Biblio. 3 and 5). Ageing, therefore, adversely affects the toughness values while, on the other hand, the tensile values are raised. The figure below shows the influence of room temperature ageing (natural ageing) on the stress-strain diagram of a steel subjected to 5% prior straining (Biblio. 6). The increase in the tensile strength values can be easily seen. The diagram also indicates that there is a reduction of elongation at fracture. This additional increase in the tensile strength can however only be utilized if ductility does not deteriorate beyond a certain critical point or if stress peaks caused by notches, junctions, etc. can be largely avoided in the structure (Biblio. 7). Should ageing however be undesirable, killed cast materials must be used. This is of particular importance for cold worked (strain hardened) materials.



Influence of 5 % Stretch on the Stress Strain Diagram After Various Periods of Room Temperature Ageing. Material: low carbon steel.

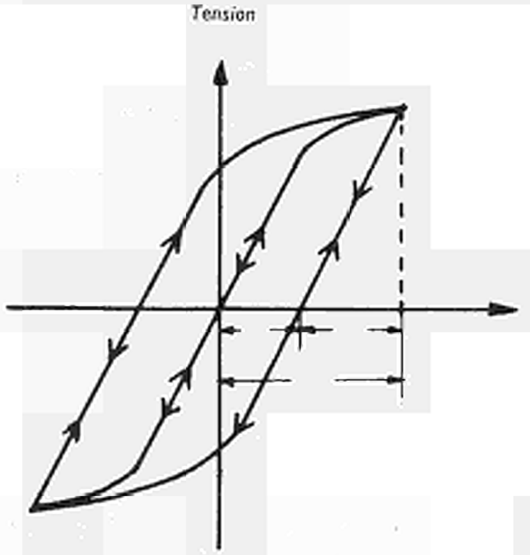
Where structural components are subject to dynamic stresses the fatigue strength of the material must be taken into account in the tensile strength calculation. It is, therefore, desirable to know whether cold work hardening also favours fatigue strength. The figure below shows the effect of a reduction in cross section on the tensile strength and the fatigue strength under pulsating tensile stresses of drawn steel wire. The effect of various drawing lubricants has been taken into account (Biblio. 8). It will be seen from the diagram that the fatigue strength is increased by cold work hardening to about the same extent as the tensile strength. Fatigue tests on unkilled Thomas steel of St 37 grade produced similar results (Biblio. 9, 10). In the case of cold work hardened materials, however, it must be remembered that residual internal stresses are often produced in the material by the cold working process and these may have an adverse effect on fatigue strength. It is, therefore, desirable to know the extent of the residual stresses after various cold working processes and, at the same time, the effect of various degrees of deformation must be taken into account.

By means of suitable combinations of various degrees of deformation, it is partly possible to achieve particularly small residual stresses or, in fact, even to produce internal stresses which will favour subsequent stressing.



Influence of Reduction in Cross Sectional Area on the Tensile Strength and the Fatigue Limit of Drawn Steel Wire.

Another influence which must be taken into account when cold work hardened sections are used is the Bauschinger effect (Biblio. 11). This refers to the variation in flow stress due to hyper-elastic deformation. With uni-directional loading following a prior hyper-elastic deformation, the flow stress is increased above its initial state while, with a reversal of stress, it is lowered.

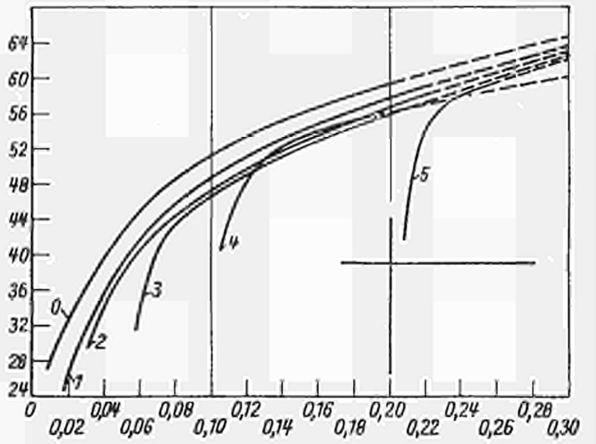


Influence of Hyper-Elastic Deformation on the Flow Stress with Renewed Uni-Directional or Reversed Loading (Bauschinger Effect).

The above figure presents this influence diagrammatically for the field of tension and compression, the stress-strain diagrams being shown first for the tensile and/or compression test in the initial state with subsequent removal of the load. When the initial direction of the stress is renewed, the material becomes plastic only when the old stress-strain curve is reached. The flow stress is therefore increased as compared with the initial state. If, on the other hand, after the removal of the load, the stress is applied in the opposite direction, the flow stress is lowered. The figure below shows the result of tests on an St. 37 steel. The specimens were first upended by various increments in the hyper-elastic region and were subsequently strained in the tensile test. The deformation of the compression test and the tensile test were added only according to the increment, i.e. without taking into account the direction of the stress. The curve marked O indicates the flow curve determined in the tensile test without prior compression. It will be seen from the diagrams that, after the reversal of deformation, plastic flow begins at stresses substantially below the flow curve with stressing in the initial direction. Subsequently however the stress required for further flow increases rapidly so that, with greater deformations, there is scarcely any difference between the flow curves with and without reversal of deformation. With greater deformations in one direction, the direction of the pre-stressing is therefore not so important for the true stress of a material. Only the extent of the stress seems to be of importance. If, for instance, the material has been first upended (e = 5%) (curve 3 in the figure below) and is subsequently stretched by the same amount, it has undergone a total deformation of about 10% (0·1) although it still exhibits its initial dimensions. Curve 3 shows that the true stress of this alternating deformation is only about 10% below that associated with uni-directional deformation. It is, therefore, possible to cold work a material without any change in its final dimensions. It must, however, where necessary be remembered that there is a drop in the 0,2 proof limit when the stress is again reversed. In the case of materials having a low tensile strength, as, for instance, the carbon steels, this reduction is not usually particularly great. The elastic limits, on the other hand, will be reduced to a substantially greater extent. Since the later direction of stressing is frequently unknown in the manufacture of sections and similar material, this drop in the proof stress is one of the disadvantages of cold worked materials because it does not permit full use to be made of the increase in the yield point. When, however, in the case of longitudinal materials as, for instance, sections, tubes and similar products, stresses are expected to be longitudinally orientated, any adverse influence of the Bauschinger effect longitudinally can obviously be avoided by cold work-hardening transversely (Biblio. 2, 10).

Specimen No.	Compression
0	0·0
1	— 0·013
2	— 0·026
3	— 0·054
4	— 0·101
5	— 0·200

Plotting of the Flow Curve in the Tensile Test for Specimens which have been Subjected to Various Degrees of Prior Compressoin. (The amount of prior upsetting was added in each case to the deformation produced in the tensile test). Material: St 37.



The processes by which the materials are cold work-hardened, are those generally applicable in normal processing technology. Whilst however, within the limits of processing technology, the manufacture of specific shapes within permissible deviations of dimension is the main object, the aim of deformation in this case, is to utilize the increase in tensile strength. In the forming process, this increase in tensile strength. is often undesirable and is therefore cancelled out by heat treatment. In wire patenting, the possibility of increasing the tensile strength by cold deformation has long been utilized. In this case, the final heat treatment is so arranged that the desired tensile strength achieved by the requisite final reduction of cross sectional area is attained by cold work-hardening. In this way, tensile strengths of 200 kg.-sq mm. and over are achieved in the wire. The plasticity of such wire is still high enough, in spite of low elongation, for springs with a 30% elongation and over in the peripheral fibre (with a volute spring rate of 3 and less) to be manufactured cold. This example shows that, with a suitable initial structure and, in spite of extreme cold work-hardening with subsequent low elongation, materials can still withstand relatively great local elongations or strain if there is a stress gradient.

In the case of wire, rods, bars and other solid or hollow cross sections, the reduction in the cross sectional area is achieved by drawing. The material is drawn through a die, in which compression stresses arise because of the taper of the die hole. The effect of the longitudinal tensile stresses and of the compression stresses in the drawing tool is to render the material plastic. With hollow cross sections, an internal tool is therefore required to reduce the wall thickness. The internal tool may be a fixed mandrel or a running centre bar. If an internal tool is not used, only the periphery of the work piece will be reduced while the wall thickness remains about constant (compression-tension).

The drawing process is mainly used for axially symmetrical cross sections.

Other cross sectional shapes are however possible. Use is particularly made of the drawing process to transform tubes into other shapes. In principle, the drawing process can be used for a large number of shapes, both solid and hollow. When occasion arises, the drawing tool can be replaced by a roller groove in order to reduce friction in the drawing tool. In this way sections can even be manufactured in limited lengths.

Normally, sections are produced from sheet or strip on bending machines or cold roll forming machines. In both cases, the sections are produced by bending. The development of the section roughly corresponds to the requisite width of strip. Bending is effected in reciprocating tools. Each longitudinal bend is produced in a single stroke while the requisite transverse bends are produced successively. The length of section achievable is limited by the size of the machine and of the tool. Cold roll forming is a continuous process directly from strip. Bending is effected progressively in a number of stands, the amount of bending in a single stand being limited, amongst other things, by the fact that undesirable additional deformations must be kept to a minimum. In bending, cold deformation is limited solely to the places of bending, unless additional restrictions such as the sheet-mounting support enforce additional deformation such as transverse straining or longitudinal alternating bending. With cold forming in roll forming machines also, the essential deformation and, consequently strain hardening, is found in the bent curvatures. It depends on the ratio of sheet thickness to bending radius. There are usually additional longitudinal alternating deformations of varying degree, depending on the sequence of deformation stages, roll diameter and sheet thickness.

Throughout the development of a section manufactured by bending or cold roll forming, there is a considerable variation in tensile strength which varies between the initial value and a maximum. Depending on the proportional distribution of the cross sectional area in a section, there is a more or less high average increase in the tensile strength values. There are various ways of achieving a still greater increase of the tensile strength of the entire section by cold working than can be attained solely by the deformation of the bent edges. First of all, it is possible to subject the section to additional cold stretching to increase the tensile strength. In this case, the fact that the internal bending stresses are reduced at the edges is an advantage. The higher production costs and a possible reduction of the yield point with compressive bending (Bauschinger effect) are likely to be disadvantages.

Another method of increasing the tensile strength of a section is to impart such a great alternating deformation during the manufacturing process in those parts of the section not normally deformed, that the tensile strength at these points is increased to the same extent as in the bent edges (Biblio. 2). The alternating deformation can, for instance, be effected so that, during the early stages of the roll forming operation, stiffening corrugations are rolled in to be pressed out again by subsequent operations (Biblio. 10). The material is, for instance, first strained transversely by about 5% and subsequently upset by the same amount so that there is an overall deformation of 10%. The resulting possible increase in the true stress roughly corresponds to curve 3 in the figure on page 479 for a deformation of $\varphi = 0{\cdot}1$.

It is further possible to increase the tensile strength of cold formed sections by using work hardened strip or sheet for cold forming. The strip can, for instance, be rolled with a 10% cold pass after final annealing before it is formed. Care must however, be taken to ensure that the material can withstand cold forming without material damage or that the toughness of the curvatures does not become too unfavourable.

Another way of producing cold work hardened sections is to work-harden hot rolled sections by cold rolling. This is, however, possible only with simple sections because of the stressing of the rolls and the materials.

The question as to whether cold work hardened sections can be welded without encountering appreciable substantial difficulties, is very important. Considerable research has been carried out on the influence of welding on cold work hardened materials (Biblio. 2, 9, 12). These investigations will not be discussed at this point. Summarizing, it can however be stated that welding does not appear to have any adverse effects. It may, in fact, frequently be possible to put down a welding seam in less highly stressed zones.

Summary

The tensile strength of materials can be increased by cold working. Care must however be taken to see that the yield point is increased more than the tensile strength. Deformation greater than 0·2 produces tensile strength and proof stress figures of about the same values. Toughness is reduced by increasing the amount of cold work. The influence of the Bauschinger effect must be taken into account.

Normal processing operations can be used for cold work hardening. In the manufacture of sections from sheet or strip, only the bent edges are substantially cold worked. By means of additional deformation or alternating deformation, the tensile strength of the entire section can be raised to a greater extent so that the yield point, for instance, is 50% higher troughout the entire section as compared with the "as supplied" condition, while toughness is still adequate.

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Rules for Calculating Building Components of Cold-Formed Thin-Gauge Steel in the United States

(Translated from German)

Traditional Steel-Construction, and Cold-formed Sections

Range of Application

The term "light structural steelwork" is sometimes applied to types of structures employing sections cold-rolled from steel sheet or strip. If the progress made in traditional steel construction is considered it becomes apparent that there is no justification for this use of the term, since, although it has continued to use the classical hot-rolled sections, the traditional steel construction industry has made appreciable progress in light constructional work. Various factors have contributed to this, among them being the use of new joining processes, the refinement of structural analyses methods involving more extensive calculations, and the use of higher grades of steel. This trend towards the use of light-weight structures for constructional work has not always brought economic advantages in its train. Thus, from time to time, cases are reported in which the advantages of a light-weight structure have been cancelled out by the higher construction costs.

If a study is made of the uses of hot-rolled and cold-formed sections in the United States, it will be found that, in multi-storey structural steel-work, the two groups are to a certain extent complementary. Whereas in the case of low-level construction the types of section are genuinely in competition with each other, in multi-storey buildings hot-rolled sections provide the supporting structures, and cold-formed sections are limited to providing roofs and, sometimes, walls. The advantage here is of the entirely dry construction of such buildings. The reason for the two types of steel section genuinely competing in the case of low-level buildings is that by skilled construction it is possible to keep the stresses on individual members low enough for cold-rolled sections to be used.

Traditional methods of calculation

Traditional hot-rolled sections are usually fairly heavy-gauge, sometimes still have bevelled flanges, and are rounded off at the transition from flange to web. These geometrical details, which are an inheritance from earlier rolling techniques, make the sections highly insensitive to phenomena such as tilting, bulging and buckling, phenomena which can be summed up by the term "instabilities."

On the other hand, sections produced by cold rolling sheet and strip have certain other geometrical properties, such as : the same wall thickness throughout the section ; a transition from web to flange consisting of a curve without thickening ; many shapes that are not characteristic of hot-rolled sections ; shapes that are frequently unsymmetrical.

The thin gauge and the absence of thickening are features which make cold-rolled sections sensitive to "instabilities." Because hot-rolled sections are insensitive to "instabilities," there was no need to specify for the calculation of steel structures such as were in use in the thirties' that these phenomena be considered at all. By not taking this kind of behaviour into consideration, these specifications did not encourage the use of cold-formed sections.

Special rules

In view of this, special investigations were started in the United States into this field of steel construction, which led, after a number of years to the development of U.S. supplementary structural steel specifications. From the outset this work was under the direction of Professor George Winter (who was originally to have given this paper). Since their first appearance in 1946 these specifications have been revised several times. The latest edition (1962), with the title "Light Gage Cold-Formed Steel Design Manual" was last year translated into German, and at the same time converted into the metric system which prevails in most of the countries of Europe.

These rules supplement the specifications for steels for high-level construction which are in force in some states of the U.S.A. Their formulae derive from these specifications, and are based on the theoretical work of Euler, Karman, and others, but the reported widely differing coefficients and assumptions regarding edge conditions are embodied in these specifications in a simplified form by giving empirical values, that is, calculation factors. These factors were derived from an extensive series of full-scale experiments carried out at Cornell University, these experiments including as many variants as possible.

Advantages of the "Light Gage Cold-Formed Steel Design Manual"

Considering the steel-construction standards, with their specifications and instructions for taking "instabilities" into account, that are current in Europe today, it would appear that they can also be used to calculate cold-formed thin-gauge sections. But these scientifically accurate data involve a great deal of intricate calculation.

It was one of the aims of the publisher of the American specifications to limit these calculations in conformity with the conditions under which cold-rolled sections are supplied, without allowing this to lead to inaccuracies in the calculations or to over-simplification. The problem was solved by adapting the specifications to the characteristics of cold-formed sections and by summarising the scientifically determined coefficients of the formulae so as to yield a number of factors which had been experimentally determined.

The manual evaluated certain essential formulae graphically in the form of families of curves. In this way it is possible to read many values of the formulae direct. For instance, the graph shown provides a means of determining the reserve width in the calculation for the load-carrying capacity. Tables have also been compiled for typical shapes of cold formed sections from which it is possible to estimate the static behaviour of similar cross-sections. For instance, there is a table for flanged double angle sections. The above two illustrations were taken from the German edition of the "Light Gage Cold-Formed Steel Design Manual."

The special methods used in the American specifications

Allowance for the over-critical buckling resistance

Compression sections reinforced on both sides

Of the special methods used in the American specifications consideration will first be given to the allowance for over-critical buckling stress σ_{Kr} of thin-gauge rectangular plates by the equation:

$$\sigma_{Kr} = K \frac{\pi^2 E t^2}{12 (1 - \mu^2) b^2}$$

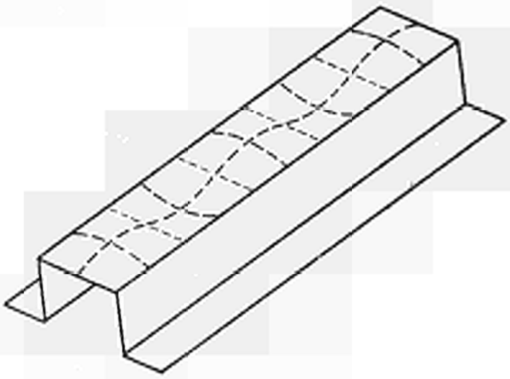
Here :

b is the plate width
t is the plate thickness

K is a shape factor that depends on the aspect of the plate, the nature of the stress, and the edge conditions.
μ is Poisson's Ratio.

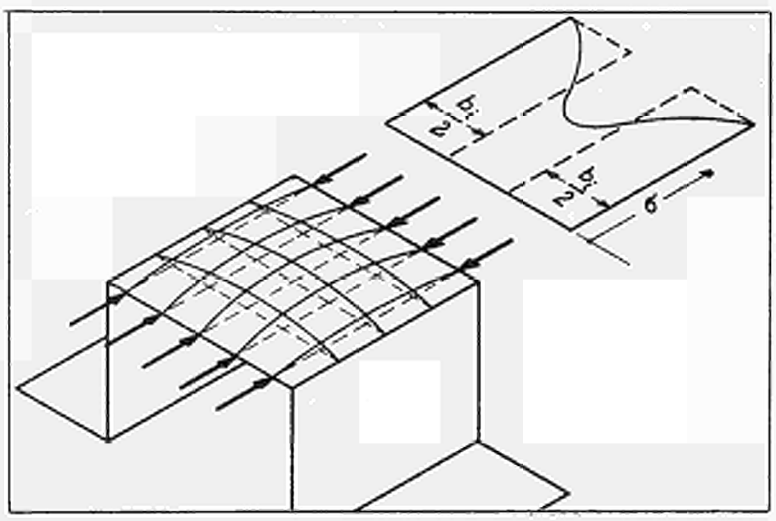
This equation is similar to the Euler equation for elastic buckling, from which it was derived. It might thus be assumed that the permitted load on this member under bending stress has been reached as soon as the stresses permitted according to this formula occur. Practical experiments, however, show that the zones of these sections that are under bending stress can absorb much greater stresses, and hence much greater forces, than the given equation would lead one to expect.

The reason for this lies in the over-critical buckling resistance due to the "diaphragm" type stresses. This can be illustrated as follows.



Consider the bulging zone of a "top-hat" profile under stress. The compressed zone is restricted to the edges of the webs, and in this representation the bending of the buckling surface alternates transversely to it at points dividing the length of the section into four.

The solid lines indicate the deformed shape and the broken lines the original shape. If the deformation of the individual strips had reached the degree of elastic buckling according to Euler, they still would not have bent, as the forces acting transversely to them, the "diaphragm" type stresses, prevent further buckling of the strip. The transverse strips in the diagram act as tension members, restraining the compression members.



As to the load-distribution within the buckled zone, the diagram clearly shows that because of their deformation the centre strips take up less of the load, while the edge zones, being stiffened by flanges, support the load. If this stress-distribution is plotted in the form of a curve over the cross-section, the picture shown on the right is obtained.

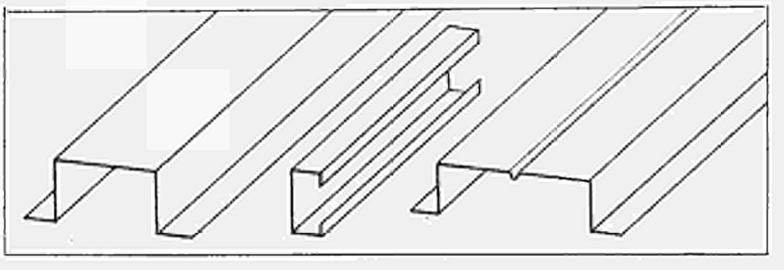
Thus the compressed cross-section will not fail until the stresses at the corners or edges, which take up most of the load, reach or exceed the yield stress. The author is here ignoring the fact that cold working has to a certain extent hardened this zone.

The specifications allow for this non-uniform stress distribution by postulating that a central portion of the compressed zone is not there and adding the stresses that really act there to the other zones. To put it another way : the total surface below the stress-distribution curve is divided by the greatest ordinate of stress at the edge ; the remaining quotient is called the equivalent, reserve width.

The following general expression applies :

$$b_l = 1{,}9\sqrt{\frac{E}{\sigma_{max}}}\left(1 - \frac{0{,}475}{b_o/t}\sqrt{\frac{E}{\sigma_{max}}}\right)$$

The left-hand side of the equation expresses the supporting width in the elastic zone, as already given by Karman. The other elements represent empirical factors derived from the experimental results obtained at Cornell University.

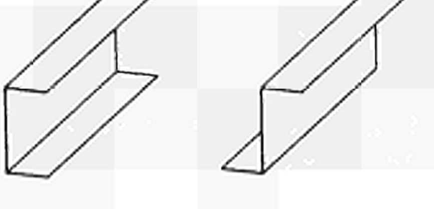


These formulae thus apply to cross-sections under bending stresses and stiffened on both sides, as found in the following forms (See the above figure) :

The figure on the left shows a "top-hat" profile, the centre one a C-profile sufficiently stiffened at the edges, and the right-hand one a "top-hat" profile with an adequate stiffening edge. For these and related profiles, the over-critical buckling resistance exercises a stiffening effect as shown.

Flanges under compressive stress, strengthened on one side only

It is also possible in the case of sections which are strengthened on one side only, to take the over-critical buckling into account as shown in the lower zone of this diagram. The economic advantages however are not as great as in the case of sections strengthened on both sides.



In the case of sections strengthened on one side only, the specifications are based on the following considerations.

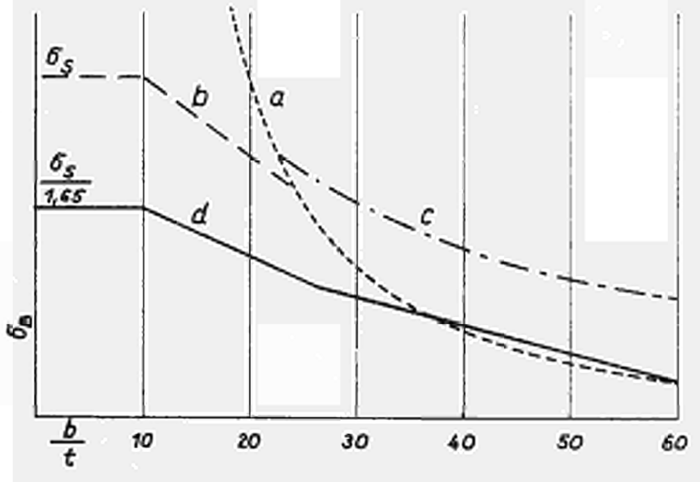
If, in a system of co-ordinates with the abscissa b_0/t and the ordinate σ_B the curve for the theoretical buckling stresses for the elastic zone is according to the formula first shown :

$$\sigma_{Kr} = K \frac{\pi^2 E t^2}{12 (1 - \mu^2) b^2}$$

the curve "a" is obtained (see the figure below).

Curve "b" represents the inelastic zone, where the limit for the zone for values of $b_0/t < 10$ is the yield point. In this zone the curve is thus horizontal.

For thin plates, the over-critical buckling resistance in the elastic zone is as shown by curve "c".



The specifications are based on the assumption that they give a safety factor of 1·65 for small values of b_0/t that is, the relatively thicker sections — with respect to the yield point and with respect to the theoretical buckling stresses in the inelastic zone.

This curve then passes into curve "a", which represents the elastic zone of the theoretical buckling stresses. In this zone there is thus a safety factor with respect to the over-critical buckling resistance, as shown by the distance between curve "a" and curve "c".

Buckling

In calculating the buckling, the specification also has its own method of calculating simply and with adequate safety the influence of local buckling on the buckling resistance.

According to the general steel-construction specifications of the U.S.A. the formula for small and medium gauges is:

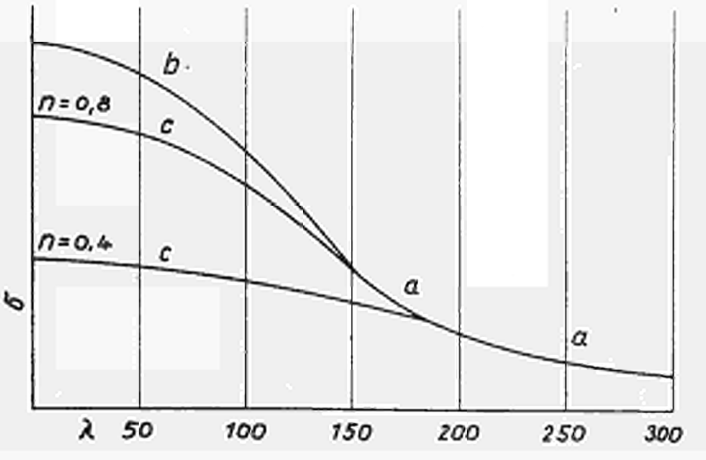
$$\sigma_{Kr} = \sigma_S - A \, \sigma_S^2 \, (l/i)^2$$

In the range in question this yields a curve with a trend similar to those of the various European buckling-resistance specifications.

In order to account for the influence of local buckling, a factor "n" is introduced into the formula, which then reads :

$$\sigma_{Kr} = n \cdot \sigma_S - A\,(n \cdot \sigma_S)^2\,(l/i)^2$$

The factor "n" represents the ratio between the load-carrying capacity as limited by local buckling and a load-carrying capacity such as would exist if local buckling did not occur. The basic assumption here is that there is a member with a slenderness ratio of almost 0, that is, a very short section of a buckling-resistant member. In conformity with the method already described for calculating the local buckling, this factor "n" is also included in the calculations. Its influence can best be shown on a graph.



The curve a-b represents the buckling stresses for the form factor n = 1. In the case of shapes that are more sensitive to buckling, the factor falls below 1·0, and so curves such as those plotted have a critical bearing on the calculation of elements subjected to buckling.

In the profile tables in the manual, these form factors are given for the commonly used profiles for two fundamental stresses. The possibility of making comparisons helps the designer to devise new profiles.

Further details

Cold-Hardening

The 1964 edition of the specifications contains for the first time directions as to how to raise the yield point by cold hardening.

Welding processes

Resistance welding plays an important part in the joining of cold-formed sections by mass-production methods, e.g. for the covering of "top-hat" profiles with plates or the joining of two C profiles to one I-profile. Values are given for the sizes of the weld spots and the distances between them.

Stiffening effect of the wall covering

It is permissible according to the specifications to allow for the strengthening effect of wall coverings on the frame posts in the case of low buildings. Fibreboard, or stiffer filling materials are included here.

Linear Process

Cold-formed sections have an almost uniform cross-section everywhere. For this reason, it is permissible to assume for the purpose of the calculation that the material of the section is concentrated at its centroid. Accordingly, only straight and curvi-linear sections are taken for the profile, and the actual plate thickness is not taken into account until the linear calculation has been completed. In this way, a given shape can be converted from one plate thickness to another relatively quickly.

An example

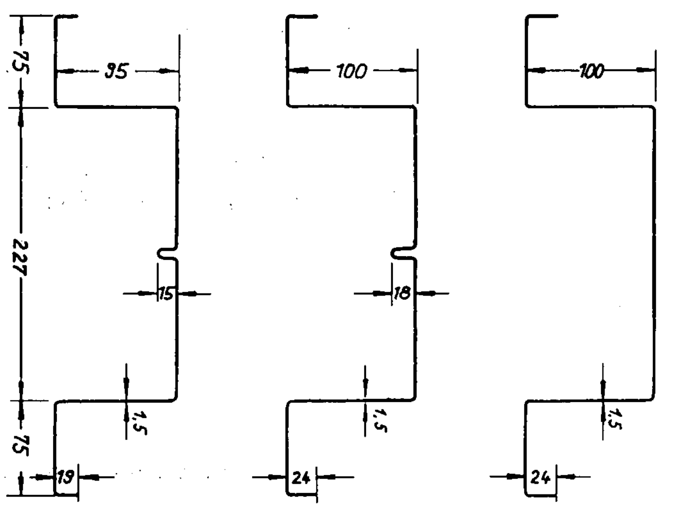
These two hat profiles were taken as calculation examples 17 and 18 in the "Light Gage Cold-Formed Steel Design Manual." The following values of the cross-section were found for the upper profile.

$J_x = 108$ cm.^{4} ; $W_x = 17{,}95$ cm.^{3}

and the following for the lower profile:

$J_x = 143{,}5$ cm.^{4} ; $W_x = 28{,}2$ cm.^{3}

This shows that a seam in the middle of the zone under compression stress has a strengthening effect and increases the load-bearing capacity of the section by more than 50 per cent.



The example shown is derived from these two profiles. The profile is similar to that of example 18, but the developed length of the profile is the same as in example 17. In order to retain the strengthening seam, the height of the profile was reduced from 100 mm. to 95 mm., and the two bevels were shortened by 5 mm. The resulting cross-sections for this profile are:

$J_x = 125$ cm.^{4} ; $W_x = 26.6$ cm.^{3}.

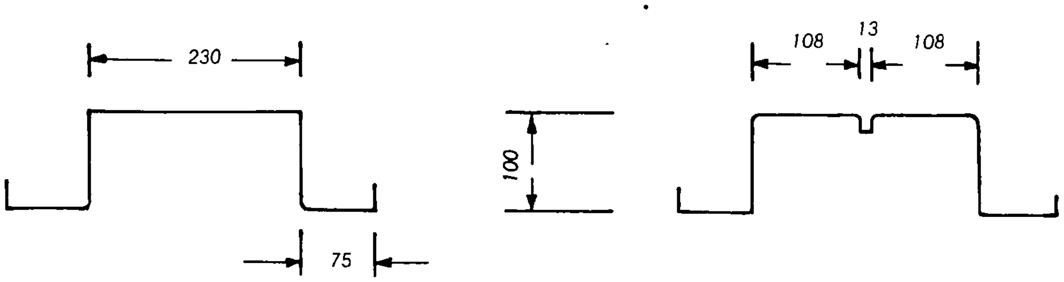
Thus, in spite of the reduction in the height of the profile, the inclusion of a strengthening seam appreciably raises the load-bearing capacity, and so makes for a more economical profile.

Rules for the calculation of components made of cold-formed thin-walled steel sheet in the United States

Example of calculation —According to German translation

In the "Handbook for the calculation of components made of cold-formed thin-welled steel sheet," calculations for two top-hat sections are given in examples 17 and 18. The two sections shown below are identical in external dimensions; they differ however in design of their compression flanges. The cross-sectional properties are obtained for the two sections in accordance with the American rules of calculations as follows.

Example 17 | **Example 18**

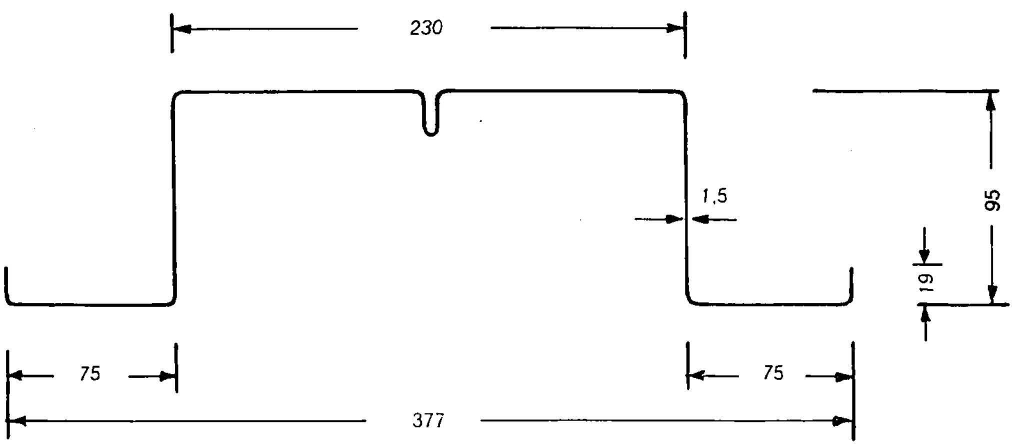


Example 17: $J_x = 108\ cm.^4$, $W_x = 17{\cdot}95\ cm.^3$

Example 18: $J_x = 143{\cdot}5\ cm.^4$, $W_x = 28{\cdot}2\ cm.^3$

It can be seen that by introducing a stiffening rib the strength is considerably increased.

The section shown below is similar in form to the section in Example 18, but the extended length of the section is equal to that of Example 17. To obtain the stiffening rib the section height was reduced from 100 mm. to 95 mm. and the height of the sides reduced by 5 mm.



Bending strength of a top-hat section. Application of the linear method.

Given : Steel with minimum yield point $\sigma S = 2300\ kg/cm^2$
(corresponding basic stress $\sigma g = 1400\ kg/cm^2$
Section as shown.

Required to find: maximum permissible bending moment:

Solution : (1) Calculation of the geometrical properties :

Radius of the centre lines of the bends

$$r' = r + \frac{t}{2} = 0.25 + \frac{0.15}{2} = 0.25 + 0.075 = 0.325 \text{ cm.}$$

Arc length of centre lines of bends

$$l' = 1.57 \times r' = 1.57 \times 0.325 = 0{\cdot}51 \text{ cm.}$$

Distance between centroidal axis of arc and centre of circle

$$c = 0.637 \times 0.325 = 0.207 \text{ cm.}$$

$$c' = r' - c = 0.325 - 0.207 = 0.118 \text{ cm.}$$

In the rest of the calculation the linear moments of inertia J'_0 of the bends relative to their centroidal axes are ignored in view of the low values.

(2) Calculation of the moment of inertia J_x.

The exact position of the line of zero stress has to be determined with an approximation calculation. First the calculation assumes an edge stress in the top, pressed part of the cross-section of $\sigma g = 1400$ kg./cm.².

According to paragraph 2.3.1.2. of the calculation rules :

$$\frac{b_0}{t} = \frac{10.45}{0.15} = 69.7$$

Since this value is greater than the permissible value $b_0/t = 60$ and smaller than 90, the equivalent width b_i60 must be determined in accordance with the formula :

$$\frac{b_i60}{t} = \frac{b_i}{t} - 0.10 \left[\frac{b_0}{t} - 60\right]$$

in this :

$$\frac{b_i}{t} = \frac{2130}{\sqrt{\sigma g}} \left[1 - \frac{533}{\frac{b_0}{t}\sqrt{\sigma g}}\right]$$

$$= \frac{2130}{\sqrt{1400}} \left[1 - \frac{533}{69.7 \times \sqrt{1400}}\right]$$

$$= 57.0\,(1 - 0.204) = 57.0 \times 0.796 = 45.3$$

$$\frac{b_i60}{t} = 45.3 - 0.10\,(69.7 - 60)$$

$$= 45.3 - 0.97 = 44.33$$

$$b_i60 = 44.33 \times t = 44.33 \times 0.15 = 6.65 \text{ cm.}$$

In the case of sections, the cross-sectional elements of which are subject to stress, it is necessary to calculate equivalent widths b_i60 ; the sectional areas of the side and intermediate supports also have to be reduced to equivalent areas F_i. According to the rules of calculation :

$$F_i = k_i \times F_{full}$$

and in accordance with paragraph 2.3.1.2. of the rules of calculation :

$$k_i = \left(3 - \frac{2b_i60}{b_o}\right) - \frac{1}{30}\left(1 - \frac{b_i60}{b_o}\right) \times \left(\frac{b_o}{t}\right)$$

$$= \left(3 - \frac{2 \times 6.65}{10.45}\right) - \frac{1}{30}\left(1 - \frac{6.65}{10.45}\right) \times \left(\frac{10.45}{0.15}\right)$$

$$= 3 - 1.273 - \frac{1}{30}(1 - 0.637)(69.7) = 0.884$$

$$F_i = 0.884\,(4 \times 0.51 + 2 \times 0.7)$$

$$= 0.884\,(2.04 + 1.4) = 0.884 \times 3.44 = 3.04 \text{ cm.}$$

Component	Length l cm.	Distance y from top edge cm.	$l \times y$ cm.^{2}	$l \times y^2$ cm.^{3}
1	2 × 1.5 = 3.0	8.1	24.3	197.5
2	4 × 0.51 = 2.04	9.31	19.0	177.3
3	2 × 6.7 = 13.4	9.435	126.3	1197.0
4	2 × 8.7 = 17.4	4.75	82.7	395.0
5	2 × 6.65 = 13.3	0.075	0.1	0.0
6	2 × 0.51 = 1.02	0.19	0.19	0.0
7	Stiffener 3.04	0.75	2.28	1.71
	53.20		254.87	1968.51

Distance of line of zero stress from top edge of section

$$y_o = \frac{254.87}{53.20} = 4.80 \text{ cm.} > 4.75 \text{ cm.} = \frac{h}{2}$$

Thus the assumed edge stress is the one actually occurring.

Calculation of the linear moment of inertia :

Linear moments of inertia relative to the top edge of the section

$$J_1 = 2 \times \frac{1}{12} \times 1.5^3 \qquad = \quad 0.56 \text{ cm}^3$$

$$J_4 = 2 \times \frac{1}{12} \times 8.7^3 \qquad = \quad 110.0 \text{ cm}^3$$

$\Sigma l \times y^2$ from tabular calculation = 1968.51 cm^3

2,079.07 cm^3

Conversion to the neutral axis :

$- l \times y_o^2 = - 53.20 \times 4.80^2$ = 1,229.0 cm^3

Linear moment of inertia J'_x = 850.07 cm^3

Surface moment of inertia :

$$J_x = J'_x \times t = 850.7 \times 0.15 = 127.7 \text{ cm.}^4$$

Moment of resistance :

$$W_x = \frac{J_x}{y_0} \frac{127.7}{4.80} 26.6 \text{ cm}^3.$$

Thus the load-carrying strength, despite the reduction in the height of the section, has been considerably increased by the introduction of a stiffening rib and thus the section has been made more economical.

Paul EIDAMSHAUS

The Application in Practice of the Increase in the Yield Point of Cold-Rolled Sections

(Translated from German)

Mr. Panknin has given us a first-class picture of the implications of the cold work-hardening of steel from the points of view of metallurgy and the mechanical properties of materials, and at the same time outlined the scope for the economic use of cold work hardening. I now propose to consider a few practical examples.

The cold work-hardening process, which has been known for a long time, was not utilized until fairly recently; its deliberate and planned utilization began only fifteen years ago. The cold-drawn wires of suspension-bridge cables and twisted concrete-reinforcing bars were already in use at that time, but with these cold work hardening was presumably not a primary consideration. With wires for cable suspension bridges the most important factor was no doubt the method of manufacture whereby these wires could be produced with the necessary degree of precision; with steel for reinforced concrete, the reinforcing bars were cold-twisted in order to obtain a better bond between the concrete and the steel inserts. Naturally those concerned were happy to benefit in addition from the strengthening resulting from the manufacture of the wires and the twisting of the concrete-reinforcing bars.

The position is different in the examples described below inasmuch as with these cold work-hardening was the main consideration and its economic utilization the primary factor determining the nature of the design.

Increasing the yield point of cold sections was first applied on industrial scale in Germany in 1950 (Biblio. 1). The account given below is concerned with the technical conditions, and some striking examples are given of the developments in this field over the past 15 years.

By far the most important process for the manufacture of cold sections is the rolling of steel strip. Only to cold sections produced by this process can the raising of the yield point be applied in practice.

The process puts certain limits on the dimensions of the sections, these relating to the width of the strip that is to be shaped, the heigth of the section towards the open side, and above all the thickness of the strip. In general the thickness ranges up to 6 mm.—only rarely up to 8. Strip thicker than this is difficult to unwind from the coil.

This restriction in thickness is of the greatest importance—and for the following reasons, which the author can here state only in bare outline:

(1) The thinness of the walls largely excludes the risk of brittle fracture.

(2) It is frequently not the stresses but the degree of deformation—above all phenomena such as crinkling, buckling, etc.—that are critical factors determining the maximum permitted limiting load on thin-walled structural components. This renders still more remote the likelihood of the occurrence of dangerous stresses.

(3) As the material is not very thick, there are no objections to welding these cold-formed sections (see also Mr. Bierett's paper for Working Party IV of this Congress page 515). In practice, the heat introduced during welding has no appreciable effect on the increased yield point.

Cold-rolled sections with deliberately increased yield points are always made in Germany from the so-called structural steels in accordance with the Standard DIN 17100. Depending on the service for which the sections are intended, the unkilled steels St. 37, quality grades 1 and 2, or killed steels St. 37, and St. 52 are used. The normal minimum yield points of

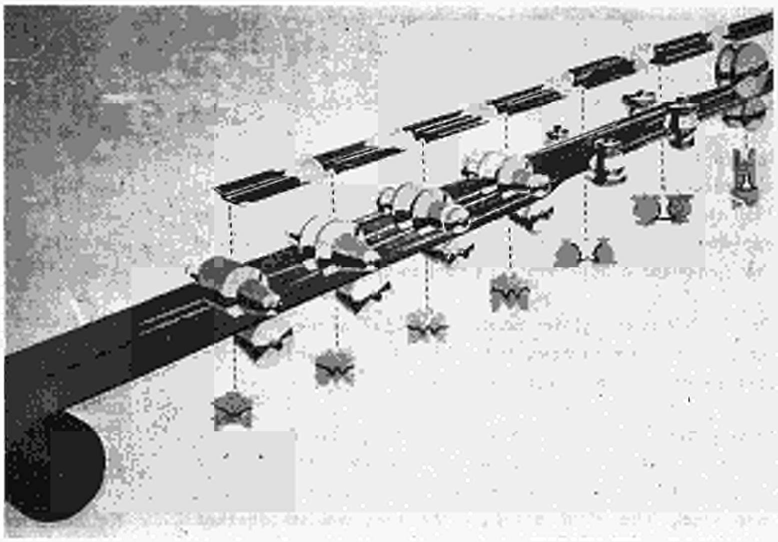


Diagram illustrating the rolling of sections

these materials in the state of unworked strip are:

24 Kg/mm² for St. 37 and
36 Kg/mm² for St. 52.

If no special measures have been adopted in manufacturing the cold sections, the yield point is naturally only increased in the deformed zones. Then only the mean value of the yield point found for the whole cross-section can be allowed for in the strength of calculation and in order to determine this mean value, the section is generally considered as a whole.

This American specifications for calculating thin-walled structural components use this method.

It is possible in Germany by a patented process which is the property of the Author's firm, to guarantee a virtually uniform increase in the yield point over the entire cross-section—and thus not merely in the deformed zone. In the case of cold-rolled sections manufactured by this process, the Bauschinger effect is in practice not measurable (Biblio. 2). In this way the optimum use can be made of the cold-working operation. Unfortunately, the German specifications do not at present make use of this possibility; in such cases it is necessary to obtain the approval of the competent inspection authorities.

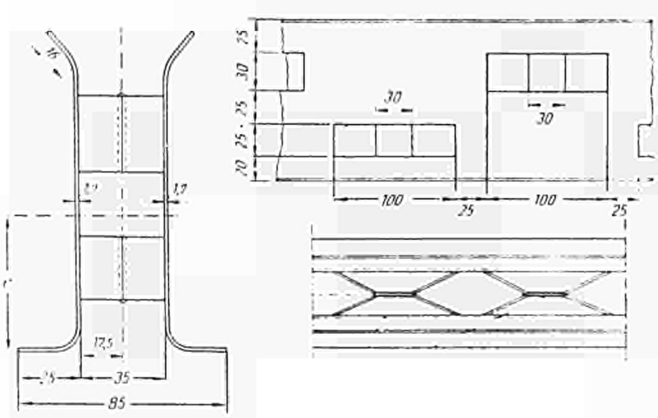
It is necessary to choose between two different possibilities as regards the use made of this process and the choice will depend on the ultimate use:

Either the cross-section is reduced (generally the thickness) in proportion to the increase in the yield point, so making a saving in material or a reduction in weight, or the original cross-section is kept unchanged and a higher-grade steel replaced by one for which the necessary yield point has been produced by cold working, so saving the extra cost for the higher quality.

In principle, the same thing happens in both cases:

Higher stresses can be applied because the yield point is higher as a result of cold working. The yield point is considerably higher than that of unworked material. For instance, the yield point of cold sections of St. 37 can be raised to that of unworked St. 52—that is, to 36 Kg/mm². In addition to the fact that the permitted stresses can be raised, there is the further advantage that St. 37 has better welding properties.

It is clear from what has been said that cold sections of this type will assume great economic importance in the future.



Girder for ceilings assembly (1950 type)

Having described the matter in general terms, let us now take in chronological order four examples of applications that are of special importance and for which all the cold sections were manufactured by the above process.

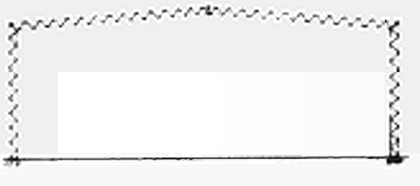
It was at the suggestion of Mr. Klöppel, Darmstadt, who had already previously indicated such a possibility, that in 1950 the increase in the yield point was first exploited by applying it to cold sections (Biblio. 1). The case was that of the girder for a hollow brick (Hohlstein) ceiling.

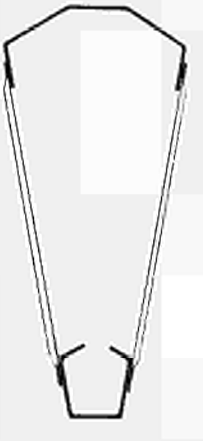
On the left is the girder consisting of two sections; at the top right is the plan view, and at the bottom right is a horizontal section (see the above figure).

This girder, which acts as an erection girder during the laying of the bricks and as a reinforcement for the ceiling after the concreting of the ribs, was made of St. 37-1 strip steel. The yield point of the two welded-together sections is 35 Kg./mm.² (as against the 24 Kg./mm.² of the original material). Later—in order to improve the bond between steel and concrete—the design was modified in such a way that the two sections became respectively the upper and lower chords of a diamod shaped lattice gircer. The cross-section was thus turned through practically 90°. This had no effect on the increase in the yield point.

For details about this and the following examples, the reader is referred to the bibliographic references.

The truss developed in 1954 (see the figure below) was the first application of the principle to high-level structural steelwork (Biblio. 1, 2). The top and bottom chords are cold-rolled sections of St 37-2 with their yield point raised to 37 Kg./mm.². The diagonals were cold pressed and their yield point was likewise raised. Working stresses of 2000 Kg./mm.² are quite in order for sections of chords (as against the 1400 Kg./cm.² permitted for the primary material).



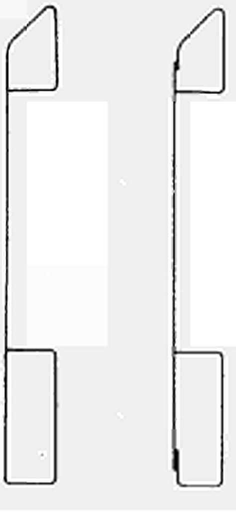


Truss

Consistent use has here been made of the construction potential of cold sections: by joining high-strength sections to a half-closed cross-section with high resistance to torsion, it is possible to dispense with special ties between the trusses and this enables the optimum use to be made of the materials.

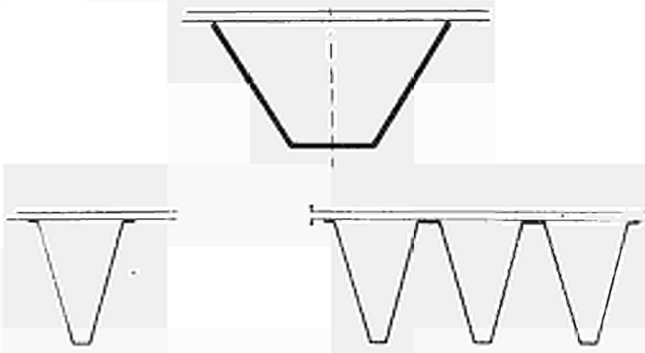
With the approval of the German Federal Railways, in 1958 the first cold-rolled sections of St. 52 with their yield point raised to 42 Kg./mm.² were used for building railway trucks. They form the upper and lower chords of the drop side of a rack truck.

The following figure shows a cross-section of this drop side. According to the original design it was to have been in only two parts (Biblio. 3). In order to lower the cost of production, the section was made in three parts—two cold sections and a flat plate—and in this way it was possible to exploit the increase in the yield point.



Drop side for goods truck of German Federal Railways

Cold sections with increased yield point were first used as load-carrying components in bridges in 1962. The longitudinal ribs of the "orthotropic" roadway of a road bridge in the Hamburg area were made of cold sections of St 37-3 with the yield point raised to 38 Kg./mm.² at the centre; however, at no point in the profile was the yield point permitted to be less than 36 Kg./mm.². Also, there has to be a guaranteed minimum breaking elongation of 20%.



Longitudinal ribs-sections for "orthotropic" roadway plates

The upper part of the figure above shows the profile of these longitudinal ribs. Because of the high calculated stresses, it was originally intended to use flanged profiles of St 52. The advantages were, firstly, the saving in the costs one pays for quality, and secondly the weldability of St 37.

A report on this application had already been made in the previous Steel Congress here in Luxemburg (Biblio. 4).

Summary

Increasing the yield point of cold sections by cold working in the process of section-rolling is one of the main ways in which steel structures can be made less costly—particularly if by a special process the yield can be made uniform at every point in the cold section. The advantages of the increased yield point then became effective as follows:

(a) In the case of profiles in tension—directly and fully.

(b) In the case of profiles under compression whose critical buckling stress is in the plastic zone.

(c) In the case of structural components under bending stress, in so far as the permitted degree of deformation is not exceeded.

Properly applied, increasing the yield point of cold sections therefore offers a good opportunity of improving the competitive position of steel *vis-a-vis* other materials.

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2 Jungbluth: Cold-hardening. A Method of Improving the Economy of Steel Construction Work. Kloppel Festschrift, Cologne 1961.

3 Eidamshaus: Cold Section as Structural Components: a means to economical construction Industrie-Anzeiger, Essen 1964.

R. TRICOT

Improving the Yield Point of Austenitic Stainless Steels by Cold Working

(Translated from French)

The austenitic stainless steels of the chromium-nickel type, sometimes containing smaller amounts of other elements and of which the most widely known is the 18/8 quality, combine a number of particularly valuable properties including high resistance to corrosion and scaling, and excellent ductility which facilitates processing. They are consequently used in the manufacture of equipment requiring steels with particular mechanical properties. The yield point, an essential factor in calculating strength, is relatively lower for these steels (20-30 kg./mm.^{2}) than for martensitic or ferritic steels. It is, therefore, necessary to increase the wall thickness, for example, of boilers pressure vessels and the like, although no advantage is derived from this extra thickness as regards corrosion resistance because these steels already have a high resistance to corrosion. One may well therefore, make the following point: although the austenitic stainless steels used for structural purposes have given every satisfaction up to now,this does not necessarily mean that the best use has been made of them, technically or economically.

Mechanical behaviour of austenitic stainless steels

First, we must consider the reasons why austenitic stainless steels must not be examined in the same way as ferritic steels. The methods of calculating the strength of materials rest on fundamental hypotheses on which the general theory of elasticity is based. These methods are entirely satisfactory as regards safety in the case of ferritic steels. The fact that a new material such as austenitic stainless steel does not fit these hypothese raises precisely the question of how to combine economy with safety. In fact, it is not so much a matter of modifying methods of calculation but of giving the symbols their true practical values.

In ferritic steels, the plastic region is not taken into account for the following two basic reasons:

(a) as a *safety limit*; indeed the shape of the tensile curves is frequently typified by

 (i) a yield point not far removed from the tensile stength (maximum stress);

 (ii) a sudden transition from the elastic to the plastic region (yield point arrest);

 (iii) a generally lower ductility than that of austenitic structure and a much more pronounced notch sensitivity (brittle fracture).

(b) as a *dimensional factor* in mechanical operations; it is conceivable that a dimensional variation in stress exceeding, for instance, 0.5%, cannot be tolerated in certain parts such as gears or a rotor.

On the other hand, with austenitic stainless steels

 (i) the yield point is much further removed from the maximum stress;

 (ii) there is a gradual transition from what is thought to be the elastic region to the plastic region;

 (iii) there is considerable cold work-hardening of the metal;

 (iv) because of the greater number of slip planes in the austenitic structure, the evenly distributed elongations and the elongations to rupture are very high;

 (v) there is no brittle fracture even at very low temperature;

 (vi) finally, in many structures such as boilers and pressure vessels, slight dimensional variations can be tolerated.

The high ductility of austenitic stainless steels gives to some extent the lie to a number of some conclusions which might be drawn from the conventional tensile diagram. It is more profitable to compare the theoretic tensile curves in which the true stress $R' = F/S$ transmitted to the true section at any given instant S is plotted as a function of the theoretic deformation $A' = \text{Log.}S_o/S$. This type of representation does, of course, have the advantage of freeing the tensile test from geometrical considerations; the area subtended represents the actual work of deformation absorbed per unit of volume and the compression curve can very often be superimposed on the tensile curve for ductile materials. The figure below shows the conventional and theoretical tensile curves for a steel containing 0·35% carbon perfectly annealed according to Houdremont (Biblio. 1).

A comparison has been made in the following figure of the theoretical curves for this same steel and for an annealed mild steel according to MacGregor (Biblio. 2), three austenitic stainless steels hyperquenched of the 302, 304 and 316 types, according to de Sisto and Carr (Biblio. 3) and a lower nickel austenitic steel (Biblio. 4).

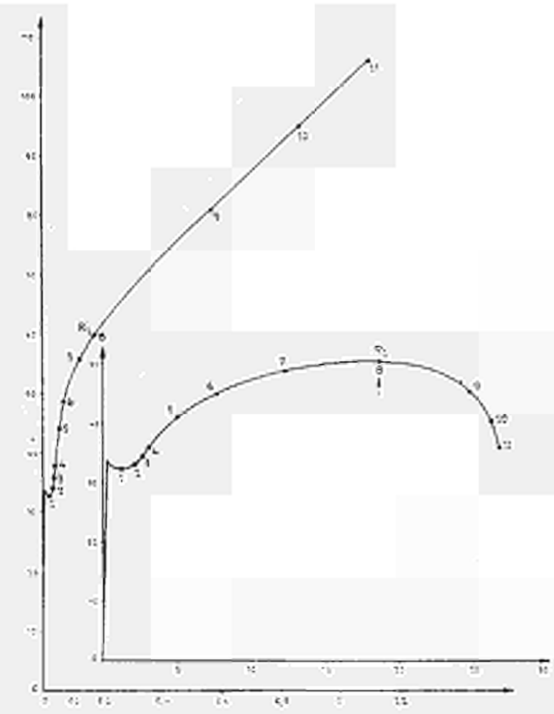
It will be noticed that

(a) the effect of cold work-hardening is much more pronounced with the austenitic stainless steels than in the case of

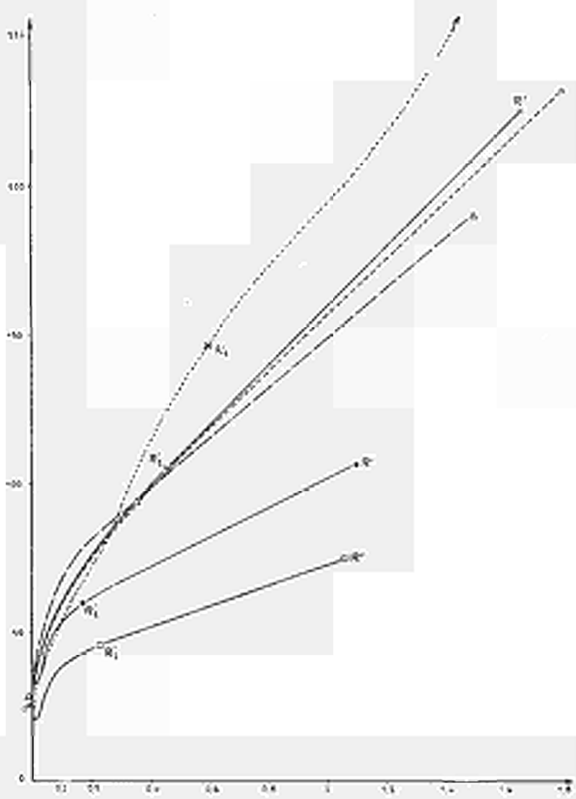
Rational stress-strain

Conventional stress-strain

Annealed 0·35%C steel



18% Cr, 8% Ni Inox
Austenitic Inox 304 (18% Cr, 9·6% Ni)
Austenitic Inox 302 (18% Cr, 9% Ni)
Austenitic Inox 316 (18% Cr, 13% Ni, 2% Mo)
Mild annealed steel (0·35%C (after Hondremont)
Mild annealed steel (after McGregor)



Comparison between the rational stress-strain curves at 20°

the ordinary steels; also that this work-hardening effect is even more pronounced with the unstable austenites containing 7 to 8% nickel (curves 6, in the above figure) because it is a result simultaneously of the work-hardening of the austenite, the partial or total transformation of the austenite to martensite and of the cold work-hardening of the martensite.

(b) the ratios of the resistance to deformation R′, or of the true maximum stress R′ to the yield point are about 2 to 3 times higher than those associated with the ordinary steels;

(c) The uniformly distributed elongation before reduction of area (A 1%) is also much higher in the austenitic material.

	Eo,2 kg./mm.²	Maxima of the conventional stress (before reduction of area)			At rupture					
		R_1	R'_1	A_1%	R'	A%	%	$\frac{R_1}{E}$	$\frac{R'_1}{E}$	$\frac{R'}{E}$
Annealed mild steel (2)	20	36	45	25·5	74	30	66	1·8	2·2	3·7
Steel containing 0·35% C annealed (1)	32	50	60	18·5	106	27	66	1·5	1·9	3·3
302 (Z 6 CN 18- 9) (3)	25	66	105	58	225	75	80·7	2·6	4·2	9
304 (Z 6 CN 18-10) (3)	24	67	108	61	232	47	83·4	2·8	4·5	9·6
316 (Z CND 18-13) (3)	28	66	94	43	189·5	65	77·5	2·4	3·4	6·8
Z 6 CN 18-8 (4)	25	80	148	66	310	70	78	3·2	5·9	12·4

(R_1 conventional tensil strength in kg./mm.²)

Thus, the utilization of austenitic stainless steels should be based solely on deformation and rupture factors.

Yield point of austenitic stainless steels and the use of prestressing

The difficulties which are encountered in determining the 0·2% proof stress for austenitic steels which have not been subjected to any mechanical stressing after hyperquenching are due to

(a) the absence, in certain cases, of a rectilinear section at the beginning of the tensile curve when a high amplification extensometer is used;

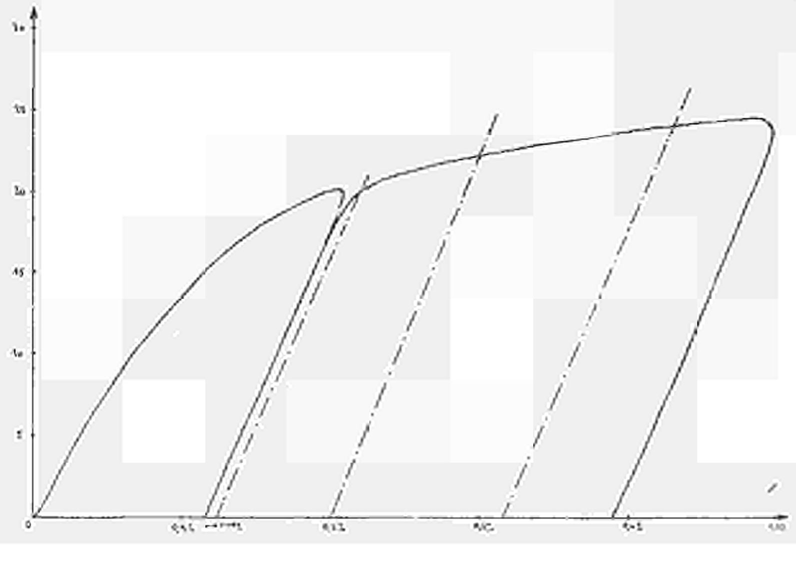
(b) a certain amount of creep of the metal at room temperature in the case of a fully hyperquenched specimen before the load is applied;

(c) the influence of the characteristics of the testing machines and of operational conditions (rate at which the stress is applied or the rate of strain).

It would take too long here to discuss these various phenomena.

In practice, the metal can undergo a certain amount of mechanical stressing between the hyperquench treatment and the commissioning of the equipment. This happens, for instance, in the case of sheets which generally undergo a slight amount of cold work-hardening by means of a skin-pass (about 1%), temper rolling or levelling. In the same way, the forming of the shell plate and the testing pressure used in the pressure testing of boilers cause a slight amount of cold work-hardening which does not however affect the ductility of the metal.

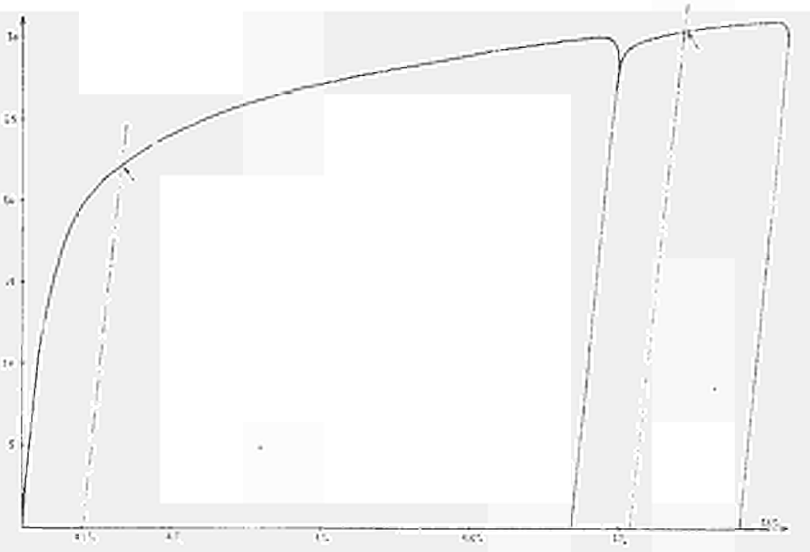
The figures below show the behaviour of a perfectly hyperquenched specimen of Z 6 CN 18-10 after prestressing at 20 kg.²mm.² (figure on p. 497) or 30 kg./mm.² (figure on p. 498) giving an 0·2% proof stress at 22·2 kg./mm.². The stress of 20 kg./mm.² in the figure produces a permanent set



Stainless steel: Z 6 CN 18-10

Stress-strain diagram: 20 kg./mm.² prestress

Austenitic stainless steels Z 6 CN 18-10



Stress-strain diagram: 30 kg./mm.² prestress

of 0·116%. If this same specimen is subjected to a renewed tensile stress, the diagram will include a long rectilinear portion corresponding to the elastic region and the stress of 20 kg./mm.² will produce only a negligible permanent set of 0·008%. The metal thus acquires a new yield point which is only slightly lower than the initial prestressing, and below this limit it correctly obeys Hooke's law. The differences in permanent set would be still less if the prestressing were to exceed the maximum working stress by 10 to 20%.

This result is extremely important because

(1) it is possible to apply classic calculation methods to the elastic region;

(2) vessels which are subjected to an internal pressure are generally tested under a stress which is definitely higher than the service pressure and the elastic properties of the material are thus improved. It stands to reason, therefore, that the tensile specimen should be prestressed under test to ascertain the actual behaviour of the material.

Cold Work-hardening

Various metallurgical phenomena can contribute to an increase in the yield point of an entirely austenitic structure. These include

(1) hardening of the solid solution, for example, by the addition of nitrogen;

(2) precipitation hardening used particularly in the case of creep-resisting steels and very high property performance steels.

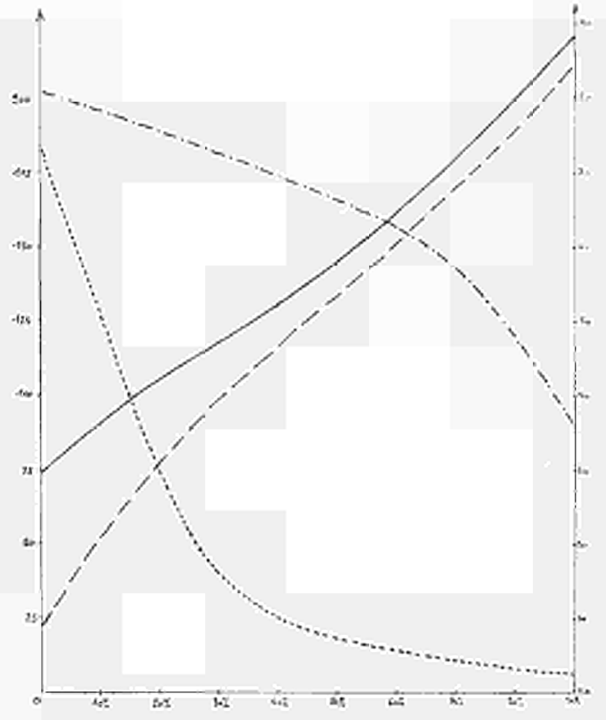
(3) the part played by the grain boundaries which inhibit deformation by means of slip (for instance, wire of less than 0·1 mm diameter in which the grains are extremely minute);

(4) cold work-hardening when the pastically deformed matrix network reduces the possibilities of slip by inhibiting the displacement of the dislocations.

This last method is particularly interesting in the case of the austenitic stainless steels which have excellent ductility and work-hardening properties. The cold work hardening of these steels produces a much greater degree of hardening than is possible with ordinary steels for the same rate of deformation:

Rate of work hardening	Mild steel		Inox 304 18% Cr 10% Ni	
	T.S. kg./mm.²	Y.P. kg./mm.²	T.S.	Y.P.
0	38	20	63	25
50%	60	53	115	102

This considerable hardening of the stable austenites can be still further increased in the case of the unstable austenites with a low nickel content (7 to 9%) which are transformed partially or totally to close-grained martensite. These phenomena can be amplified by working at a temperature lower than room temperature (— 70° to — 196° C) either by rolling (zerolling) or by pressure forming (hardforming). The hardening of the martensitic transformation can be further completed by the effects of a final tempering at about 400 °C.



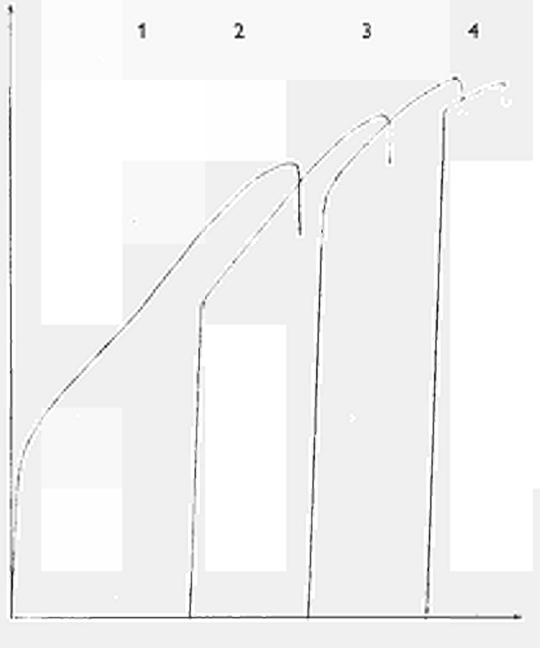
Cold-drawing curve: drawing of Z 6 CN 18-8 wires

The figure above shows an example of a work-hardening curve obtained by wire drawing Z 6 CN 18-8 material at room temperature (Biblio. 4). With increasing rates of work hardening, it will be seen, generally, that the properties associated with resistance to deformation increase rapidly (yield point, maximum stress) while the properties characterizing ductility (elongation at rupture, reduction of area) diminish.

It should be noted that work-hardening of a metal cannot be defined unequivocally because it depends not only on the type of deformation used to work-harden the metal but also on the direction of future stressing by which it will be sought to be defined.

Two main fields of application appear in this (see the above figure):

(a) The region of 0-30% of work-hardening where the yield point rises rapidly while the metal preserves a completely adequate ductility for safety as will be seen from the recorded tensile curves in the figure below. A well-known application is the construction of railway carriages: the use of an austenitic stainless steel work-hardened to give a tensile strength



1. Superhardened state 1050°
2. 8% cold-drawn wire
3. 16,5% cold-drawn wire
4. 24,5% cold-drawn wire

Some conventional stress-strain curves for superhardened cold-drawn wires (Austenitic stainless steel C = 0·63%; Ni = 8·1%, Cr = 18·1%)

of 105 kg./mm.², a yield point of 77 kg./mm.², an elongation of 18% min, has the following advantages:

(i) a saving due to the light-weight construction of the vehicle;

(ii) a saving in maintenance costs because painting is dispensed with;

(iii) good fatigue resistance (which increases with the rate of work-hardening) and good impact strength (absence of embrittlement at low temperatures);

(iv) easy forming and welding.

(b) The region of high work-hardening rates (over 75%) which allows very high working temperatures. An example of this is austenitic stainless steel springs subjected to a high rate of work-hardening.

Effect of work-hardening on service properties

Without going into too much detail regarding the developments which have taken place, various studies have shown that the fatigue limit increases with the rate of work-hardening and that the impact strength of an austenitic stainless steel, work-hardened, for instance, by 20%, are completely maintained down to a temperature of 196° C and lower (absence of transition temperature and brittle fracture).

The work-hardened sheets can be easily formed by bending. The machinability of an austenitic stainless steel which has been work-hardened is also improved.

Finally, the welding of work-hardened materials does not give rise to any problems. A recent study by Messrs. Castro and de Cadenet (Biblio. 5) showed that specimens which include a weld have a maximum stress and a yield point which are equal to, or higher than those of work-hardened sheets which have not been welded. The joint coefficient of the 0·2% proof stress remains therefore higher than, or equal to unity over a wide range of yield point.

Conclusion

This brief examination shows that the calculation of structures in austenitic stainless steel must be based on the actual behaviour of these steels. It has been seen that an austenitic stainless steel which has been subjected to a degree of prestressing N behaves essentially in an elastic manner under all stresses lower than N. Moreover, the good ductile and work-hardening properties of this material mean that work-hardening can be utilized to provide a very varied range of mechanical properties.

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Some Technological Aspects of Rolling Sheet and Tinplate on 5-Stand Tandem Cold-Reduction Mills in the Light of Operational Measurements

Due to the intense development of many branches of industry higher and higher requirements according to mechanical properties, surface quality and also accuracy and thinner gauge of cold rolled sheet and strip, are demanded. It is significant that the sheet and tinplate consumers' ever increasing demands have greatly influenced the design of modern hot and cold strip mills. Sheet and tinplate producers are fulfilling these requirements by introducing correspondingly improved designs in new rolling mills, and also by modernization and carrying out technological investigations of the hot and cold rolling process to improve production quality in mills just operating.

The rapid development of 5-stand tandem cold-reduction mills has been strongly influenced by the specially intense development of the can industry. Some years ago 0·28 mm. (100 lb/bb) was regarded as a typical thickness of tinplate, but there is a trend in the United States to produce very thin tinplate of a gauge of 40 lbs/bb in average, i.e. 0·116 mm. (Biblio. 1). It has been found that typical 5-stand tandem mills, specially designed for rolling of tinplate, are insufficient for rolling of very thin gauges. It was endeavoured to solve this problem by applying 6-stand tandem mills (Biblio. 2), combining the 5-stand tandem mill with a second reduction on a 3-stand tandem mill after annealing (Biblio. 3), and also the use of a 2-stand tandem mill for second reduction or temper rolling.

The demand for thinner tinplate is also to be found in Poland. It is apparent that in spite of theoretical possibilities of rolling very thin tinplate there are considerable difficulties in achieving this under operational conditions. Each decreasing of the final thickness of the sheet or tinplate being rolled must be preceded by corresponding operational undertakings, and is usually connected with great effort. It is necessary to carry out trials of the behaviour of technological and electrical parameters, when introducing any change in the technology of rolling, and to work out optimum rolling conditions for the given rolling programme. Until now the most credible method of investigation of rolling parameters has been direct measurements carried out under normal operational conditions of the mill.

Technological investigations carried out on the existing tandem mills concern determination of optimum properties of hot rolled initial material, working out of optimum technology of cold rolling, annealing and temper rolling.

The purpose of this paper is to discuss some results of investigations carried out in this direction in Poland on the 5-stand tandem cold-reduction mill of Lenin-Steelworks. The results are based on operational measurements of the most important technological and electrical parameters of that mill, and the purpose of these investigations was to determine optimum properties and shape of hot rolled strip, and also to analyse the technology of cold rolling and roll crowning based on operational measurements.

Discussion on published references

It is not an easy task to work out optimum cold rolling schedules for tandem cold-reduction mills, and great practical experience and theoretical preparatory studies are necessary. Various rolling schedules are therefore used on different rolling mills, and based on practical experience these schedules are being continuously improved. As an example of such improvement the discussion which appeared in the Soviet journal *Mietallurg*, in 1961-62 should be mentioned.

Two rolling schedules are there discussed by Lejtshenko (Biblio. 4). According to the visit of Soviet specialists to Great Britain the table below gives the rolling schedule used at Trostre and Velindre Steelworks, as a typical schedule applied in British and American 5-stand tandem cold-reduction mills. This schedule is compared with that applied at the Magnitogorsk-Steelworks.

Comparison of rolling schedules of the 5-stand tandem mill of Trostre-Velindre and Magnitogorsk, according to Lejtshenko

No.		Parameters	I stand	II stand	III stand	IV stand	V stand	Remarks
I	1	Thickness h_0 (mm.)	2·25					Trostre-Velindre
	2	h_1 (mm.)	2·0	1·08	0·67	0·43	0·25	
	3	Δh (mm.)	0·25	0·92	0·41	0·24	0·18	
	4	ε (%)	11·0	45·0	39·0	36·0	42·0	
	5	ε_t (%)	11·0	52·0	70·0	81·0	89·0	
II	1	h_0 (mm.)	2·2					MMK
	2	h_1 (mm.)	1·2	0·63	0·40	0·28	0·25	
	3	Δh (mm.)	1·0	0·57	0·23	0·12	0·30	
	4	ε (%)	45·5	47·5	35·6	30·0	10·7	
	5	ε_t (%)	45·5	71·4	81·8	87·3	88·7	

It will be seen, that the smallest possible reductions are used in the first schedule (11%), and maximum ones in the last stand. The purpose of that schedule was to obtain a strip of corresponding shape and final thickness for minimum wastage of material. There is a considerable difference between this schedule and the Soviet one, which basically is the maximum utilization of plasticity of the tinplate being rolled in the first stand (45·5%), and rather small reduction per pass in the last stand (10·7%). Operational results have shown that considerable difficulties occur when applying this schedule, due to numerous strip breaks between stands.

Lejtshenko recommends the use of the first schedule in the table above, using additionally a camber of 0·04 mm. for work rolls of stand I and II, by cylindrical rolls in stands III, IV, and V.

The rolling schedules discussed by Lejtshenko have been attacked by Bieniakovski and Volegov (Biblio. 5) from the Ural Iron and Steel Institute. They confirm it is impossible to apply the rolling schedule proposed by Lejtshenko, as it is not based on the rule of equal strip elongation along the width in each of the stands. Additionally, there is a lack of thermal conditions for that schedule. According to biblio. ref. 6-8, (see table below) this schedule is not a typical one. Bieniakovski finds that a reduction of 11% in the first stand will cause a double concave shape of the strip, which in turn will result in the formation of ridges at the strip centre.

Rolling schedules used on British and American tandem rolling mills

No.		Parameters	I stand	II stand	III stand	IV stand	V stand	Remarks
I	1	Thickness h_0 (mm.)	2·25					according to Powell and Kaufmann (5)
	2	h_1 (mm.)	2·0	1·08	0·67	0·43	0·25	
	3	Δh (mm.)	0·25	0·92	0·41	0·24	0·18	
	4	ε (%)	11·0	45·0	39·0	36·0	42·0	
	5	ε_t (%)	11·0	52·0	70·0	81·0	89·0	
II	1	h_0 (mm.)	2·12					according to Polakowski (6)
	2	h_1 (mm.)	1·65	0·95	0·49	0·35	0·25	
	3	Δh (mm.)	0·47	0·70	0·46	0·14	0·10	
	4	ε (%)	22·0	42·5	48·5	28·5	28·5	
	5	ε_t (%)	22·0	55·0	77·0	83·5	88·5	
III	1	h_0 (mm.)	1·9					according to Archibald (7)
	2	h_1 (mm.)	1·5	1·0	0·58	0·38	0·25	
	3	Δh (mm.)	0·40	0·50	0·42	0·20	0·13	
	4	ε (%)	19	33	40	33	33	
	5	ε_t (%)		47·3	69·6	80·0	77·0	

Based on the rule of equal elongation along width of the strip being rolled, a rolling schedule has been devised for the Magnitogorsk 5-stand tandem mill.

Faisulin and Shubin (Biblio. 9) describe the development of rolling schedules at the Magnitogorsk 5-stand tandem mill.

Some rolling schedules used on American 5-stand tandem mills are also given by Stone (Biblio. 1).

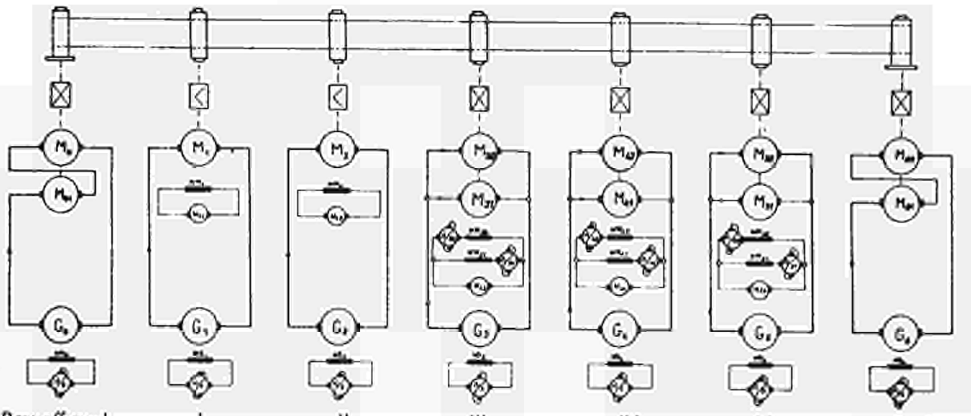
Several experiments have been made to combine rolling schedules on tandem mills concerning crowning of work and back-up rolls. Some methods of roll crowning are given in the tables.

Recent Soviet data have shown (Biblio. 10) that several advantages are achieved when using bevelled back-up rolls.

The present state of development on design and technology of rolling on modern tandem cold-reduction mills has been discussed extensively by Billigmann and Lenze (Biblio. 11). As far as rolling schedules are concerned results of long-term experiences in American tandem mills are given, which confirm the advantages of using minimum percentage reduction in the first stand, and maximum in the last one.

Rolling schedules used on the Magnitogonsk tandem mill.

No.	Parameters		I stand	II stand	III stand	IV stand	V stand
A	Thickness	h_1 (mm.)	1·10	0·65	0·45	0·32	0·28
	Reduction	ε (%)	45	41	31	29	12
	Total reduction	ε_t (%)	45	67·5	77·5	84	86
	Strip tension	T (t)	20	10	8	4	—
	Roll camber of the top work roll	(mm.)	0·16	0·10	0·10	0·10	0·05
B	Thickness	h_1 (mm.)	1·40	0·85	0·55	0·35	0·28
	Reduction	ε (%)	36	30	35	36	20
	Total reduction	ε_t (%)	36	6·15	75	84	87·3
	Strip tension	T (t)	10	10	8	4	—
	Roll camber of the top work roll	(mm.)	0·10	0·10	0·10	0·10	0·10
C	Thickness	h_1 (mm.)	1·60	1·07	0·62	0·42	0·28
	Reduction	ε (%)	27	33	42	32	33
	Total reduction	ε_t (%)	27	51·4	71·8	81	87·3
	Strip tension	T (t)	12-14	8-10	6-8	3-4	—
	Roll camber of the top work roll	(mm.)	0·10	0·10	0·10	0·10	0·12



Lay-out of the 5-stand tandem mill

Personal investigations

The investigations carried out have included

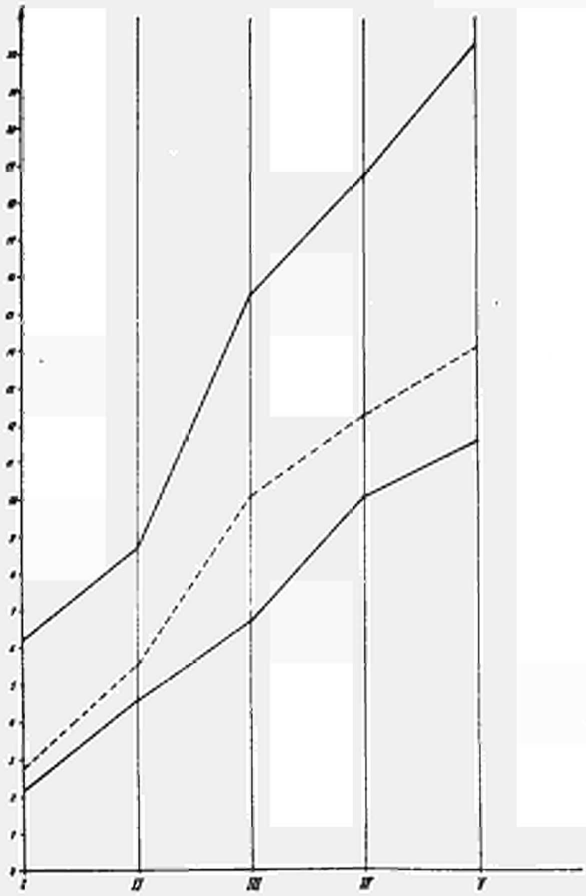
(a) testing of the initial hot rolled strip to determine its optimum properties;

(b) operational measurement of the most important technological parameters (roll force, reduction per pass, rolling speed, strip tension, temperature distribution along roll barrel) and electrical ones (loading of the main drive and reel motors) for the total rolling programme of the 5-stand tandem mill being investigated,

(c) analysis of the applied rolling schedules, and testing the the possibility of rolling thinner gauge tinplate than produced at present.

Description of the rolling mill investigated

Investigations were carried out on the 5-stand tandem mill which rolls initial hot rolled strip of 1·80 to 2·50 mm. down to tinplate and galvanized sheet within 0·24 to 0·70 mm. thick, and 790 to 1020 mm. wide. This mill was put into operation in 1956, and is of Soviet design. When tinplate is rolled a mixture of palm oil and water is used for lubrication and cooling, and when rolling galvanized sheet a recirculating soluble oil is used. It is of 400 mm. in diameter work rolls, and 1300 mm. back-up rolls by a barrel length of 1200 mm. The back-up bearings are of Morgoil type. The total power of the main drive motors, pay-off reel, and reel equals 16860 kW. The above figure gives the simpfiled lay-out of the drive system of the tandem mill: Stands I and II are driven through a pinion stand, and twin-drive is used for stands III up to V. The pay-off reel is driven by two d.c. motors connected in series, of a total power of 160 kW, whereas the total power of the reel is 1100 kW. The figure below gives the speed-cone of the tandem mill, and it can be seen that the maximum rolling speed equals 22·5 m./sec.



Speed cone for the 5-stand cold reduction mill being investigated

Measurement of technological and electrical parameters

During operational measurements the following parameters were measured and recorded:

(a) Roll force of all the stands, P_1-P_5;

(b) Strip tension between all the stands, T_1-T_4;

(c) Current of main motors, I_1-I_5,/ in stands III to V current of the bottom motor only were measured;

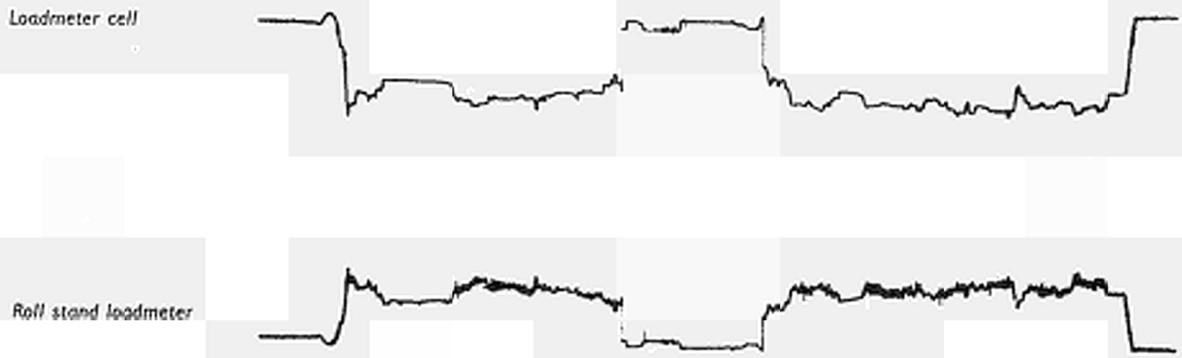
(d) Number of revolutions, and current of the reel motor, n_1, n_5;

(e) Number of revolutions of main motors, n_1-n_5;

(f) Strip thickness after the last stand.

Strip thickness after each stand, together with temperature distribution along roll barrel, were also measured.

Measurements for the total rolling programme of the tandem mill were carried out in two series. Due to the lack of recording channels the number of revolutions and loading of the reel motor were not measured during the first series of measurements.



Calibration of the roll stand loadmeter

As a first step, and to reduce preparations necessary for the measurements, it was decided to use roll stand loadmeters instead of loadmeter cells. Both types of loadmeters were therefore, mounted on stand IV, and their indications recorded. The recordings obtained are shown in the figure above and a high conformity can be seen. Roll stand loadmeters were used for measuring roll load in the first series. These loadmeters are of electrical resistance gauge type forced to elongation, and mounted on the roll housing. Long-term operational measurements however, have shown a considerable variation of zero of the roll stand loadmeters probably due to thermal deformation of roll housings. Electrical gauge type loadmeter cells were used for measuring the roll load. For power supply and amplification of signal from the loadmeters, amplifiers of the KWS II/45-type were used.

For measuring the strip tension existing on the mill, 3-roll tensionmeters were used. There is a magneto-elastic loadmeter cell mounted below the middle roll, and the value of strip tension is indicated by a micro-ammeter.

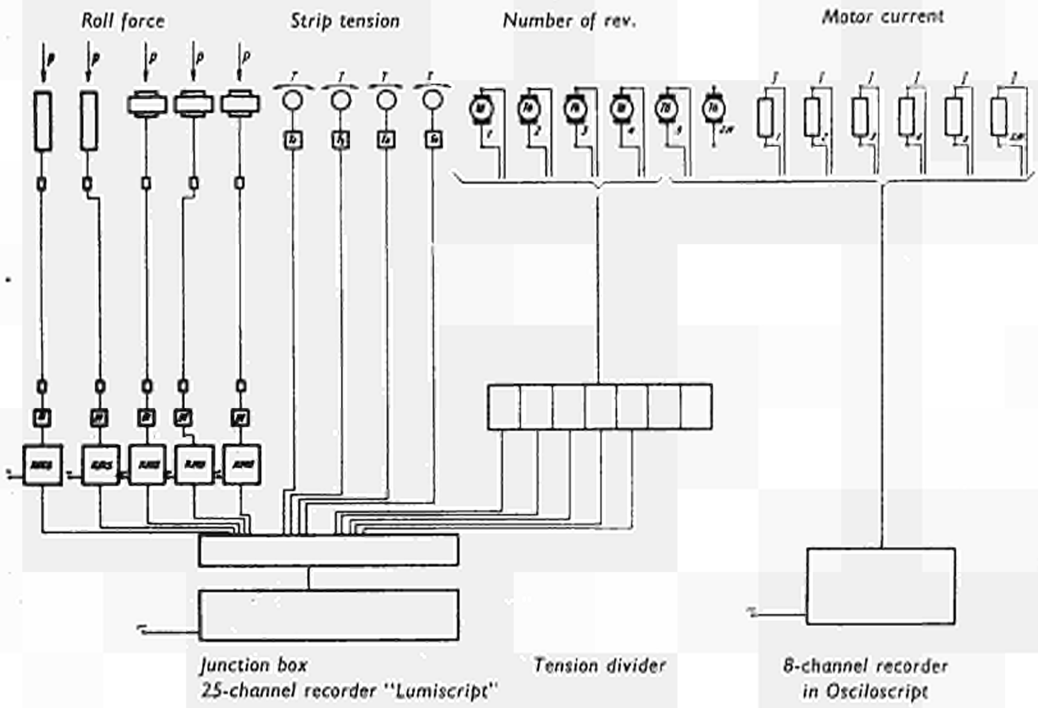
For measuring the rolling strip speed the existing tachogenerators were used and these were driven by the main motors. A special tachogenerator was installed for measuring the number of revolutions of the reel motor.

The loading of the main drive was calculated by measuring the current of the armeture of the main drive and reel motors, and as sensor of motor current the existing shunts were used.

During the first series of measurements as many as four different recorders were used which in turn considerably influenced the data processing.

A more advantageous situation developed during the second series of measurement due to the installation of a 25-channel light-beam oscillograph of Lumiscript-type. The general measuring lay-out is shown in the following figure. It can be seen from this figure that during the second series of measurements the number of recorders has been reduced to two. The total number of measured and recorded parameters amounted 22, and it should be mentioned that this was the first complex operational measurement carried out in Polish rolling plants.

The thickness of hot rolled strip was measured for all the coils. The final thickness of cold-reduced strip was measured



Schema of connexion during II series measurement

and recorded continuously by means of a radioactive gaugemeter. It was difficult to measure the current strip gauge between all the stands as measurements were carried out under normal operational conditions of the mill. Therefore, strip gauge were measured for each third or forth coil, only, as after rapid breaking from the operational rolling speed, as also for the threading speed.

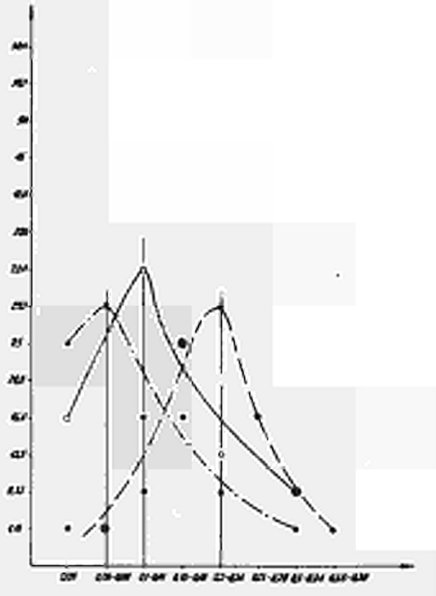
The temperature distribution along the roll barrel was measured by means of a termistor contact thermometer (range 0 up to 210° C). Along the barrel of each roll 5 to 13 measurements were made, i.e., for one stand the number of measurements amounted to 20 to 52. While measuring the roll temperature that of the coil being rolled was also measured. To check the continuous increase of temperature, measurements were made for idle rolling conditions, after rolling two or three coils, and for steady state conditions.

Quality control of the hot rolled strip

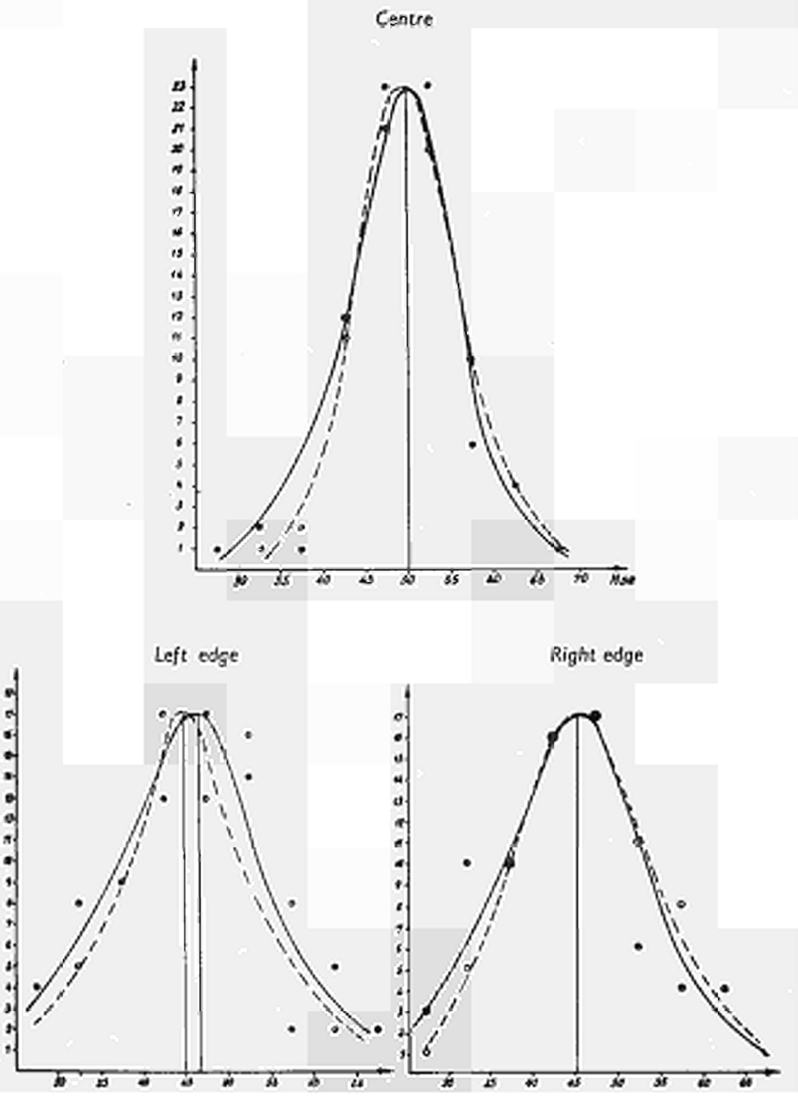
It is known from the rolling practice that the quality of cold rolled tinplate and sheet is influenced by that of the hot rolled initial material. Special efforts were therefore made to determine all possible properties of the hot rolled strip, which in the next slip will be cold-rolled. Specimens were taken from the head, centre, and tail of each hot rolled coil. These specimens were taken at the gui llotine shear before welding in the continuous pickling line. Metallographic, mechanical and dimensional tests have been carried out, and the results obtained were processed, using statistical methods.

Special attention has been paid to hot rolled strip for tin-plate, as some problems developed with cold rolling of tin-plate one of which was the problem of ridges.

Thickness variation between:
——— coil head and tail
— . — coil head and centre
— — coil tail and centre



Distribution of thickness variations between head, centre and tail of hot-rolled coil



Distribution of hardness of hot-rolled strip

The figure gives the thickness variation between head, centre, and tail of hot rolled coils. It can be seen from this figure that the distribution of thickness variation of strip caused by temperature drop during hot rolling, and also by variation of tension between the finishing stand and down coiler, is of a form similar to the normal distribution. The most frequently occurring thickness variation between coil head and centre amounted 0·05 to 0·09 mm., between coil head and centre 0·10 to 0·14 mm., and between coil tail and centre 0·20 to 0·24 mm. Convex cross-sections of hot rolled strip were mostly confirmed, and the convex camber of strip was within 0·016 to 0·025 mm. for coil centre and tail, and within 0·026 to 0·035 mm. for coil head. Some wedge-type cross-sections have also been confirmed.

Among mechanical properties the distribution of yield point, tensile stress, elongation and hardness of hot rolled strip were tested. The distribution of hardness is shown in the figure above. For some coils, and it can be seen that the most frequently occurring strip hardness at coil centre is 50 H_{SR}, whereas that of the strip edge 45 H_{SR} .

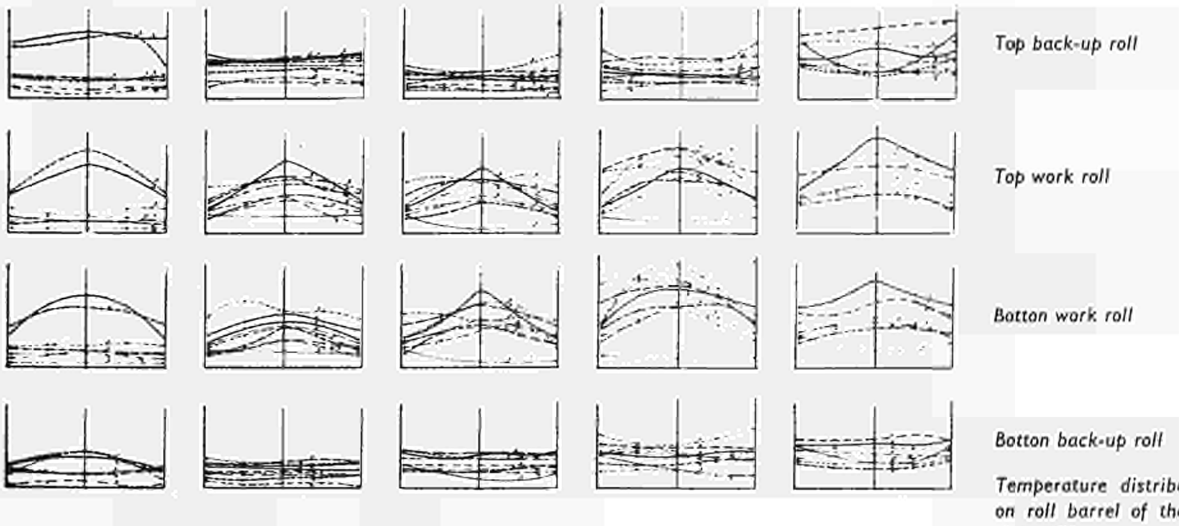
The behaviour of hot rolled strip has been carefully tested during cold rolling and temper rolling. It has been found that the most suitable shape of hot rolled strip for cold rolling is the slightly convex one, and this conclusion corresponds to the experience of other mills (Biblio. 12).

The purpose of the metallurgical tests was to check non-metallic inclusions and structure quality of hot strip, and results obtained will not be discussed here.

Based on results obtained, new reception conditions for hot rolled strip have been worked out within the steelworks. These conditions less down stringent requirements with regard to the permissible wedge-form, and telescope of hot rolled strip.

The problem of roll crowning

As far as roll crowning is concerned the tandem mill investigated showed that many problems still have to be solved. Ridge problems have occurred due to incorrect roll crowning and an additional complicating factor was the small diameter of the work roll of only 400 mm. resulting in difficulties with thermal crowning of rolls. As a wide production programme for the tandem mill is foreseen, the proposed system of roll crowning must be an almost universal one. The solutions of this problem were based on practical experience and theoretical analysis, supported by the necessary operational measurements. It was necessary to check the temperature distribution along roll barrel, and roll deflexion due to roll loading. It is rather troublesome to determine the temperature distribution along roll barrel, as until now there has been a lack of thermometers allowing for continuous measuring and recording under normal cooling conditions. Our possibilities were very limited; nevertheless, using the contact thermometer a number of measurements of temperature distribution were made for the tandem mill being investigated. The figure below gives results of one series of measurements, and it can be seen from this figure that the temperature is unequally distributed along the barrel of separate rolls and stands. The theoretical parabolic character does not always occur. Based on these measurements the mean temperature differences have been calculated, which should be taken into account when analyzing the roll crowning.



Temperature distribution on roll barrel of the tandem mill

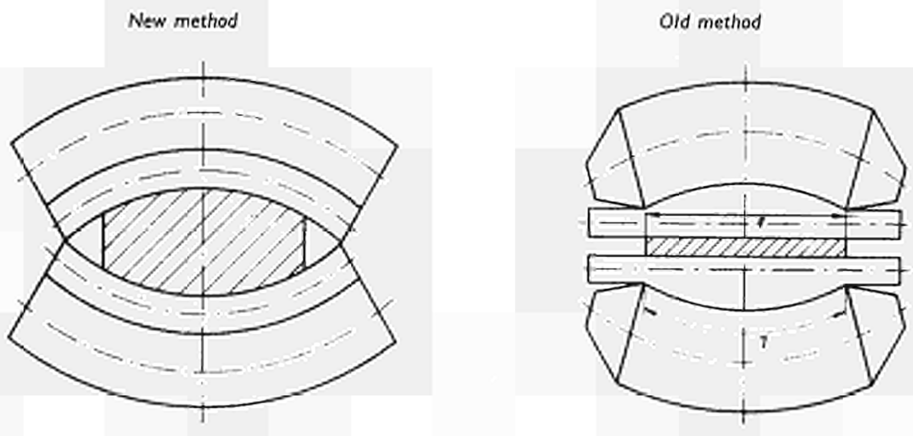
Based on roll deflexion being considered as a supported beam (influence of bending and shearing), and taking into account the roll temperature distribution, according to Larke, and also the roll flattening, according to Hertz's theory, a special method for roll crowning of the tandem mill investigated has been devised. Although this graphic method has been worked out very carefully, unsatisfactory operational results were obtained. Considerably smaller values of roll camber were determined theoretically than those required in practice for the mill. It was necessary to look for reasons of such considerable divergences. Preliminary analysis has shown that the assumption of Hertz's theory for determining roll flattening is doubtful, due to differences in presumptions of this theory and the true state of stress in back-up rolls. This concerns specially the edges of barrel of back-up rolls. This has been confirmed by Soviet investigations (Biblio. 13). Another method should therefore be chosen, and it has been decided to use bevelled back-up rolls.

The development of methods of roll crowning of the mill investigated is given in the table below.

Development of rolling schedules for tinplate and roll camber on the 5-stand tandem cold reduction mill being investigated (initial thickness 20 mm., final thickness 0·28 mm.)

Period			Stand I	Stand II	Stand III	Stand IV	Stand V
A	Rolling schedule	(mm.)	1·10	0·65	0·45	0·32	0·28
		(%)	45	41	31	29	12
	Roll camber						
	Top back-up roll		0·00	0·00	0·00	0·00	0·00
	Top work roll		+ 0·15	+ 0·10	+ 0·10	+ 0·10	+ 0·05
	Bottom work roll		0·00	0·00	0·00	0·00	0·00
	Bottom back-up roll		0·00	0·00	0·00	0·00	0·00
B	Rolling schedule	(%)	12·5	45	35	34	35
	Top back-up roll		0·00	0·00	0·00	0·00	0·00
	Top work roll		+ 0·08	+ 0·08	0·00	0·00	+ 0·15
	Bottom work roll		+ 0·08	+ 0·08	0·00	0·00	0·00
	Bottom back-up roll		0·00	0·00	0·00	0·00	0·00
C	Rolling schedule	(%)	12·5	45	35	34	35
	Top back-up roll	Bevelled	0·00	150/2	150/2	150/2	150/2
	Top work roll		+ 0·07	+ 0·07	0·00	0·00	0·00
	Bottom work roll		0·00	0·00	0·00	0·00	0·00
	Bottom back-up roll	Bevelled	0·00	150/2	150/2	150/2	150/2

Period (a) concerns the period of putting the mill into operation. Period (b) closes a period of intensive research of a corresponding system of roll crowning. Although rolling conditions and sheet and tinplate quality were improved, further possibilities of devising a still better method were taken into consideration. Period (c) gives the present state of roll crowning, and the introduction of bevelled back-up rolls has been successfully confirmed. This new method resulted in an improvement in the shape of rolled sheet and tinplate, improvement of rolling conditions (decrease in number of strip breaks, and down-time), and also in an increase of roll life. The following figure gives an exaggerated comparison of roll deflexion for the old and new method of roll crowning.



Comparison between new and old method of roll cambering

Rolling schedules applied

There has been a parallel development of rolling schedules and methods of roll crowning at the tandem investigated mill (See the table above). Operational experience has shown that the rolling schedule with maximum reductions in the first stands and minimum in the last (period (a)) is incorrect, and due to operational troubles the maximum rolling speed could not be achieved. Serious troubles occurred with strip guiding, as considerable reductions in the first stands resulted in bringing into relief the incorrect shape of hot rolled strip. It has been decided therefore to introduce a quite different rolling schedule with minimum percentage reduction in the first stand (10 to 12·5%), and a large reduction in the fifth stand (35%). In this way the long-term experiences of an other foreign 5-stand tandem mills have been confirmed (Biblio. 14, 15, 16). During the time the measurements were carried out the behaviour of technological and electrical parameters has been observed when using the improved rolling schedule and the method of roll crowning.

The table on the right gives some results obtained for three assumed groups of tinplate gauge. Only ranges of values are given in this table, as a number of coils were measured. The table gives only values which seem to be limiting ones for the rolling of thinner gauge tinplate, i.e. roll force, the relation of roll force being measured to the safe one, current of main motor and reel motors, as also the relation of measured current to the nominal one.

It can be seen from this table that really minimum reductions per pass are applied in the first stand, and these values vary within 7·7% to 23·6% for the 0·22 to 0·24 mm. gauge group, and from 15·1 to 25·5% for the 0·30 to 0·32 mm. group. In all cases the thickness of hot rolled strip was within 1·8 to 2·0 mm. Maximum values of reduction have occurred in stand IV and V. It has been confirmed that the considerable differences of reduction for individual stands were caused not only by variation of gauge and properties of the hot rolled strip, but also by separate mill crews themselves.

Values of roll force for the total programme were determined from oscillograph records (See the figure below). It can be seen from the table above that for tinplate the roll force varies within 248 to 290 t in stand I to 556 to 578 in stand V (gauge group 0·22 to 0·24 mm.), and from 282 to 325 t in the first stand up to 455 to 545 t in stand V, correspondingly, for the 0·30 to 0·32 mm. gauge group.

The measured values of roll force have been compared with the safe roll force, assumed as one of the basis of estimation of rolling schedules. According to Larke (Biblio. 17) the safe roll force is

$$P_{safe} = \frac{\pi \cdot d^3 \cdot \sigma_S}{16 \cdot n \cdot \triangle} \quad (kg) \qquad (1)$$

where

d — roll neck diameter,

σ_S — alternative safe stress, which equals to 1500 kg./cm.^{2}, according to Korolev (biblio. 18), for forged steel rolls,

n — distance between reaction on roll neck and roll barrel,

$\triangle$ — stress concentration factor, equals to 2·1 for the given conditions.

For the tandem mill being analysed this safe roll load is equal to 1350 tons. For this load contact stresses were calculated for the set work roll — back-up roll, and work roll — rolled strip, which do not exceed the safe one.

It can be seen from comparison of measured and safe roll load that in any pass the safe values were not exceeded when rolling tinplate. Furthermore, it can be seen that the roll force or strength of rolls will not be a limiting factor when rolling thinner gauge tinplate.

The existence of the speed effect on the tandem mill analysed was confirmed, as it can be seen from the distribution of roll force in the preceding figure. This effect is more distinct for higher rolling speeds (stand III to V).

Another purpose of the investigations carried out, was to analyse the possibility of rolling thinner gauge tinplate on the tandem mill. It is not easy to solve this problem, as has been previously stated. According to Stone (Biblio. 1) the minimum thickness that can be rolled on a given mill, for given rolling conditions, may be expressed by a linear equation as

$$h_{min} = 3{\cdot}58 \frac{D \cdot \mu \cdot (K_f - \sigma_{ef})}{E} \quad (mm) \quad (2)$$

where

D — work roll diameter,

K_f — yield stress of work hardened strip,

Results obtained when rolling tinplate within a thickness range of 0·22-0·32 mm.

Stand No.	Thickness of tinplate : 0·22 - 0·24 mm.					0·26- 0·28					0·30 - 0·32				
	Percent. reduction	P (t)	$\frac{P}{P_{safe}}$ (%)	J (A)	$\frac{J}{J_{nom}}$ (%)	Percent. reduction	P (t)	$\frac{P}{P_{safe}}$ (%)	J (A)	$\frac{J}{J_{nom}}$ (%)	Percent. reduction	P (t)	$\frac{P}{P_{safe}}$ (%)	J (A)	$\frac{J}{J_{nom}}$ (%)
I	7·7-23·6	248-290	18·4-21·5	170-260	5·8-8·9	15·3-21·8	235-290	17·4-21·9	90-700	3·1-24·0	15·1-25·5	282-325	20·9-24·0	88-90	30-31
II	26·9-35·9	350-430	26·0-31·8	880-1760	18·9-37·7	30·7-34·8	324-513	24·0-38·0	1410-2290	30·1-49·0	23·3-29·3	378-486	28·0-36·0	1670-1760	35·7-37·7
III	23·1-44·8	365-405	27·0-30·0	2330-3840	50·0-82·0	31·1-36·5	353-382	26·2-28·3	2190-2740	48·0-58·7	26·1-37·1	331-433	24·6-32·0	3010-6710	64·8-142·0
IV	24·1-49·4	355-392	263·3-29·0	2330-3108	50·0-66·5	31·1-38·1	281-302	20·8-22·4	1940-3880	41·5-83·0	30·9-45·4	387-435	28·6-32·2	3100-3490	66·5-74·9
V	32·5-47·6	556-578	41·2-42·9	4370-5180	77·1-91·2	36·2-40·8	353-525	26·2-39·2	3890-5180	68·5-91·2	31·0-36·1	455-545	33·7-40·4	4050-4210	71·5-74·2
	—	—	—	1120-1600	70·0-100·0	—	—	—	320-1340	20·0-83·7	—	—	—	620-950	38·7-59·3

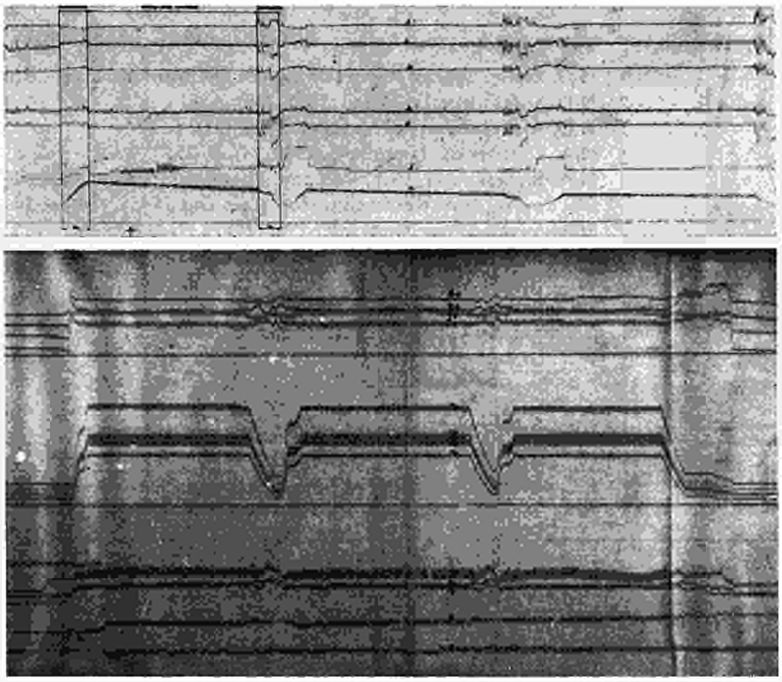
Example of recording the measured technological and electrical parameters when rolling tinplate from 1·87 mm. initial to 0·28 mm. final thickness

J — current of main or coiler motor

n — number of revolutions of main or coiler motor

r — front- or back-tension

p — roll force



μ — coefficient of friction between strip and rolls,
σ_{ef} — equivalent tension stress,
E — modulus of elasticity of rolls.

It can be seen from equation (2) that as the work roll diameter and the coefficient of friction decrease, and as the strip tension and the modulus of elasticity of the rolls increase, thinner strip can be rolled.

According to equation (2) the minimum thickness of strip rolled on the analyzed tandem mill equals to:

$$h_{min} = \frac{3{\cdot}58{\cdot}500\ (84 - 17{\cdot}82)\ 0{\cdot}018}{2{\cdot}1\ \ 10_4} = 0{\cdot}1015 \text{ mm.}$$

Loading of the main drive

The loading of the main drive for the tandem mill investigated has been checked by measuring the armature current of the stand and reel motors. The figure above gives a typical distribution of values of current along the length of one big coil. It can be seen that during acceleration and deceleration transient conditions occur.

The previous table gives the range of measured values of armature current of the main drive and reel motors. The values of current vary within 170 to 260 A in stand I for the 0·22 to 0·24 mm. tinplate group up to 4370 to 5180 A in the last stand, and 1120 to 1600 A in the reel. Assuming as the basis the nominal motor current, the utilization of that current varies within 5·8 to 8·9% in stand I up to 77·1 to 91·2% in the last stand, and 70 to 100% in the reel. The measurements carried out have shown that in agreement with practical experience, stand V and the reel carry the heaviest load. Furthermore, it can be seen from the previous figure that during transient conditions of rolling higher power consumption occurs.

The distribution of strip tension is also shown in this figure. It is known that this distribution of strip tension is one of the most important features of modern drive and control systems of tandem mills. It can be seen from the figure that during steady state conditions of rolling a rather constant strip tension occurs, but during the transient conditions some variations of this tension takes place.

Conclusions

1. The operational trials carried out made it possible to determine true values of general technological and main drive parameters, occurring during rolling of the total production programme of the tandem mill.
2. Quality control of the initial hot rolled strip of varying properties and shape made it possible to formulate new conditions of reception and transfer of initial material for the tandem cold reduction mill being investigated.
3. Results of operational measurements have shown that (a) A large variation of roll forces occurs in individual stands, and maximum loading exists in the last stand, and minimum loading in the first. When rolling tinplate none of the roll stands were overloaded, and the degree of utilization of the safe roll load varies within 17·4 to 24·1% in the first and, up to 42·8% in the last stand.

   (b) A similar distribution to that of roll force has been determined for the motor current of the main drive: maximum loading in the last stand and reel, and minimum in the first stand. Except in one case, no overloading of the drive motors has occurred for any stand.
4. The theoretical and practical analysis of methods of roll crowning has shown that it is doubtful to assume Hertz's theory for determination of roll flattening, due to differences between presumptions of this theory and true strain conditions occurring in the back-up rolls. It has therefore been proposed to use bevelled back-up rolls within the new method of roll crowning. Operational results have confirmed that this system of roll crowning is correct.
5. It has also been established that from the point of view of loading of the main drive and roll stands there exist possibilities to roll thinner tinplate then 0·24 mm. on the tandem mill investigated, and such trials were carried out.

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DISCUSSION

Charles ROUX

(Translated from French)

The members of our federation, to which all the leading French producers of cold-rolled sections belong, will be greatly interested in Professor Dr. Ing. Pankin's excellent paper on raising the yield point by cold forming. They are convinced that it is in the economic interests of the structural steelworks industry to make use of the considerable possibilities of this technique which is, moreover, one of the special characteristics of cold forming and, above all, of forming between rollers, as is the more general practice today.

The French section manufacturers have therefore instructed their technical committee to study this technique more closely with the aim of working out rules enabling it to be used systematically in practice for calculating strength. Moreover, it should be noted that this work has been carried out as part of a more comprehensive research programme drawn up by the European Research Committee on Cold Forming, representing the associations of section manufacturers of the six E.C.S.C. countries.

A number of tests have already been carried out and others are in progress. In general, they consist of comparing all the mechanical properties of a section measured over its entirety with the properties of test pieces in the steel strip before forming, or at different points of the section.

The sections tested came from hot-rolled, mild Basic Bessemers steel of the most in demand. In the case of parts, the tests relate to sections of different thickness and of either conventional or more sophisticated shape. Analysis of the results obtained demonstrates the advantages of cold forming; the overall yield point, which is an important parameter in the calculation, is raised sometimes by more than 50%, the proportion varying with the thickness and shape of the section tested.

Other French organisations concerned with promoting the use of steel in building are following our work with interest, and we are giving them every assistance, with the aim of introducing new calculating standards.

We therefore feel justified in hoping that, in France at least, the builder will soon be provided with rules taking into account the increase in yield point and other static properties of the structures using thin-walled components.

This would certainly make things easier for the structural, steelworks industry, making it more competitive and enabling it to use more and more steel products.

WORKING PARTY IV

Modern Assembly and Jointing Methods

Chairman:

Ugo Guerrera

Rapporteurs:

Georg Bierett

Gerhard Oehler

Christian Trognon

Robert J. Schliekelmann

Henri M. Schnadt

L. Capel

André Gaubert

Umberto Biffignandi

Wilhelm Rädeker

Introduction

Working Party IV was concerned with modern assembly and jointing methods.

Of the many methods in use, such as bolting, clamping and adhesive bonding, the one which was discussed in most detail was welding, which has enabled building in steel to make enormous strides and countless problems of design and engineering to be overcome. One point, it was emphasized however, does need very careful watching by producers and users, namely the tendency to brittle fracture at low temperatures under comparatively minor stress.

Georg BIERETT

Choice of Steel Qualities for Constructional Steelwork and Allied Uses

(Translated from German)

There are so many constructional steels included in the standards and specifications and so many special qualities available that the user and especially the structural engineer needs guidance to enable him select the appropriate steel qualities for any given construction. Unfortunately the effective service properties defining the strength of steels, especially as regards welded structural components, are only inadequately provided for in the existing standards. This deficiency has not been seriously felt in respect of bolted and riveted structures. The reserve of ductility has in general ensured that within the normal range of stress conditions, in even rolled plain steels, the unfavourable natural brittleness of the material has exerted no damaging effect in the zones of high local stress. Unexpected and almost clean breaks have nevertheless occurred in these structural components, for example, at holes punched in components of medium and greater thicknesses, at higher stress values and especially, at low temperatures. An official regulation issued towards the end of last century after the introduction of mild steel into bridge construction is significant:

> "Bridges of mild steel must be traversed only at a slow speed especially at very low temperatures. External damage and notched connections etc. of the mild steel component parts are to be avoided."

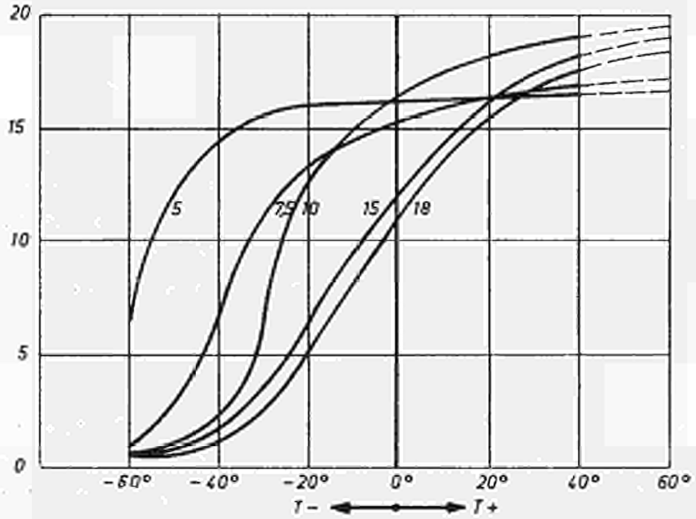
The importance of the effect of temperature and of notches, i.e. of local stress conditions, had been early recognized in these old regulations. Experience gained with welded structural components and steel construction of all kinds as well as the active research carried out throughout the technical world in regard to the problem of brittleness, has not yet found sufficient recognition in the general standards. Certain advances in this respect have of course been introduced into the contents of most of the standards such as in the specifications regarding notch strength, in certain specifications regarding the method of pouring and regarding the metal structure, also in respect of the subsequent treatment of the rolled material etc. These specifications, in addition to fixing the degree of purity, to limiting the carbon content, have with other stipulations gradually favoured the production of steels with smaller tendencies to embrittlement i.e. of steels with relatively lower natural brittleness, without it being possible to assert that this is the direct, the most rapid and the most reliable way to obtain such improvements. This could probably be achieved if the steel qualities and the standards for the user were to be based solely on the mechanical service properties. Remarkable work was carried out and promising proposals were made in this connection some years ago (Biblio. 1and 2).

Since the specification for the desired steel qualities will in future be carried out according to the existing national standards or, in the Common Market, according to the Euronorms, my proposals must also be compatible with these classifications. These standards provide in essence for a division into higher, i.e. more unfavourable, medium and lower transition temperatures. It is not my task in this paper to formulate a criticism regarding the basis of this classification. The specialists are well acquainted with all the pros and cons, but for those less familiar with the problem of the strength of materials, lengthy explanations would be necessary. I must however point out that in my further remarks nothing final is to be expected in this regard.

The brittle failure problem is not a matter of steel quality alone. From the technical point of view, the welding process, the deposited metal, the quality of the weld and, in this case especially, the nature of the underlayers, as well as the heating and cooling conditions of the layers added subsequently, all exert a greater or lesser influence. From the constructional point of view the stress conditions and especially the local stress systems are important. Should these, under unfavourable conditions, be such as to prevent ductile deformation even a material with suitably low natural brittleness may fail.

Every recommendation of steel quality must therefore assume that the welding conditions are chosen correctly and that in construction, especially in the essembly of the structural members, as far as is normally possible, it will be ensured that the normal stresses in combination with the internal stresses will not completely prevent ductile adjustment. This is of course easier said than done, but it is even more difficult where thicker structural components are used. If these requirements cannot be complied with at all or only with difficulty it is necessary to use higher qualities of steel than those usually specified in codes and standards of all kinds.

More need not be said at this point in this regard. It must however be stressed that the trend in load-bearing members for steel structures, crane construction and also often for machine engineering, towards more open and lighter units in the form of box girders, dished plates, folding components etc. mitigates against this requirement. The moderate and often even very small thicknesses of the materials used, open up a wide field for the utilization of constructural steels since the question of brittle failure caused by stress loses its importance for technical reasons. Exhaustive investigations carried out in France, Germany and elsewhere, to determine the effect of thickness on the behaviour of materials in notch-impact tests (Biblio 3, 4 and 5), have shown the relatively much smaller importance of this factor in the case of small and moderate thicknesses. The figure below shows some partial findings of these investigations.



Width of test piece in mm.

20 mm. sheet, semi-killed open hearth steel.

Rolling temperature checked.

42-50 kg./mm.²

V-notch Charpy tests.

Notch impact tests for determining the effect of the test-piece width.

This seems to apply also when plain steels of moderate thickness in the cold deformed state or even zones with considerably cold deformation are welded. Tests carried out at home by cold-rolled section manufacturers on impact loading on welded cold-rolled sections with welding seams in very unfavourable zones, using simple basic converter rimming steel, have not as a rule, resulted in brittle failure even at temperatures of −30°C, as shown in the table below. Up to six mm. in thickness these results were generally favourable. Some practically clean breaks did occur at the low test temperatures in eight mm. thick arc-welded steels owing to their very coarse structure, as was subsequently established. On the whole the expectations regarding these plain steels have been exceeded considering the rigorous test conditions. There need be no hesitation therefore in welding such cold-rolled sections of simple steels if appropriate guarantees can be given by the manufacturers regarding the metal structure. These findings will be taken into consideration in the new German general welding specifications DIN 4100 now under discussion. For strip steel rolling mills as well as for the manufacturers of similar strip steel sections and for people interested in light construction, these regulations will be invaluable.

Impact-tests carried out on welded cold-formed sections

Specimens		Testing Temp.	Impact energy	Gas welding		Arc welding	
Thickness e in mm.	Shape			Bending angle °	Finding	Bending angle °	Finding
4	A	+ 20	44	95	no flaws	95	no flaws
		− 30		95	no flaws	95	no flaws
	B	+ 20		95	no flaws	95	no flaws
		− 30		95	no flaws	95	no flaws
6	A	+ 20	111	95	no flaws	62-70	no flaws
		− 30		85-90	no flaws	60-62	no flaws
	B	+ 20		95	no flaws	65-95	no flaws
		− 30		90-95	no flaws	58-65	2% no flaws, 1% flaws (1)
8	A	+ 20	447	95	no flaws	95-100	no flaws
		− 30		80-90	no flaws	rupture with practically no deformation (2)	
	B	+ 20		95	no flaws	70-90	no flaws
		− 30		85-90	no flaws	rupture with practically no deformation (2)	
10	A	+ 20	447	70-75	no flaws	65	no flaws
		− 30		65	no flaws	52	no flaws
	B	+ 20		73	no flaws	68-70	no flaws
		− 30		1 % 68	no flaws	53	2% no flaws
				2 % rupture	without deformation	35	1% rupture

Unkilled T-steel

Analysis of pieces in %

C = 0·12 Mn = 0·28
P = 0·034 S = 0·026
N = 0·008/9 Si = 0·01

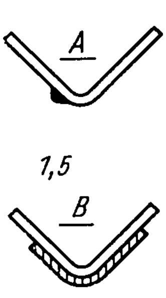
Three parallel tests each

Shape of specimen :

longitudinal seam

r/e = 1·5

seam less than 45°

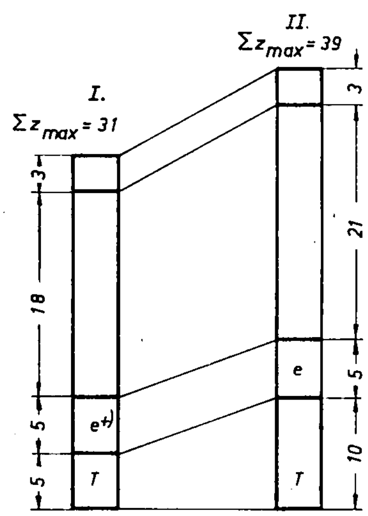


(1) in pitting at end.
(2) caused by coarse grain.

Efforts to establish rules for determining the appropriate qualities, having regard to the usual thicknesses in steel construction, especially for the greater thicknesses, based on the standard steels but taking into account the manner of the construction and its purpose, deserve special consideration. For large constructions such as bridges, buildings, ships or even for large steel structures in mechanical engineering, the individual co-operation between the materials specialist and the structural and welding specialist will result in a much more satisfactory choice of quality than could ever be made from a selection scheme. The same applies to mass produced welds or those produced in large batches or frequently repeated. For the numerous single structures which account for the greater proportion of the output of steel construction contracts and of similar production branches, exact and complete directives are, in our opinion, indispensable. Even for large engineering structures no differentiated quality selections can be made at the stage of the tender preparation, which happens in most cases under pressure of time and without sufficient drawings being available. For costing purposes one is dependent on suitable directives which, because of competition, must be the same for all competitors. Even the ordering of the materials is often carried out on the strength of such directives alone, before sufficient detailed informations is available.

In order to arrive at a uniform procedure, the German Committee for Steel Constructions (DASt) issued in 1957 the "Provisional recommendations for the selection of steel quality groups" (PR) (Biblio. 6) which are valid among the important German construction authorities. This was a beginning. It would therefore be idle on my part to criticise this arrangement or the individual regulations of this directive. If in what follows I refer to this, I do so of necessity in discussing more recent proposals and their deficiencies and omissions, already recognized, and which DASt will have to take into account in the non too distant future.

These PR allocate different ordinal numbers to all the factors considered important, such as service temperature and thickness of the material, and also to the various other influences related to the conditions of manufacture and to the constructional assembly, the sum total of which determines the quality of the steel. The higher this total the higher must be the quality. As may be seen from the following figure, the influences of temperature and of thickness, in comparison with those relating to manufacture, stress conditions and construction, have not yet been credited with the importance that should be attributed to them. Additional quality specifications in respect of thickness, from a given value upwards, have however in practice re-established the proper balance.



Cold-forming.

Effect on design, manufacture, stresses, etc.

Thickness.

Temperature.

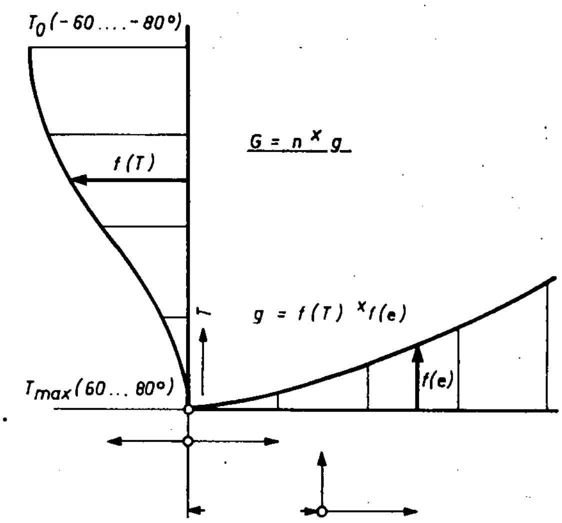
Proposed grading of steels for use in welded structures.

A Japanese opinion which originated in shipbuilding circles within the International Institute for Welding Techniques (I.I.W.) considers this proposal favourable but recommends that a greater influence be ascribed to the temperature effect at low temperatures, as shown in the figure below. This appears to me to be an improvement in the case of medium and large thicknesses, but as regards small thicknesses, the effect of temperature, as explained in the introductory notes, need not be considered as being so important. Both proposals allocate only minor importance to the influence of cold forming. In the case of small thicknesses this is in fact correct, as is proved by test results on cold-rolled sections communicated to me, but for medium and large thicknesses these regulations are insufficient.

Effect on design, manufacture, stresses, etc., factors n considered.

Effect of temperature and thickness.

Embrittlement — thickness e Cold-forming by upsetting.



Proposed grading of steels for use in welded structures.

These recommendations were the subject of lengthy discussions and voluminous memorials in Committees IX and XV of the I.I.W. Objections were directed in the main to the fact that:

(1) the present state of knowledge does not justify such an approximate method;

(2) the basic assumptions are not adhered to;

(3) the different factors are not independent of each other.

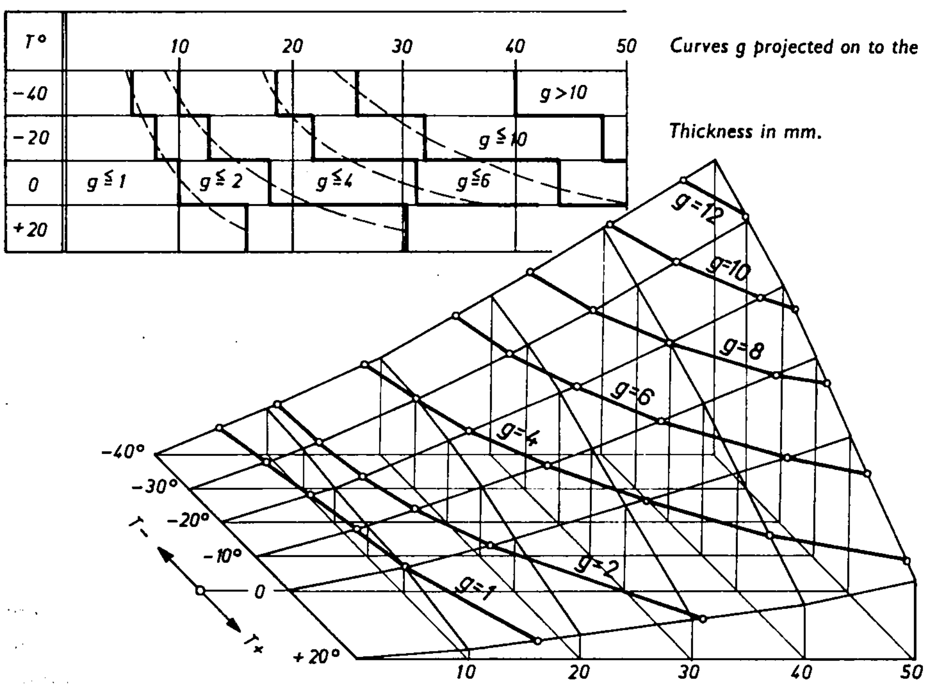
Although these objections, taken individually, are certainly justified, it can be maintained that practice often precedes scientific knowledge and that the latter, in the fulfilment of its task, has often had recourse to ways and means based on experience and statistical data alone for bridging gaps in knowledge. It must also be pointed out that in complex problems which have baffled scientific explanation, an empirical treatment based on experience has often been necessary, sufficient and useful. We are now in the fourth decade of the application of welding techniques to large engineering constructions; its great successes have not however been free from heavy material damage. One should now be in a position, on the strength of good and bad experiences, to recommend a useful and practical method for quality selection.

The wide range of scatter in the quality values of steels of the same type constitutes a serious obstacle, which attaches a certain degree of uncertainty to every quality selection, even with the use of exact methods, when quality is not ensured. On the other hand this zone of scatter simplifies the problem of preparing selection schemes in which the special decisive influences are correctly considered in relation to one another whilst the influences of the second and third order are neglected, as in any case they would be of no consequence, considering the wide zone of scatter of the quality values of constructional steels and of manufacturing conditions.

On the strength of many years' experience and observation I am convinced that especially important influence is to be assigned to service temperature and to the dimensions of the structural components. These are, at the same time, the only two definite values available to the constructional engineer at the beginning of his task after he has determined the dimensions in accordance with his static calculations. Both these influences stand in close relationship. They increase in parallel with falling temperatures and increasing thicknesses according to an unknown law which, as experience has shown, cannot be expressed by an additive expression for these two influences. At low temperatures and with small thicknesses, such treatment would call for excessively high quality requirements, and in case of thick components for too low a quality. Within the frame of practical probability, multiplication would appear rather more likely than the expression of the figure on p. 519. Such a procedure appreciably lowers the practical discrepancies in the selection of an approximately correct yardstick for evaluating the material.

Regarding the influence of temperature, it is known that in the case of the usual constructional steels the tendency to embrittlement at temperatures considerably above room temperature is small. This is general and has no direct connection with the temperature-transition curves, which depend on the shape of the specimen, on the thickness of the material and on the frequency of loading. This tendency can be expressed by a linear relation or better still by a law which gives a smooth transition.

H.M. Schnadt (Biblio. 2) points out with reference to the influence of thickness, that in specimens, such as in the well-known welded bending test specimen, the influence of thickness increases as the square of the thickness, whilst in a structure the increase is linear. Whether there always in fact exists such a simple and constant relation between specimen, which after all is only a special shape, and construction, is doubtful. Today, especially after the verification in this respect of the more favourable assumptions in my earlier proposal (Biblio. 7), I believe that the influence of thickness must be assumed in constructions to be at least linear, or even that it should be included in the form of a slightly greater factor, somewhat in the form of $e^{1.2}$. A combination of such reasonable relations, as the temperature — thickness dependence, can be used for calculating the safety factors or the coefficients of difficulty, the compilation of which represents, initially, simply a criterion to be used after confirmation by a comparison with practical values. The values so determined are shown in the following figure in a three-dimensional representation. The curved plane contains the plotting of equal values joined by curves. The top figure shows the same curves projected on to the T-e plane but replaced by histograms. These lines are the starting points for the division into qualities.



Curves g projected on to the T-e plane.

Thickness in mm.

Coefficient of difficulty due to temperature and thickness.

In regard to the influences resulting from manufacturing conditions, constructional forms, internal and working stresses, one may doubt whether the complications thus created are not taken care of by the addition of constant amounts as provided for by the PR. Many specialists will probably agree with me that for small thicknesses these influences are small. Results of notched strength tests with specimens of varying widths and of impact tests on cold-rolled sections also confirm this opinion. With thicker components the coefficient of difficulty appears to preponderate on account of this thickness.

These facts cannot be represented either by means of an additional additive constant for all thicknesses as provided for in the PR or by a constant factor as used by me in my original publication. So far as I can judge today, this type of influence could best be taken into account by the use of factors depending on thickness, with a maximum in the region of medium thicknesses.

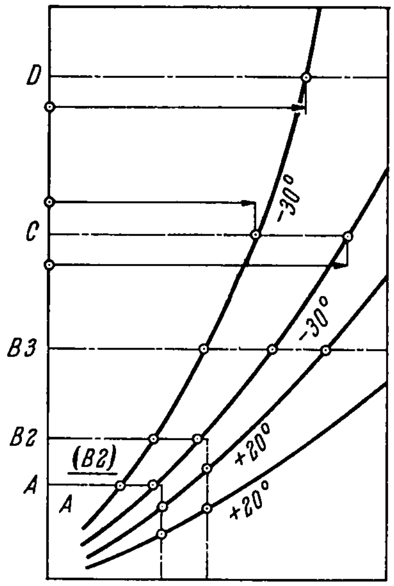
Regarding the stress systems originating from the structural layout and from the conditions of production, there is general agreement on the need to distinguish at least two conditions, difficult and normal, if not three, by taking into consideration further, the economics of the conditions of construction, i.e. normal, difficult and very difficult. A more differentiated subdivision increases the range of decision to a considerable extent. Nor must the importance of any structural member in respect of the behaviour and safety of the entire construction be lost sight of, by classifying it at least as of the first or second order. Further, the utilization of the permissible stresses, especially in dangerous zones, whether high or low, should not be left out of account in view of the possibility of the formation of cracks and especially of their propagation, even if the question of the cost price of the steel is of great importance. This subdivision is shown in the figure below.

For constructions with high loading frquencies this sub-division will have to be further extended. Consideration for more severe service conditions, for structural members carrying frequently repeated loads, are also indicated and are under consideration in German steel constructional circles.

On the strength of the basic relationshp between the influences of temperature and thickness, several graphs can be drawn for each temperature zone from considerations of the different conditions of production, constructional and stressing, according to the different points of view explained above. A large proportion of these graphs lie so close together that a combination of several into one curve is easily possible. Considering the wide range of scatter of the steel qualities of the same type, such a simplification is almost inevitable. The figure below shows several such graphs in explanation of this principle for determining the limiting thicknesses of the individual steel types as a function of the constructional conditions. The determination of these limits for each type of steel is then a matter of experience and of collaboration with experts.

The points of intersection of the limiting curves with the G-e curves give the limiting thicknesses for the individual cases. If the inter-relationships in respect of the temperature dependence or of the given constructional conditions are greatly in error, disagreements with data from practical experience will be easy to detect when introducing a constant limit for each type of steel. This resulted, for example, in the fact that in my first publication, because of too favrourable a dependence relationship upon thickness, in order to arrive at an agreement with the conceptions of a group of experts, I had to reduce this limit in respect of greater thicknesses. It was also apparent at that time that the temperature relationship was assumed rather too unfavourably.

On the strength of these considerations simple selection tables can be drawn up (see the figure below). The upper table was constructed drawn up by the Materials Committee of the German Steel Construction Federation (DStV) on the principle of my proposal and was then used as a basis of comparison by a working committee of the German Federation for Welding Techniques (DVS) (Biblio. 8). It also formed the subject of a



Thickness e

Special steel
e_{max} *for — 30° case "a"*

D steel
e_{max} *for — 30° case "a"*

C steel
e_{max} *for — 30° case "e"*

B_3 steel
e_{max} *for + 20° case "a"*

B_2 steel
e_{max} *for + 20° case "e"*

The thicknesses e_{max} selected are determined by the points of intersection of lines G-e with the limiting lines of the different grades of steel

Method of determining limiting thickness having regard to the structural specifications

Symbol	Effects of the structure	
K	Structural and manufacturing specifications	(Particulary strict) (Strict (S) normal (N)
O	Importance of the component	1st. order 2nd. order
A	Efficiency (ratio of stress — permissible stress)	high low
V	Rate of strain	normal (usual case) high
N	Load frequency	low to moderate (chiefly static load) frequent (continuous stress)

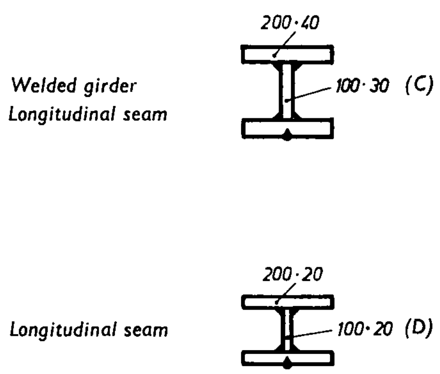
Case V = normal. Cases "a" to "e"

Least favourable case "a"	Most favourable case "e"	
K = strict	K = normal	b, c and d
O = 1st. order	O = 2nd. order	intermediate cases
A = high	A = low	

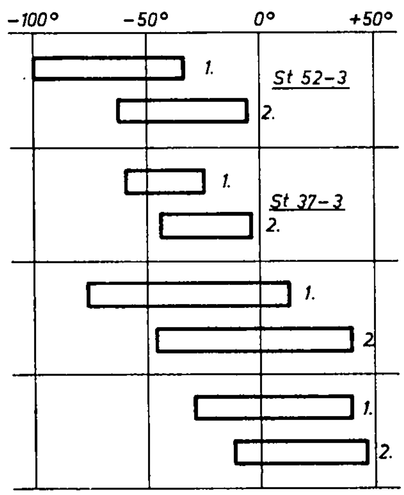
critical assessment by U. Guerrera, leader of the XV Committee of the I.I.W. The results are set out below. These findings are based on a comparison with M. Mackenzie's results (Biblio. 9) of Charpy notch-impact tests and lead to considerably higher requirements as can clearly be seen from the graphical representation. I would not feel able to contradict U. Guerrera in regard to the advice he offered but would only ask whether or not he thinks that direct application of the results of such tests to construction would not call for much too high a quality of steel.

Table showing grades selected for welded parts. Tension — stress

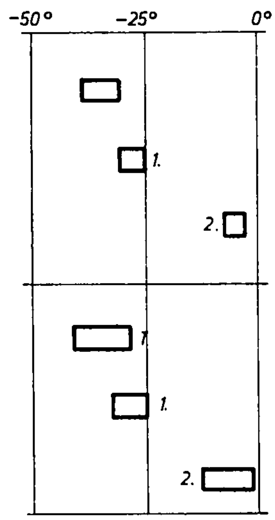
Minimum service temperature ≧ 15°	≧ —10°	≧ —30°	< —30°	Category	Thickness of material e in mm. (10 – 20 – 30 – 40 – 50)
Structural specifications					
			a	I	special steel
		a	b	II	C (RR-3)
	a	b	c	III	D > 20 (25) mm. standard
b	b	c	d	IV	B3 (R-2) > 20(25) mm. standard
a	c	d	e	V	A (U-1); B2
c-e	d-e	e	—	VI	(R-1) (U-2)
Structural specifications				I	C; r
As above				II	B 3; C; E (special steel)
				III	B 2; B 3; C; D
Data supplied by U. Guerrera IIW. Doc. G.T. XV-St. 4				IV	B 2; B 3; C
				V	A; B 2; B 3; C
				VI	



Transition temperatures compared.



Comparison between round notch tests and V-notch Charpy tetst.
(3.5 mkg./cm.²)
1. Round notch tests
2. Charay tests



Comparison between girden tests (static) and notch impact, tests.

It is well known from a large volume of tests, both at home and abroad, that even notch-impact tests with differently shaped notches lead with increasing acuteness of the notch to the displacement of the transition temperatures towards higher levels. A comparison of some results (Biblio. 10) between acute and rounded notches is shown on the left-hand side of the following figure. The drawing on the right compares the transition temperatures of such notch-impact tests with those obtained under static tests with welded girders. These results are considerably more favourable, especially when compared with those of the Charpy tests with V-notch specimens.

In general, directives for quality selection should be left as the responsibility of the various industries themselves, possibly also to the control authorities. Selection tables can be easily altered by chosing more or less stringent limits within the system represented. Thus, the figure below shows a table constructed on the basis of more stringent specifications, drawn up in collaboration with expert engineers of the German Steelworks, which will probably form the basis for the delivery conditions of steelwork cranes. This table should also be suitable for the components of steel frames for high grade machines.

Code of practice for the selection of grades for steel-mill cranes (under discussion)

	Stress	Upper limits of thickness for various grades of steel in mm.						
I. Riveted and screwed components	Tension	8			25		36	
	Pressure	USt 37-1	16	RSt 37-1	30	RSt 37-2 40		

II. Welded components			
1. Conditions	2. Importance of the component	Grade selection acc. to stages I - IV: under tension	Grade selection acc. to stages I - IV: under pressure
S	1	I	II
S	2	II	III
N	1	II	III
N	2	III	IV

Re 1. Manufacturing and structural specifications:

S = strict N = normal

Re 2.

1 = first-order 2 = second-order

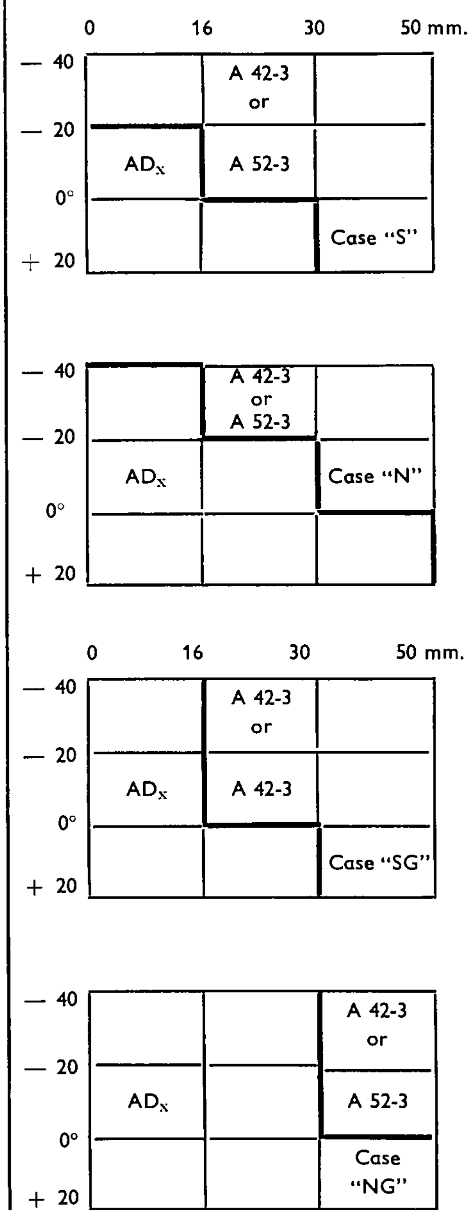
Stage	Upper limits of thickness for various grades of steel in mm.					
0 (¹)	6	16				
I		14	25	special steels		
II	RSt 37-2	20	St 73-3	36		
III	6		25			50
IV	RSt 37-1	14		36		

(¹) The preceding stage should be used for welding near zones of cold-formed material. Stage I becomes stage 0

The top of the figure contains the regulations for riveted and bolted constructional components for which, we believe, directives are also necessary. Both for these and for welded constructional components, the selection directives for those parts taking compression are considerably more favourable, as are also those for the compression members for general steel construction.

A proposal recently published by Mr. Gerbeaux (Biblio. 11), which is reproduced in the figure below also confirms this view. The drawing on the left is taken from the original but is slightly altered. That on the right follows from the application of this proposal to the working table in the figure on p. 522. Gerbeaux explains that the warranties given in the standards in respect of quality group 2 - B3 of the Euronorm, are too moderate to justify with certainty more favourable conditions in steel construction than are given by the AD_X or even by the A37 steels. Not much more remains to be said except that this remark ought to be regarded with understanding by steel manufacturers. The abovementioned author deduces from this a very simple classification into only two quality groups. After a general analysis of this proposal, I would think that Mr. Gerbeaux' assumptions regarding the significance of temperature and thickness agree to a large extent with mine, as explained in this paper.

Proposed selection



Manufacturing and assembly conditions	Minimum service temperature ≥ 0	≥ —20	≥ —40	Maximum thicknesses of material to ... mm. 0–16	16–30	30–50
			S			
		S	N		A 42-3 or	
		SG	SG		A 52-3	
	S	N	NG	AD_X		
	SG	NG				
	N NG					

Symbol	Structural specifications	
S =	strict	Classification generally recommended
N =	normal	
SG =	strict	Under optimum conditions of manufacture, transport and assembly at moderate temperatures (¹)
NG =	normal	

(¹) Considered still permissible

Steel grade in cases S and SG still to be determined for cold-forming > 2% to 5%.

Whether the French Steel Construction Industry, after due technical and economic considerations, can and will adopt this proposal remains to be seen. We hope that in the common work of the Convention of European Constructional Steelwork Associations a unified conception and a uniform procedure can be evolved. Since the proposal of the above figure has been taken over in the eastern zone of Germany almost unaltered as a valid standard (Biblio. 12), with additional provisions only for impact loads, a fact which will certainly not remain without effect in the other Eastern European countries, it is to be hoped that the countries working together in the European Organizations can work out a set of uniform regulations.

In this paper I have only been able to touch upon the general points of view regarding a rational and methodical treatment of the problem of quality selection without having the time to consider the difficult questions regarding, for example, the coefficients of difficulty according to manufacture and constructional assembly, or the stress systems or notch effects, nor could I go into explanations regarding the utilization of rimming or killed steels. I hope nevertheless, that I have been able so to present the general tenor of the proposal for classification, based on service temperature and thicknesses of the materials, with due consideration of the proper manufacturing and constructional conditions, that they may be of service in the development of steels, in the elaboration of standards and in practical applications.

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DISCUSSION

François-Henri GERBEAUX

(Translated from French)

Conventional welded structures exposed to normal climatic conditions — and this means the great majority of structural steels — necessarily involve a great variety of shapes and sizes of steel sheet, sections, bars and tubes. Hence it is important that the range of qualities and grades available should be strictly limited, so that delivery times, stock building costs and the risks of ordering or supplying the wrong products are reduced to the minimum.

The present standards for products in the qualities currently most in use comprise far too many variants, the differences between which many builders and welders consider to be quite meaningless, but which tend to be used according to the type of structure concerned as an unnecessary refinement.

In this category there should be only two classes, similar to those adopted for motor fuels, viz.

— the standard quality; corresponding to class B of IIS, for it has been shown that all the inferior products, Adx included, actually meet 95% of requirements regarding resilience to ambiant atmospheres corresponding to this class ;

— the super quality, equivalent to class C of this same recommendation with KVO at an appropriate level selected with due regard to the particular yield point of the product (unless Mr. Schnadt's classification is preferred).

As for the grades a very important limitation exists as regards the hardenability of the metal and the serious risks arising from this in fusion welding.

The mild grade C-Mn steel which in the as-manufactured condition contains $C < 0{\cdot}22$ and $C + \frac{Mn}{6} < 0{\cdot}43$ and can be welded without special precautions should comprise two grades of elasticity :

— the standard grade with a yield-point of $\geqslant$ 23/24 kg./sq. mm. ;

— the select grade with a yield-point of $\geqslant$ 32/33 kg./sq. mm., equivalent, for example, to French steels of 48 kg. tensile strength.

In short for normal carbon steels altogether four products identifiable by the shade of colour should be available from the distributors — two resilience grades and two elasticity grades.

In addition there ought to be high-elasticity grades which would enable the builder to safely weld onto medium or heavy steel parts, without preheating or other further treatment, and without excessive tempering, angle strips of 25 sq. mm. cross-section which are used in more than three-quarters of the mechanical and structural steel assemblies. Present C-Mn steels 52 are unsuitable for this purpose because they require a degree of tempering which, according to the Kihara and Inagaki tests generally exceeds the permissible limits. This problem is very real owing to the increasing use made of this grade of steel. Hence, the designers, builders and welders should obviously get together and among them adopt economic formulae for steels, which may be low-alloy steels, for instance of the dispersed type, which would enable the builder to erect, without having to worry about special treatment, tough but comparetively light assemblies, fabricated in one pass, suitable for speedy downhand welding, without deformation, without the risk of creating, through excessive tempering the present kind of cracks formed under stress and the metallurgical notching which impairs the ductibility of the assembly in places.

Gerhard OEHLER

Bending and Folding of Steel Sheet and Plate

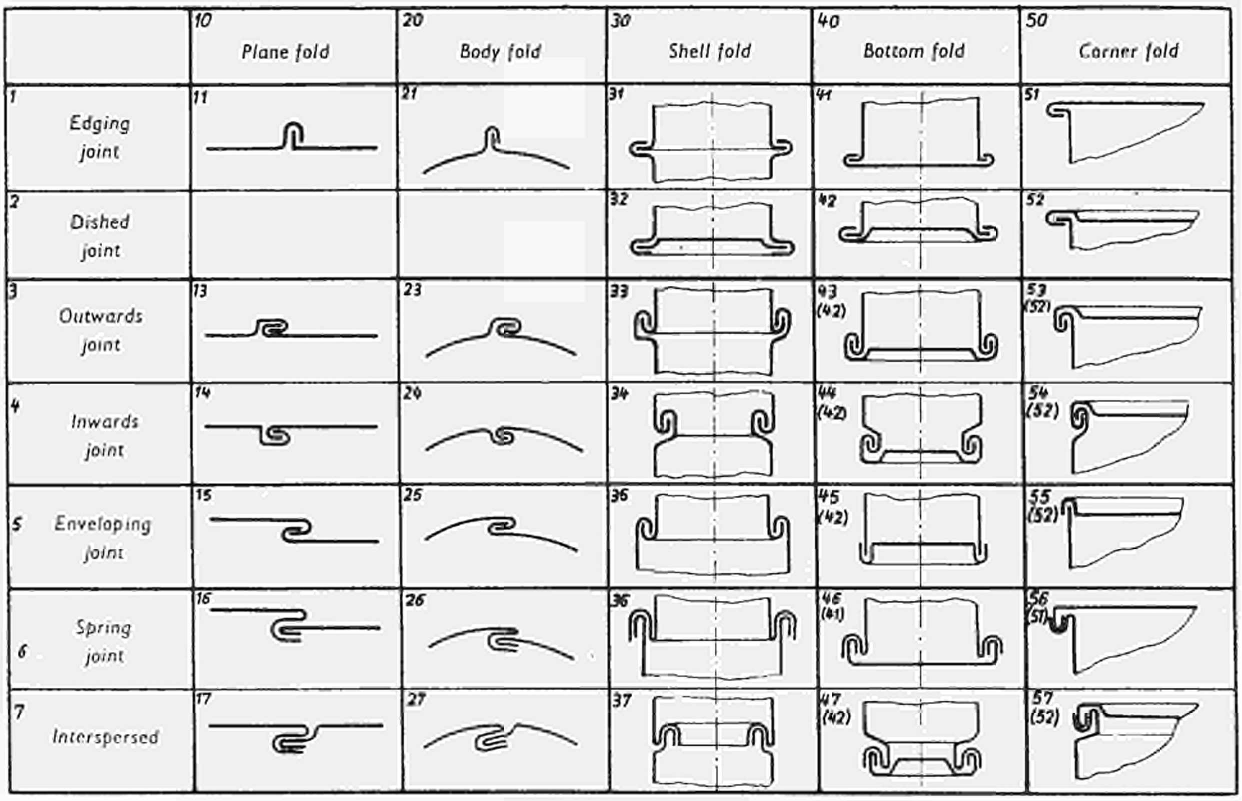
(Translated from German)

Folding is a technique for the self-secured jointing of sheet edges by trapping and folding. This involves stressing the material mainly in bending and we shall therefore conclude this work with a section on bend tests. Folded joints are used for tinplate and high quality sheet containers, vessels, boxes, etc., galvanized or lead-coated steel sheet ventilation, supply and exhaust ducts, uncoated steel sheet stovepipes, galvanized roofs and various other materials and types of product. However, the premier field of application of this type of jointing lies in the packaging industry to whose requirements we shall therefore devote particular attention. Folds are sometimes preferable to welded joints in cases where the distortions liable to be caused by welding would be unacceptable (Biblio. 7-10, 18, 19, 26).

The load on the process material is specially severe when forming a narrow fold through 180° whereby the fibre stress will of course be tensile on the outside and compressive on the inside. The stretch zone must not exhibit tension cracks, the appearance of which would indicate a cross-sectional reduction and lead to failure of the fold-joint even under a very slight load. Strain-hardening is very often observed in the line of the bend as a result of the cold-working process, particularly in austenitic steels. The intensity of this age-hardening varies in proportion to the deformation rate. Sheet heavily bent in this fashion will often develop deep flaws in its compression zone fibres also; this is caused by the compressive interaction of structural elements of dissimilar hardness and likewise reduces the original cross-section and hence the strength of the joint. Crack genesis is governed less by the deformation rate which, according to the accepted theory of plasticity, is hardly hereto relevant as a factor of material behaviour, than by the nature of the bending process in conjunction with the quality of material.

It has been found that a gradual progressive forming advance over as long a distance as possible gives greater strength and robustness than a series of folding actions carried out stage by stage over short lengths or even simultaneous folding of the whole edge length, unless of course short straight edges have to be worked. Clearly the size of the workpiece must largely determine the length covered in each forming action. Be that as it may, the tendency nowadays is to pay extreme attention to forming-roller design in order to influence the detailed behaviour pattern of folding deformation. This is tantamount to inferring that folds are now mostly produced by form-rolling, a technique on which a number of investigations have been carried out in recent years whilst others are planned for the near future. (Biblio . 1-6, 11, 12, 14, 15, 19-23, 27).

There are many kinds of fold-joint all with different and sometimes inconsistent names. The suggested categorization in this figure may perhaps help to unravel this conceptual tangle. The arrangement here adopted is based on the principle that the name of a joint must indicate both its position (per column) and its shape (per horizontal row). A fold may lie on a flat surface (10), e.g. where flat sheet structures require to be joined or extended. It is very often used as a closure for the longitudinal seams of containers, the most common example of this being found in the can-making industry (20). It can equally well be used for corner jointing, usually in a rectangular marriage, in which case we refer to it as a corner fold (50). Much more ambiguous are the expressions "shell fold" and "bottom fold"; all the more so since "shell", "case" and "body" are often loosely used as synonyms. The case shown (31, 33-37) where abutting shells are joined at their ends, is relatively rare; obviously the term shell fold is here the "*mot just*" and its use should cause no confusion. Where, however, a fold is used to form a shell, bottom or top joint, then obviously the choice

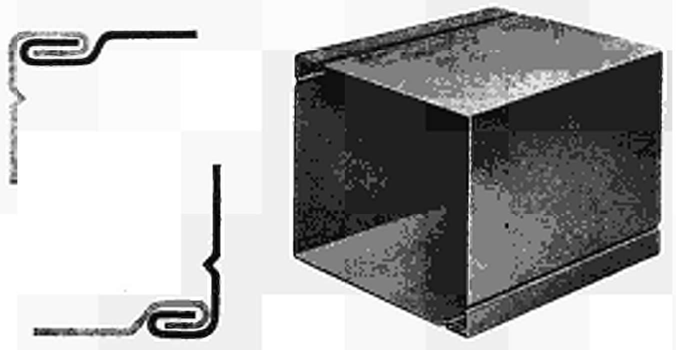


Different lock-joints

of designation "shell fold" or "bottom fold" will entirely depend on the precise position of the fold. On these grounds the name "shell fold" has been retained for joint No. 32. It is difficult to make up one's mind in cases where there are folds on both the bottom and the shell, as, for example, in bottom folds 34, 44, 46 and 47, and these could with with equal justification be termed "shell folds". To accept a distinction between body fold and shell fold is questionable practice, in that "body" is colloquially used with the same meaning as "shell." It would be better to call a "body fold" a "longitudinal body fold" and a "shell fold" a "circumferential shell fold;" true, these terms are something of a mouthful but at least they prevent misunderstanding. In the figure the column headings plane fold, body fold, shell fold, bottom fold, and corner fold are numbered 10, 20, 30, 40, 50 respectively. Horizontally we have lines 1-7 for indicating various generally known fold shapes. Thus in the edging fold (1) the edge of one sheet is bent through 90° and this single edge then closed in the reverse-folded edge of the other sheet. Confusion must naturally arise, particularly in bottom joints and corner joints, as to which is truly the flexed member.

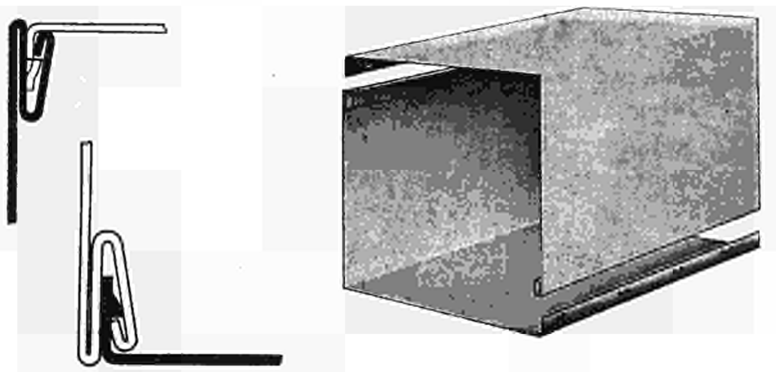
Joints are usually grooved. In the case of flat-surface paned-down joints and body paned-down joints (11 and 21), this is impossible, but knocked-up joints are nearly always so treated. The knocked-up joint does not have a flange stand-off like its paned-down counterpart but lies snug to the sheet surface. Naturally, in so doing, it forms a ridge so that outwards (3) or inwards (4) grooving is necessary to preserve the flush sheet surface. The double-grooved or strap joint (or enveloping fold) (5) lies proud of the sheet surface and demands wiring of various diameters as for example in the shell fold (35). The enveloping fold (5) is seldom used and the same holds good for the spring fold (6) which may also be partly interspersed

(7). Unlike the types previously discussed, these folds are mostly used for dismantlable jointing. This brief survey is merely intended to give an idea of some of the more usual fold-joints, but to attempt to describe all possible permutations and combinations by words alone would be a thankless task indeed. Thus, in the following figure a corner joint is shown which is in practice described as an internal edging fold (internal paned-down fold) with grooved longitudinal fold, which in the nomenclature of the figure on p. 529 is equivalent to a corner joint with grooved knocked-up fold. A spring fold joint with an additional fold-back and paned-down cam fold shown in the next figure; this type of joint can be said to be dismantlable only with difficulty. The edged sheets can however be compactly stacked for dispatch and assembled to hollow-ware



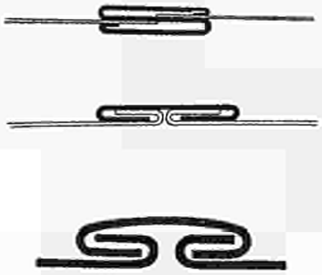
Corner joint with grooved knocked-up fold

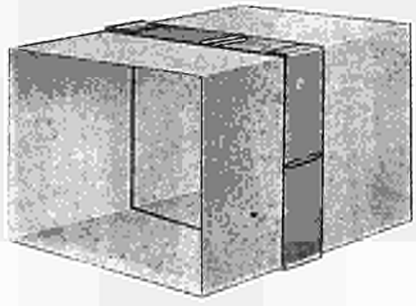
in the finishing shop. When making a cam fold by roll-forming, care must be taken to enure that the top roller is exactly synchronized with the lower; this can best be achieved by intermeshing the roller shafts outside the pass. For pieces of constant fold length < 4 m. it is recommended that all the cams requiring to be indented and chamfered should be produced in one single stroke of the folding press. If it were not



Spring fold joint with additional fold-back and paned-down cam fold

for the trapping edge of the spring fold in the above figure this joint would be readily dismantable. The same is true of the S-fold shown top left in the figure above. This consists of an S-section strap whose edges have each been given an additional fold-back and into which the two sheets can be inserted from either side to any distance required. This is not so much a true fold-joint as a self-secured seam and the same must be said of the enveloping fold where the strap is a C-section. Neither the S-fold nor the enveloping fold meet the definition of paned-down or grooved joints but are in fact strap-secured double-grooved joints.

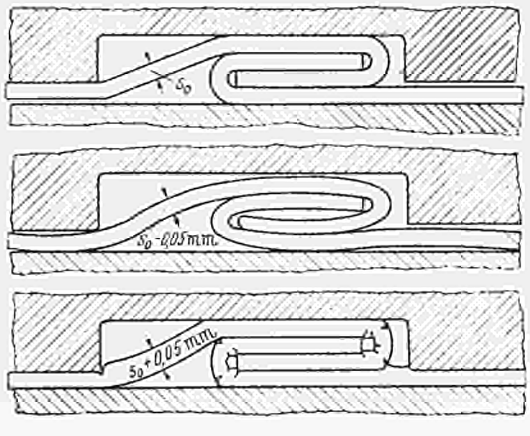




Double lock seam

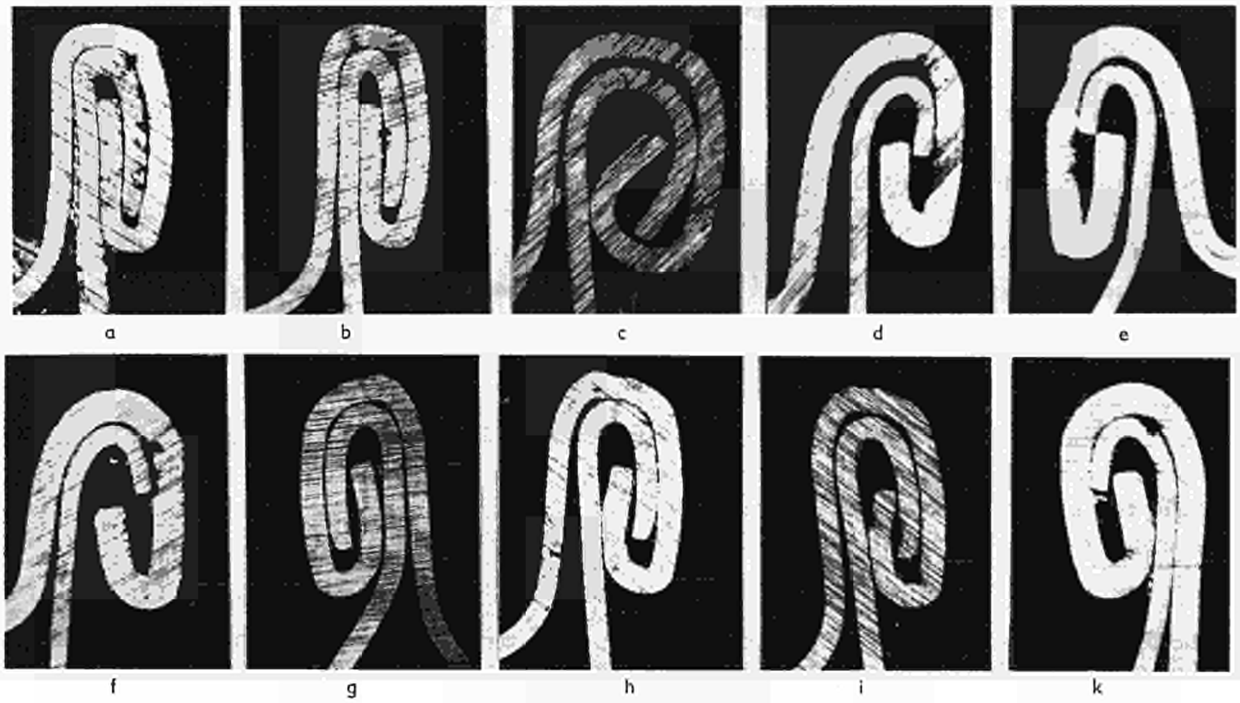
By far the most common types of fold are firstly the inwards grooved body longitudinal fold (24 in the figure on p. 529) as formed in the bodymaking machine and the circumferential fold (43 in the same figure) for jointing to a grooved bottom or top. However, the closure of longitudinal seams in the bodymaking machine is a process prone to a certain defect incidence usually caused by deviations in sheet thickness.

If the sheets are too thick there will be too high a pressure in the folding groove which will cause cracking at the fold-lines (see the following figure). These fractures will often develop only after a certain amount of ageing i.e. they will appear unexpectedly on the finished product. Another effect of these excessive stresses



Seams in bodies under bodymakers

is to cause slight relative displacements between the soldered parts during solidification of the solder, and this in turn lowers the strength of the soldered seam, particularly at the overlapped ends. The result is sprung laps and consequent loss of sealing efficiency. A fold made with too thin a sheet will, on the other hand (see above, centre) be too loose. The solder metal, which is deposited on the outside of the joint and is supposed to permeate it by capilalry action, will be unable to do its job properly as the interstices are too large; gaps (unsoldered positions) will be left, and can spoil the tightness of the joint. The adverse effects of incorrect truing of sheet thickness or improper roll adjustment are evidenced by examination of the fold section. Sectioning for microscopic examination is best effected with a synthetic resin grinding wheel, though a hand-saw may naturally be used if desired. The following figures a-k show a series of such sections taken from various container folded seams. For this purpose a fairly thin shell sheet was used (equivalent to normal bottom or top thickness). The first thing we notice in these micrographs is the presence of distortions outside the fold which can only be attributed to the sawing or cutting. Apart from this, variations of sheet thickness are visible which are in all probability the cause of these defects.



Cross-section of double seam

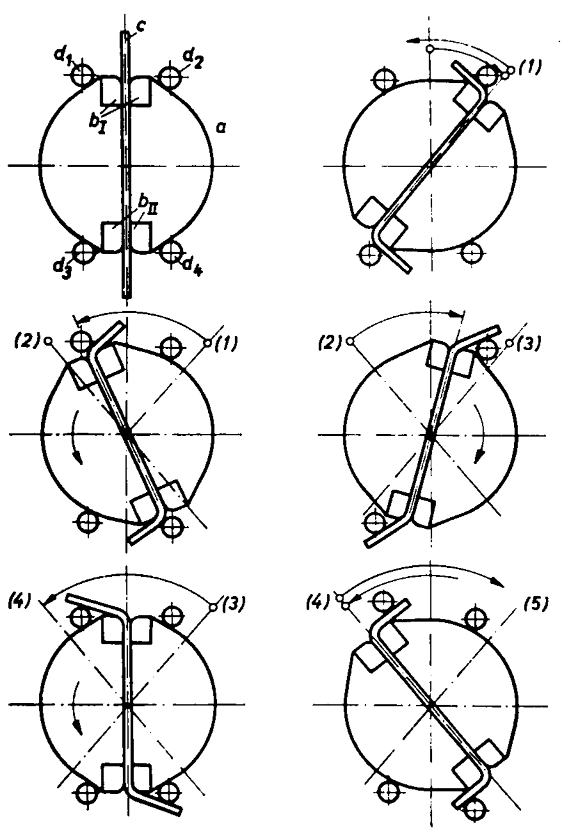
When the pressure of the spindle-sleeve or rollers is too light, this will probably have been due to a transitory fall below tolerance of the body or bottom sheet thickness. Figures b, c and f show examples where such thinning may have occurred. The following comments on this series of micro-sections are also relevant: Figure a shows good lapping with an approx. 80% overlap length — just as it should be. The fold in b can also be assessed as good, even though the laps appear somewhat less complete with a 65-70% overlap and the adjustment of the second roller was possibly too light.

In c the adjustment of the second roller was incorrect. In d the spindle-sleeve pressure appears to have been insufficient and the joint was most likely understressed. Figure e also indicates too low a spindle-sleeve pressure whilst the top contour of the joint offers evidence of a worn roll profile; f indicates a worn roll profile and fold overlap has not been achieved. The spindle-sleeve pressure and the first and second roller adjustments were too light. The sections in g, h and i suffered from incorrect adjustment on too wide a groove of the first roller whilst the second roller exerted too low a pressure. Whilst in g overlapping has been reasonably well achieved, in h and i it is pretty poor. It is even worse in k where to the effect of too low a spindle-sleeve pressure must be added that of a worn pass profile. The above examples represent a purely arbitrary selection of fold-joints which can of course be added to *ad. lib.* In any case, the most usual cause of imperfect joint forming is to be found in locally encountered compression inadequacies, possibly due to no fault of the operator, but rather to periodic fluctuations below tolerance of the sheet thickness. A second cause is worn, and hence widened, roller grooves. These thickness variations pose a problem which has been an evergreen item on the agenda of the standards committees concerned for almost as long as one cares to mention. There is no doubt that the sheet and strip manufacturers are doing everything in their power to meet the needs of consumers in this respect and will continue to do so until the problem is finally solved. Certainly, by using additional stands or passes, variations in thickness can be kept well below what is normal, but this increases costs and is not really economically viable. One might perhaps advise consumers to consider sorting their panels automatically into pre-determined thickness ranges. Were this to be done and a sufficient stock of the various thickness categories maintained, folding could be carried out in batches and the machine reset for each successive batch thickness. Another way of avoiding defects caused by too low a roller pressure would be the use of oil-hydraulic instead of mechanical screw adjustment. This would ensure that bodies of differing sheet thickness passed through the bodymaker machine would be under constant roll pressure.

Since modern oil-hydraulic valve and sealing technique allows working pressures up to 315 atm.g., there should be no difficulty in designing a roll adjustment system on this principle for use in folding machines. Moverover, thanks to the development of new materials, roll wear can now be largely minimized.

Attention is drawn in this connection to the various hard-metal qualities available and to the sintered material developed a few years ago.

Finally, we proceed to a description of a newly developed double reverse bend testing machine (see figure 1, p. 537) which was specifically designed to meet the requirements of the packaging industry in determining the foldability of thin sheet. In conventional reverse bending test machines, the slewing gear usually consists of a slewable lever with laterally projecting guide pins between and with which the top end of the test bar is placed and bent to and fro. The disadvantage of this method is that the bending point gradually moves upwards from the restraint position as a result of work-hardening thereby falsifying the test results (Biblio. 16). In view of this, a reverse bending process was developed whereby a spring-loaded bending roller was fitted above and to the side of the restraining mandrels with the aim of preventing migration of the flexure point. Examples of this type of test are the Jenkins bend test and the double alternating bend test described hereunder (Biblio. 24). In this machine, the specimen is tested at both ends simultaneously. This was achieved by departing from the Jenkins principle, wherein the to and fro moving is the bending roller, and making the restraining block itself slewable. The latter only holds the centre section of the bar as it slews to and fro the two ends of the bar are correspondingly bent and reverse-bent by the four pressure loaded bending rollers.



Action of the slewable restraining block in the double alternating bending test

The method of operation of this machine is illustrated in the above figure by six diagrams showing successive working positions of the slewable restraining block (a) with its two pairs of mandrels (b_I and b_{II}), the clamped test bar (c) and the four peripheral bending rollers (d_1, d_2, d_3, d_4). In top left the initial position is shown. In top right the block slewed clockwise onto the stops is shown whereby the ends of the bar are bent through 90° by pressure rollers (d_2 and d_3).

The first bend (1) has now been completed and the block is slewed anticlockwise for the second bend (2); rollers (d_1 and d_4) underrun the bar ends just before the block reaches its limiting position of slew (2) and bend them in the reverse direction. If the limit stop (2) is reached, the bar will be reverse-bent still further. The right centre diagram shows rollers (d_2 and d_3) underrunning the reverse-bent bar ends prior to rebending them (3) in the original or bend (1) direction. This cycle is continued until one of the ends of the test bar ruptures.

The left bottom diagram shows the slew from bend (3) to bend (4) with rollers (d_1 and d_4) in the same halfway underrun position as were (d_2) and (d_3) in the right centre diagram. In the bottom right the block has completed its anticlockwise slew onto the stops and bend (4) is now fully executed. Further bending can then be continued in the same way (5).

In this test each pair of mandrels can, if desired, be differently radiused. In such case pair I, for example, will be given the standard radius r specified for the test and the behaviour of this end of the bar will be decisive for the test result. Pair II will be radiused to approx. 1·1r and the breaking behaviour of this end of the bar also observed. Any specimen whose end II ruptures before or simultaneously with its end I, and equally any specimen whose end II withstands more than 3 bends after fracture of end I is discarded as unsuitable for evaluation, thereby ensuring that the test results are not vitiated by excessively anisotropic specimens. Furthermore, the proportion of anisotropic stock can be determined over a large number of tests, providing information which may sometimes be a more valuable guide to a material's operational suitability than knowledge of the mean value of reverse bend test results.

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J. de LACOMBE

Bending and Folding of Steel Sheet and Plate

(Translated from French)

Mr. Oehler has given a remarkably complete report on the fold-jointing of sheet, including a classification of the various procedures involved and the main working precautions to be taken.

It is, of course, the very large-scale mass-production of ordinary sheet steel articles that offers the widest field of application for these processes.

In the case of stainless steels, of which we ourselves have had greater experience, fold-jointing is also commonly used for mass-production of all types of goods.

Figure 2 on p. 537, for example, shows the assembly of the base of a washing-machine drum made from 17% chrome steel to a body of the same material by means of a single circular fold-joint.

Figure 3 on p. 537, which illustrates a pail made from chequered 17% chrome steel sheet, shows a double rectilinear fold closing the body and a double circular fold-joint joining this to the base.

Figure 4 on p. 538, relates to a very different application of 17% chrome steel, i.e. that of roofing, where the header joints, which can be seen, are likewise fold-joints made on site using appropriate portable equipment.

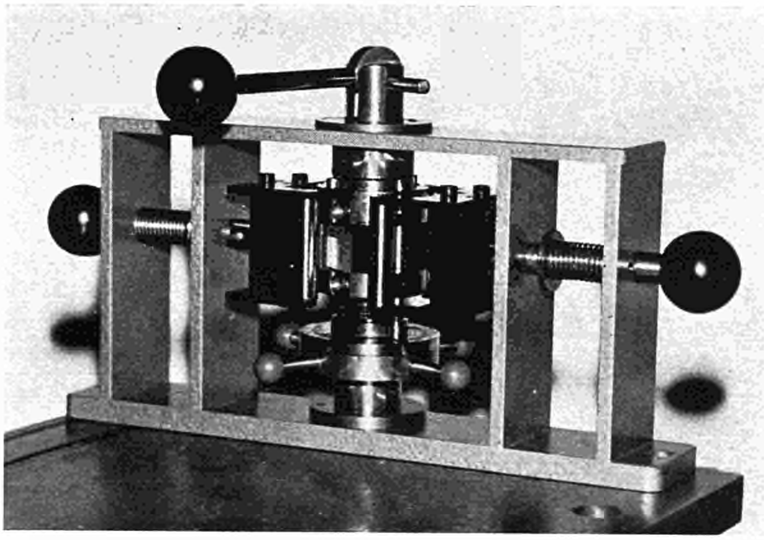
Figure 5 on p. 538, shows a small 18% chrome, 8% nickel steel dish for the photographic industry in which the bottom and one of the corners are fold-jointed.

The examples could be multiplied but it must still be recognised that electric spot welding or continuous seam welding also constitutes an economical method which is widely used alongside fold-jointing for similar mass-production assembly work.

It is important to stress that, as a general rule, both austenitic and 17% chrome ferritic stainless steels, as at present supplied by steelworks, are suitable for the bend-jointing of thin sheet, up to at least 1 mm., without any fear of crack formation. Roughly speaking, it may be said that tight folding of these steels is always possible both lengthwise and crosswise.

Nevertheless, as Mr. Oehler has pointed out so well, when working with forming-rollers, a gradually progressive operation is advisable.

List of illustrations



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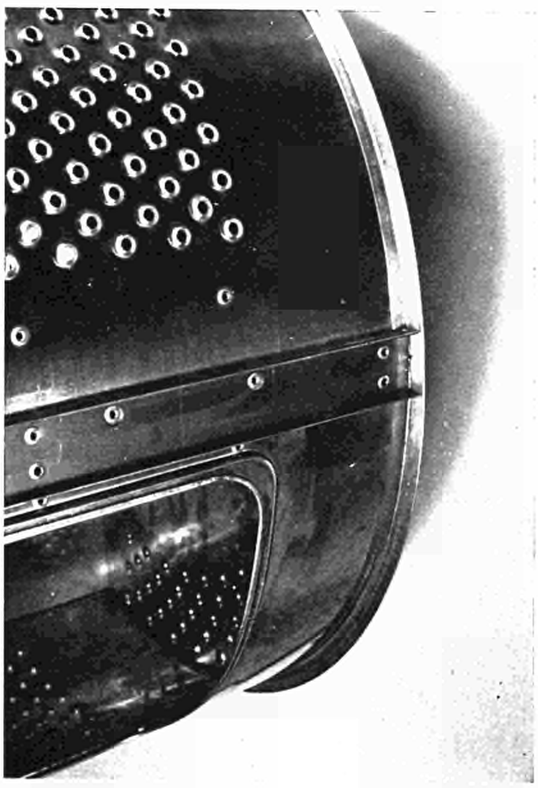

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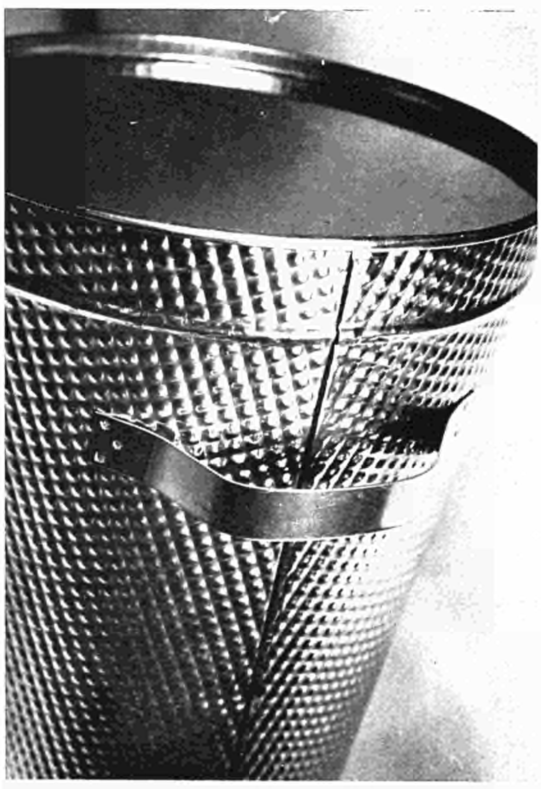

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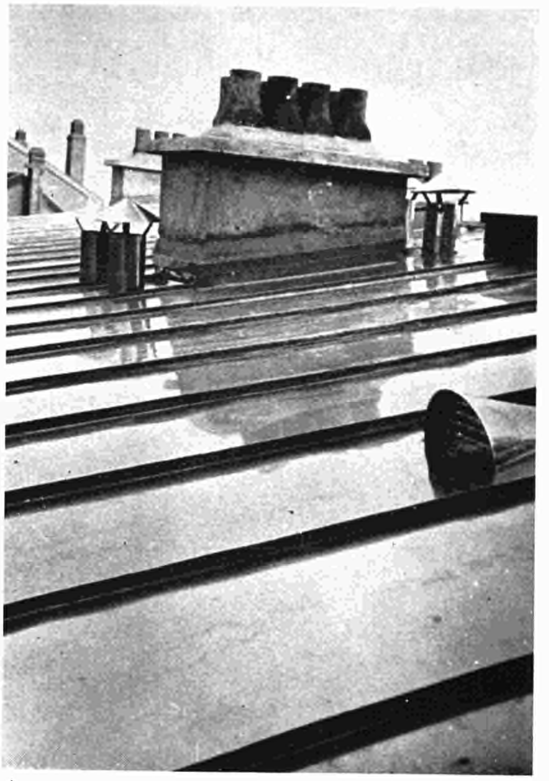

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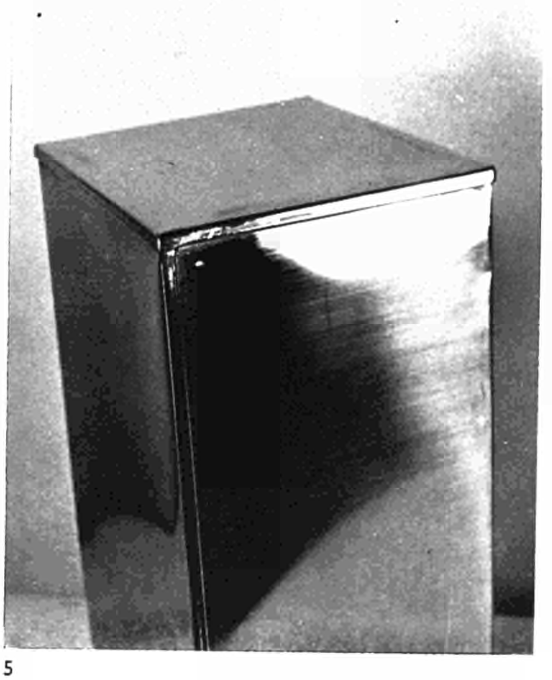


5

Christian TROGNON

Riveting and Bolting

(Translated from French)

The aim of this paper is not to cover fully the subject of jointing and assembly by riveting and bolting, but to show the practical development of these techniques in the form of a summarized report, with special emphasis on modern assembly techniques.

Riveting

This is a very well-known assembly technique for constructional steelwork, but its use is declining.

Structural connexions are designed on the assumption that rivets act in shear, whereas in fact calculations should allow for the fact that the assembled — or riveted — plates are held together by friction.

As stated by the Rapporteurs at the 6th I.A.B.S.E. Congress in Stockholm in 1960, it is unwise to calculate riveted connexions on friction, and such calculations are in fact based on shear stress and bearing stress on the shanks.

Application of these two design methods to a conventional connexion shows that in the case of rivets with an elastic limit between 21 and 24 kg. per sq./mm. there is a frictional stress of 8 to 11 kg. per sq./cm. with a shear stress of 4 to 5 kg. per sq./mm.

In many cases however the number of rivets calculated is considerably increased, particularly when they support longitudinal slip.

This practice is adopted to ensure a tight joint or to obtain a snug fit of the plates between the rivets in order to prevent the spread of rust by the Evans effect. It must be remembered that the contact surfaces of the connexion should never be painted to protect them against rust (reduction of the coefficient of friction).

Riveting on site requires considerable equipment (rivet heater, riveting hammer, compressor), and very often the holes have to be reamed; this makes it difficult to control the riveting operation, particularly as regards strain hardening of the heads through riveting at too low temperature.

The total thickness of the plates to be joined is limited by practical regulations, but experience shows that if the total thickness of the connexion is consistent the expansion of the central part of the shank when hot is greater when pneumatic rivet guns are used than with hydraulic or pneumatic riveting.

Special rivets, mainly used in:
steel sheet (car bodies, refrigerators)
boiler plating (floors and sides of wagons)
repair work (blind riveting).

These are pop rivets of all makes and Rivelons. The latter have recently been used in all the connexions for mass-produced steel swimming pools made in France.

This assembly technique has proved to be the most reliable. As none of the parts of a swimming pool exceeds 500 kg. in weight, it was necessary to retain the basic "Meccano" principle with a range of tightening in the use of the bolts and control of the tightening tension during assembly on site, thereby largely avoiding disturbance due to bad weather.

The principle of this special rivet called "Rivelon" is as follows: it is a steel rivet of a well-known quality, the shank of which is composed of

(a) a smooth part, the nominal grip;
(b) a series of circular grooves on to which the collar is crimped;
(c) a breakable section (circular neck);
(d) a stub with circular grooves for setting the rivet.

The Rivelon is completed by a special collar which, when the rivet is set, is crimped on to the shank by cold plastic deformation in the axial direction.

Riveting is done by means of special generator-operated pneumatic or hydraulic guns.

This equipment enables the following operations to be effected automatically:

(a) alignment of the connexion members;
(b) crimping of the collar;
(c) breaking the shank of the rivet through the neck and ejection of the stub of the shank used for setting the rivet.

These rivets are made in diameters from 4 to 16 mm. and may be used for connexions of a total thickness from 3 to 51 mm., depending on the diameters used.

Bolting

Standard bolts

As with rivets, the bolts in a connexion are calculated on shear. In fact, the real strength lies in the pressure exerted by the head (tension of shank at the head).

In structural steelwork assembles, we prefer bolts which:

(a) are machined (shank under shear stress instead of bending moment should there be slight slip if the tightening is inadequate);
(b) have short treading (so that the shear planes pass through the solid shank and not the threads);
(c) fit into holes perfectly reamed by the reaming machine (play approximately 0·2 to 0·3 mm.).

At the present time bolts are used only in special cases on site, or for blank assembly tests in the workshop for structural members whose assembly tolerances on site are very strict.

The machined bolt with short thread, known as the turned bolt, necessitates careful broaching followed by perfect reaming. The cost of this operation is so high that it is used only for assembly on site of units riveted in the workshop. The standard thread bolt is still used for ordinary structures under low stress.

High-strength bolts

The high-strength bolt is today considered as a fundamentally new method of assembly since this technique of American origin was chiefly used to replace defective rivets. It is now being increasingly used in France.

At the present time, as far as we know, there are no official French regulations on the use of high-strength bolts for connexions, with the exception of

(a) an Appendix No. 2 to Bulletin Technique No. 9 of April 1962 published by the "Chambre Syndicale des Entrepreneurs de Constructions Métalliques de France", entitled "Directives pour l'utilisation des boulons à haute résistance établies par la Commission No. 10 de la Convention Européenne de la Construction Métallique" (Recommendations for the use of high-strength bolts issued by Committee No. 10 of the European Convention of Constructional Steelwork Associations);

(b) the provisional specifications for the supply and use of high-strength bolts issued by the public authorities for civil engineering or industrial structures.

The principle of using high-strength bolts is well-known and has been the subject of extensive research on assembly and jointing. The technique consists of applying a tightening torque to the bolt in order to induce in the bolt a stress sufficient to clamp together the connected members so that the friction (or adhesion) between these parts prevents relative slip.

The tightening and friction moments are vital in design and the permissible friction load is the characteristic limit which is the criterion in evaluating safety.

The permissible friction load (for a bolt and a single plane of slip) is obtained from the shank tension at rest P (or axial force) multiplied by the slip factor (or coefficient of friction) μ, allowing for a load factor ν in relation to slip.

In the recommendations of the European Convention of Constructional Steelwork Associations the following directives are given:

ν = 1·25 in the case of the most unfavourable load for the connexion concerned, according to the rules for the design of constructional steelwork, for both bridges and building frames.

μ = 0·30 if the contact surfaces are not prepared in any way;

μ = 0·45 for mild steel;

μ = 0·52 for steel 42-44;

μ = 0·60 for steel 50-52, provided the contact surfaces have been either flame-cleaned or sand- or grit-blasted.

The applied torque is given:

— either by the formula: C_{mkg} = K.D.P. where:

K = 0·18 for nominal diameters between 16 and 17 (S.I. thread)

D = nominal diameter of bolt

P = shank tension at rest = 0·8 $R_{e\omega}$

where R_e = elastic proof load

ω = cross sectional area of shank.

With this formula the result is increased by 10% in order to provide a definite guarantee of the actual presence of this force after tightening.

— or in practice with a given rotation of the wrench tightening the nut, starting from the position of the hand tightened nut:

$\alpha = 90 + t + D$, where:

α = rotation in degrees

t = total thickness of connected members in mm.

D = nominal diameter of bolt.

We should mention that manufacturers of high-strength bolts originally gave a tightening torque in mkg. equal to the nominal diameter in mm. for all bolts up to 24 mm. diameter.

Let us examine the theoretical formulae for the tightening torque (very thorough research has been done on this by S.N.C.F. and E.D.F. engineers). We see that the tightening torque is equal to:

(I) a torque C_1 due to the friction of the nut on its bearing surface and a force parallel to the axis of the bolt — equal and opposite to the tension of the bolt — due to the action of the bearing surface on the nut, assuming the tension of the bolt to be equally distributed amongst all the points of contact of the nut on its bearing surface and that the stress is constant throughout the cross section of the bolt shank;

(II) a torque C_2 due to the obliqueness of the primary reactions on the threads (this obliqueness being the result of the pitch of the threads and the friction between the contact surfaces) and a force parallel to the axis equal to the tension of the bolt due to the action of the bolt on the nut, assuming the coefficient of friction (f) between nut and bolt is the same all along the thread.

It is interesting to apply the theoretical formulae to all diameters from 10 to 30 and to one grade of steel, and to obtain from them formulae for practical use. We give below the values of the tightening torques for the use of high-strength bolts at 80% of the elastic proof load of the bolt (51 kg. per sq./mm.):

either $C_{mkg} = 0{\cdot}278\,(\varnothing - 8)^2 + 3{\cdot}9$ where $f = 0{\cdot}15$ if the threads are oily or bonderized and not greased,

or $C_{mkg} = 0{\cdot}344\,(\varnothing - 8)^2 + 4{\cdot}8$ where $f = 0{\cdot}20$ if the threads are dry,

where $\varnothing$ = nominal diameters in mm. (valid from $\varnothing$ 10 to 30).

We should not end this section without giving the results of static friction tests in simple tension on a series of specially designed test pieces, some of which provided very flat contact surfaces without need to remove the scale, while others were planed, sanded and coated with various paints.

These test pieces, consisting of two flats of 80 × 10, were connected by a high-strength bolt $\varnothing$ 20 passing through an oblong hole 22 × 30. To ensure that the plane of slip was on the axis of the tensile machine, the ends of the test pieces were of flats 20 mm. thick, welded and staggered.

After the bolt had been tightened to 40 mkg., not with a torque wrench but with a one metre long lever with an accurate spring balance, each test piece was subjected to tension on a machine belonging to the "Centre Expérimental de Recherches et d'Etudes du Bâtiment et des Travaux Publics", which applied the load very gradually. The relative displacements (of the contact surfaces of the connexion formed) were measured by means of two opposing extensometers, then curves were plotted on the basis of the results obtained.

The following table shows the average stresses, F, read at the moment t when the two contact surfaces of the joint started to slip.

Tightening on	F in tons
Scale	3·9
Very slightly greasy sanded faces	3·4
Surgically clean sanded faces	4·5
1 coat on each face, of paint with + 90% zinc powder, "Soudee" binder, extremely hard after drying	5·47
3 coats on each face, of paint with + 90% zinc powder, "Soudee" binder, extremely hard after drying	4·8
1 coat on each face, of paint with + 90% zinc powder, glycerolphthalic binder	4·3
1 coat on each face, of paint with + 90% zinc powder, rubber binder	3·5
1 coat on each face, of paint with + 90% zinc powder, oily binder	4·05
1 coat on each face, glycerolphthalic red lead	3·3
1 coat on each face, graphitized glycerolphthalic red lead	2·8
1 coat on each face, of graphitized red lead in oil	1·9
1 coat on each face, of metallic lead, epikote binder	3·16
1 coat on each face, of metallic lead, oily binder	1·54
1 coat on each face, of calcium plumbate	1·6

In view of these results, the experiments were repeated with test pieces coated with the type of paint which had given the best results in static tests, but this time they were conducted on the premises of a French constructional steelwork company, with a system of highly accurate lever compression and tensile testing machines.

Verification of the above static tests first gave results of between 4·1 tons and 5·75 tons depending on the smoothness of the coat of paint.

The alternate stress tests gave results of 3·5 tons with the following stresses:

(I) 10 successive tensions from 0 to 3·5 tons, then 0;

(II) 10 successive compressions from 0 to 3·5 tons, then 0;

This cycle was repeated 10 times, then:

(I) 9 successive tensions from 0 to 3·5 tons, then 0, and finally

(II) 1 tension untill slip, or in all 210 loadings.

Following these tests, the "Association Technique Française de Galvanisation et Zinc et Alliage" conducted static friction tests with the same test pieces, the results of which, converted to apply to the same experimental conditions, were as follows:

(a) Galvanized test pieces:
depending on the thickness of the coat, the loads required to cause slip between the two surfaces in contact ranged from 2-4 tons;

(b) Zinc coated test pieces:
depending on the thickness of the coat, the loads required to cause slip between the two surfaces in contact ranged from 3·8 to 6·2 tons.

In one special case of large steelwork structure, where in situ exposure tests of test pieces protected against corrosion corroborated the friction tests, the use of paints with a high zinc content enabled all the steel members to be protected without any concern about the connexions arising. This technique thus obviated difficult inspection and the meticulous work on the contact surfaces which would have been necessary if traditional protection against corrosion had been used, and also provided an additional guarantee against the spread of corrosion (Evans effect).

The following types of torque wrench are suitable for controlled tightening of high-strength bolts:

(1) manual: wrenches with flexion shaft with or without release, torsion bar wrenches, spring wrenches (not very accurate);

(2) pneumatic or impact wrenches with or without torque limiter.

The thightening operation may be based on a given rotation of the nut after the parts to be assembled have been brought into close contact by hand.

All the bolts in a connexion must be tightened in a given order according to a tightening scale.

Special high-strength bolts

(a) Extended bolts. — These are bolts with an extra long thread which can be tightened from one side of the joint only by means of a special torque wrench.

(b) Torshear bolts. —These are extended bolts having a circulargroove in the shank, calculated to shear off under the action of a torque equal to and in the opposite direction to the tightening torque to within plus or minus 10%.

These bolts greatly facilitate (visual) control and their use in emergent countries is increasing.

Ribbolts, Dardelet and similar bolts

These "rivets-bolts" have a round or milled head and a grooved shank (the grooves being longitudinal or longitudinal and circular) for a thickness equal to the total thickness of the connexion, terminated by a threaded section with either an ordinary nut or a special lock nut.

These bolts are calculated on shear. They are tightened with a torque wrench.

Huckbolt fasteners

These rivets with circular grooves are often incorrectly called bolts.

American standard A.S.T.M. 325 on the use of high strength bolts permits the use of other clamping systems, provided all the components comply with the chemical and mechanical properties of high-strength bolts and the contact surfaces (washers) are equal (of equal nominal diameters).

This gave rise to the Huckbolt high-strength fastener which is derived from the rivelon and which complies with the requirements of A.S.T.M. 325.

The manufacturers of these special rivets have conducted numerous tests in independent laboratories in many states in the U.S.A. These tests covered:

1) the Huckbolt: chemical analysis, tensile strength, residual stresses, hardness, breaking off of the head, contact surfaces of the heads and collars.
2) the connexion: friction, slip, fatique (up to 2,000,000 cycles).

The driving of these Huckbolt rivets is identical with that of Rivelons; the required range of tightening is easy to obtain.

We would mention that they can easily be removed by means of a special wrench which bursts the locking collar.

Other assembly and jointing techniques

(1) Philips and Nelson studs.
These are chiefly used for securing rails, flooring, cladding, etc. and in steel bridge decking.
They are contact-arc-welded onto metal parts by means of special guns.

(2) Various steel screws (Sin, Parker, etc.) widely used in all the sheet-steel industries.

(3) The fasteners for roofing and cladding sheet-steel may be considered as means of assembly. Mention should be made of a roofing system of galvanized sheet with trapezoidal corrugations assembled without fixing holes and the joining of galvanized corrugated sheet cladding by means of special fasteners with recessed nuts, without slot or angle, tightened by means of a friction screwdriver.

(4) We shall end with lock-forming or overlapping, an assembly technique used only for sheet, and mainly for ventilation ducts.
This method of assembly is very quick, thanks to machines with wheels or a series of rolls, and it simplifies complex connexions (Y-shaped pipes, conical elbows) because of the play it permits.

Conclusion

Because of the rapidity with which they can be fixed, because of the fact that they require only limited and unskilled labour on site, because of the remarkable facility with which they can be inspected, because they can be dismantled, because of their unchanging mechanical qualities even under alternating dynamic stresses it appears to us that there will be a considerable increase in the use of high-strength bolts, Torshear bolts, Huckbolt fasteners, etc.

It is hoped that numerous experiments will enable the friction coefficients required for their use to be defined with greater accuracy.

They will then make a noteworthy addition to a widely used assembly technique-arc welding.

Robert J. SCHLIEKELMANN

Adhesive Bonding of Steel

(Translated from Dutch)

The first real breakthrough in the application of adhesive-bonded joints in load-carrying metal structures was in light-alloy airframes (Biblio. 1). Since then, adhesive bonding has been adopted in other fields, including light alloy, and more recently also of steel structures.

It may be questioned whether the use of adhesive-bonded joints in steel structures has not been delayed unreasonably long.

This paper deals with certain aspects related to metal-bonding in general, and it is therefore also relevant to steel structures and products; in addition, it discusses the specific advantages and difficulties of the adhesive bonding of steel.

General design aspects of metal-bonded joints

Classification

Given the nature of the process, adhesive-bonded joints must be classed as permanent joints which cannot be dismantled during normal use. Adhesive bonding of metals thus falls into the same class of joining methods as welding, soldering, brazing, riveting and permanent bolting.

Continuity of the joint

The great feature of the bonded joint is its continuity over the whole contact surface area of the parts to be joined. Much of its attraction is due to its possession of this property.

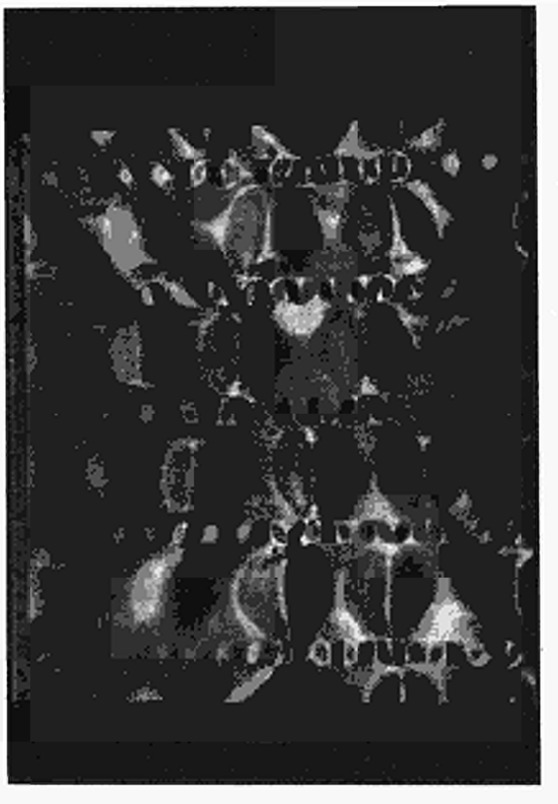
Strength of bonded joints

Thanks to this continuity, it is possible to obtain very efficient joints with the aid of cured synthetic resin as a bonding agent, even though this in itself a relatively weak material compared with the materials to be joined. As regards strength, bonded joints compare favourably with traditional riveted, bolted and welded joints, which normally have only concentrated spot-joints (Biblio. 2).

Enlarging the contact surface area of the bonded joint increases the joint's load-carrying capacity. Account must, however, be taken of the stress distribution in the adhesive layer itself; a point discussed in detail below.

The value of this continuity characterizing bonded joints is perhaps most clearly apparent in the case of joints between relatively thin components the load-carrying capacity of which is limited owing to local stability. The use of bonding in connecting members is not only an efficient method in itself, but also adds considerably to the stability of the separate units which are being connected.

The two continuously-joined components support each other via the adhesive layer, with the result that any tendency to local buckling occurs only at much higher load values. The required load-carrying capacity can thus be obtained with a much lighter structure. A typical example is shown in the figure below, which shows the buckling of a panel under compression loads in its own plane. The panel is backed by vertical adhesive-bonded stringers of thin sheet metal which prevent buckling of the sheet. In the areas of the bonded flanges of the stringers the buckling fields are effectively separated. Each field being thus reduced, buckling occurs at a much higher stress than when the joint is nearly local, as in the case of rivets or spot-welds.



Adhesive-bonded stringers offer by reduction of the buckle-fields a stability increase of sheet structures

This not only increases the static strength, but also lengthens the life of the structure under alternating loads.

With alternating loads, cracks tend to start at specific joint points such as rivet holes, and to increase rapidly in the buckling sheets. The continuous adhesive-bonded joint eliminates this source of trouble, and furthermore reduces the amount of buckling of the sheet (Biblio. 3).

One limitation on the use of adhesive resins is that they are so far less resistent to heat than most kinds of steel; at high operating temperatures the heat resistance of the adhesive must be taken into consideration.

The continuity of the adhesive-bonded joint enables it to be made water and gas-tight. Consequently, sealing operations, necessary to make spot joints similarly hermetic — and these can be difficult and time consuming — can be dispensed with.

Adhesive-bonded joints do not distort the components joined, and the joint is invisible from the far side. Moreover the mechanical properties of the joined materials are unaffected, in contrast to the effect in welding; also serious temperature stresses cannot occur. This considerably benefits both the external appearance of the construction and its technical performance.

The continuity, water-tightness and chemical resistance of many of the adhesives employed make it possible for the corrosion resistance of bonded joints to be very much superior to that offered by traditional methods.

Adhesive bonding as a process permits simultaneous joining of large surfaces or large numbers of components, which can represent a considerable saving in costs.

These important advantages can however, be turned to full account only if the inherent properties and problems of the adhesive-bonded joint are borne in mind during both the design and the production stage.

The design of the bonded joint

The designer must make certain that the adhesive selected will be strong enough to stand up to the anticipated operating conditions.

There are a number of first-class adhesives on the market today, full particulars of whose properties are available from the manufacturers (Biblio. 4). It should be borne in mind, however, that test results depend to a considerable extent on the geometry of the specimen and on the test method.

I should like to emphasize in this connection the desirability of framing standard European specifications for bonding adhesives, for steel in particular, which could be used by the designers as a basis for their work.

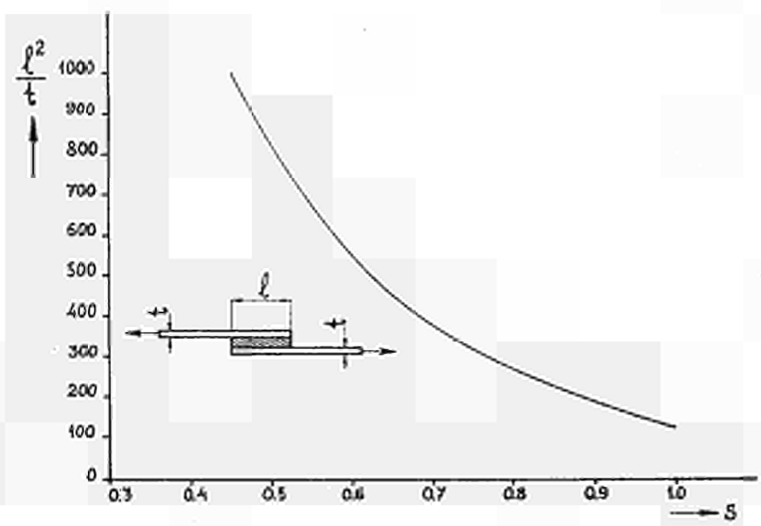
The American specification MIL-A-5090 D, defining five classes of structural adhesives of which the two highest relate exclusively to corrosion-resistant steel, might well be taken as a model. The highest class lists adhesives suitable for use in a temperature range of — 55° to + 260°C (Biblio. 5). For lap joint specimens of 1·27 mm.-thick 17-7 PH corrosion-resistant steel with 12·7 mm. overlap length, the shear strength figures must correspond to the values shown in the following table. Also room-temperature shear-strength figures given must be met after exposure to a number of specified environments, such as 30 days salt-spray, 30 days at 100% R.H. and 49 °C, etc., and 7 days submergence in various test liquids.

Specification of properties for adhesive bonded metal-to-metal joints according to U.S.A.F. Spec. MIL-A-5090 D
Steel 17-7 PH $t = 1{\cdot}27$ mm. $l = 12{\cdot}7$ mm.

Condition	Min. shear strength $\bar{\tau}_S$ kg./mm².
At 24° C	1·6
At 24° C after 30 days saltspray	1·5
At 24° C after 30 days 100% R.H. 49° C	1·5
At 24° C after 30 days water	1·5
At 24° C after 7 days JP-4	1·5
At 24° C after 7 days alcohol	1·5
At 24° C after 7 days hydr. oil	1·5
At 149° C after 192 hrs. at 149° C	1·4
At 260° C after 10 min. at 260° C	1·3
At 260° C after 192 hrs. at 260° C	0·7
At —55° C after 10 min. at —55° C	1·6

When, and only when, the manufacturer can produce official certificates showing that the material meets the given specification or that the results were obtained with tests under the specified circumstances, can the designer consider he has a sound basis for starting his work. Even so, he must remember that these data were obtained with specimens of a certain well-defined configuration. After all, the strength of the adhesive itself is only 5-10% of that of the materials to be joined. When this relatively low failing-stress level of the adhesive is reached only locally, the whole bonded joint will fail. The average failing stress obtainable in the adhesive bonded joint depends on the stress distribution, which in turn depends on the strain differences under load in the parts to be joined. If these differ from those in the specified test specimen, the average failing stress will differ from that of the specimen. A number of scientists have formed theories concerning the shear-stress distribution in bonded joints under shear load that open the possibility for conversion calculation (Biblio. 6, 7 and 8). The stress distribution in the adhesive-bonded joint is governed by the ratio of sheet thickness (t) to lap length (*l*), and by the modulus of elasticity of the sheet material and the shear modulus of the adhesive.

In the following figure, for 17-7 PH steel and the usual structural adhesives a rough but very useful conversion factor S is given, to be used for various (t/*l*) ratios on the shear strength values obtained with the specification specimens.



Conversion method for the shear strength at failure of the standard lap-joint specimen into the strength of a lap-joint with sheet thickness t and overlap length l.

The average shear stress at failure will then be

$$\bar{\tau}(t,l) = S(t,l) \cdot \bar{\tau} \quad \begin{matrix}(t = 1{\cdot}27 \text{ mm.})\\ (l = 12{\cdot}7 \text{ mm.})\end{matrix}$$

This factor S is based on Volkersen's theory, which is valid only where the bonded components are loaded in the elastic range i.e. follow Hooke's Law.

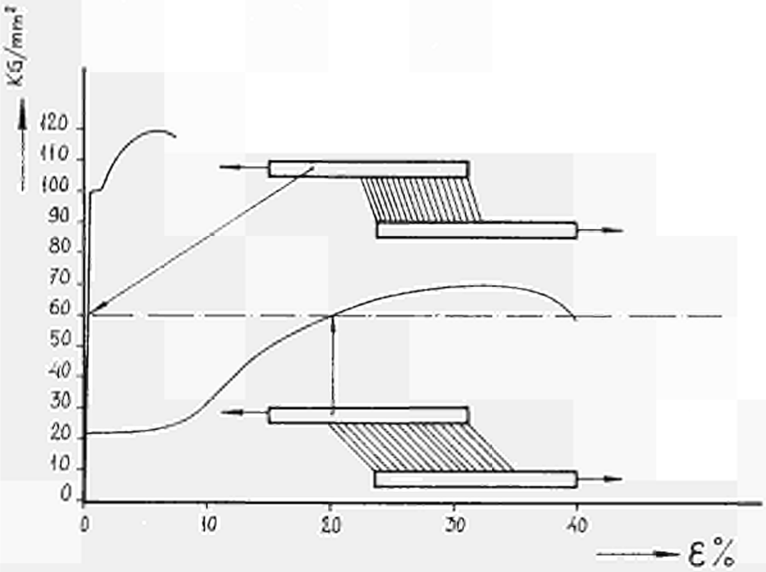
When the proportionality limit is exceeded, the characteristic differences between the various kinds of steel have to be borne in mind.

Alloy steels such as 17-7 PH, which after passing the proportionality limit show only a very limited yield and finally only a small plastic elongation at failure, of only around 4-7% allow calculation by the above method to a high stress level. (17-7 PH is a precipitation hardened steel with

$$\sigma_B = 125 \text{ kg./mm.}^2,\ \sigma_{0.2} = 105 \text{ kg./mm.}^2 \text{ and } \delta_{10} = 4\text{-}7\%)$$

With steels such as 18-8 chrome-nickel steel, which deform plastically at a low stress value and have a well-defined plastic yield zone and high elongation at failure, special care is needed in connection with the sheet stresses in the plastic region.

The high plastic deformation in the sheet at the edge of the bond area causes large sheet-deformation differences and stress concentrations in the adhesive layer. This is shown schematically in the figure below. Only adhesives with a high elongation at failure and a low shear modulus can be used for joints between the latter kinds of steel, which have to reach failing stresses well within the plastic deformation region of the joined steel.



The influence of the stress-strain relation of the steel-sheet on the stress distribution in the adhesive-bonded joint.

The data for many adhesives are expressed as average shear stress at failure determined with dural 2024-T3 lap-joint specimens of 1·6 mm. sheet thickness and 12·7 mm. overlap length. These data can be converted into the values of the standard specimens of steel (t = 1·27 mm. and *l* = 12·7 mm.) by taking into account the influence of E-modulus and sheet thickness according to Volkersen. On this basis the shear strength figures of the standard dural specimen (t = 1·6 mm.; *l* = 12·7 mm.) can be converted into those of the standard steel specimen (t = 1·27 mm. and *l* = 12·7 mm.) by multiplying by 1·33. Application of the figure on p. 549 then offers the further possibility of calculation of the other steel lap-joint configurations.

This too applies only provided the deformation of the sheet metal is elastic. In other cases a large reduction has to be taken into consideration, and even lower values than with dural can be expected.

The following examples illustrate these aspects.

(a) *Adhesive*: *EC - 1838 epoxy*

. 302 stainless steel (18-8 Cr-Ni)
metal properties $\sigma_{0.2}$ = 28 kg./mm.²; δ_{10} = 50%
bonded joint t = 1·27 mm.; *l* = 12·7 mm.
$\tau_{av.}$ = 2·7 kg./mm.²

. 2024-T3 dural
metal properties: $\sigma_{0,2}$ = 26 kg./mm.^{2} δ_{10} = 15%
bonded t = 1·6 mm.; l = 12·7 mm.
joint $\tau_{av.}$ = 2·0 kg./mm.^{2}.

(b) . *Adhesive: Redux 775 phenol-vinyl formaldehyde*

18-9 chromium nickel steel
metal properties: $\sigma_{0,2}$ = 22 kg./mm.^{2} δ_{10} = 55%
bonded t = 1 mm.; l = 10 mm.
joint $\tau_{av.}$ = 2·9 kg/mm.^{2}

dural
metal properties: $\sigma_{0,2}$ = 34 kg./mm.^{2} δ_{10} = 17·5%
bonded t = 1 mm.; l = 10 mm.
joint $\tau_{av.}$ = 3,15 kg./mm.^{2}

In case (a) a factor 1·35 was found between standard test specimens of steel and dural. At the moment of bond failure the stress in the steel sheet was 27 kg./mm.^{2} and in the dural sheet 15·9 kg./mm.^{2}; thus in both cases below the metal yield stresses.

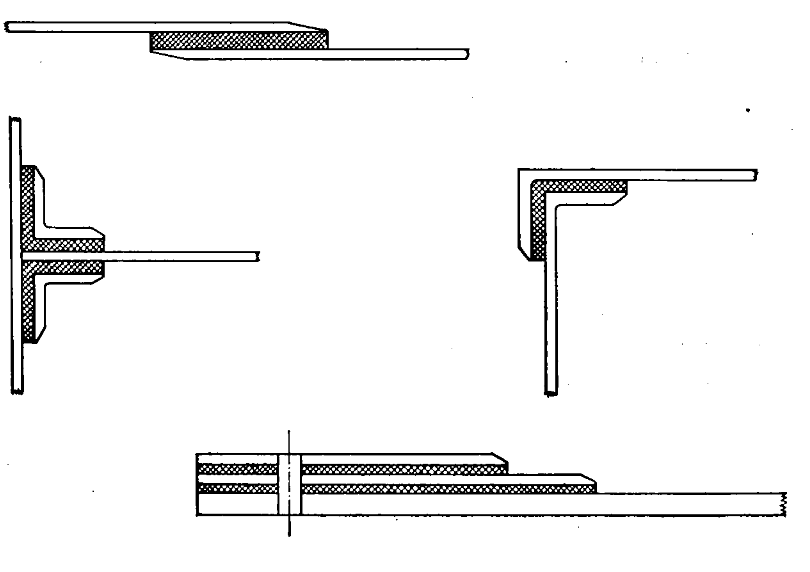
In case (b) the comparison was not between standard specimens but between specimens both with a (l/t) factor of 10. The shear stress at failure coincided with a sheet stress of 31·5 kg./mm.^{2} of the dural specimen, which is below the $\sigma_{0,2}$ yield stress. With the steel specimen a lower shear stress level at failure was reached at a sheet stress of 29 kg./mm.^{2}, already 5 kg./mm.^{2} higher than the yield stress.

It is clear that plastic deformation in the case of steel caused the early failure.

When only little experience is available, it will be advisable to check the strength of the adhesive bond configuration by means of failure-strength tests.

Generally, in the design of adhesive-bonded joints, the joint areas should be as large as possible in order to keep the stress values in the joint low.

Moreover, the structure chosen must be such as to ensure that stress concentration in the joints caused by eccentricities and "peel" forces is kept to a minimum. The figure below shows several good examples of well-designed bonded joints.



Typical examples of well-designed adhesive-bonded joints.

Pre-treatment of the bond surface

In the foregoing the mechanical properties of and stress distribution in the adhesive layer were taken as decisive factors for the joint strength, i.e. attention was concentrated particularly on the so-called *cohesion* properties of the adhesion layer.

It was presumed in that case that the joint strength between adhesive layer and steel bonding surfaces, the so-called "*adhesion*" strength, would not be lower than the "*cohesion*" strength of the adhesive layer itself.

The cohesion strength depends on the chemical composition and the curing of the adhesive; the adhesion strength, however, depends on the surface condition of the steel prior to the application of the adhesive. In order to enable the designer to predict with reasonable accuracy the strength of the bonded joint and to design rationally, production must always be so organized that the prerequisite condition: Adhesion > Cohesion is fulfilled.

The adhesion between the adhesive and a metal surface depends on the attraction forces between the molecules in the metal surface and the adhesive. These can only exist when the bond surface is completely free of grease, dirt and oxides, which could make contact between the polar steel and the adhesive elements impossible.

Before bonding every steel surface must at least be degreased and deoxidized. There are various methods of doing so.

De-greasing can be effected by dipping in liquids or in vapour which condenses on the surface. The latter method is the most reliable.

For the removal of the oxide skin, either mechanical or chemical methods can be used. For example, grit-blasting according to the Vacublast principle is a very effective method of cleaning steel (Biblio. 9).

One major practical problem is the fact that the deoxidized surfaces oxidize again very rapidly in air unless special precautions are taken.

Moreover penetration of moisture through the adhesive layer itself or from corrosion adjacent to the bond-edges must be prevented in order to exclude the possibility of corrosion of the contact surfaces under operating conditions. There are various methods of dealing with this problem. Good results can be obtained with water-thin liquid adhesives; the so-called "adhesive primers," which can be applied and dried immediately after the pre-treatment of the bond-surfaces, and if possible also on the adjacent areas of the bond.

The final bonded joint can then be made later by applying the adhesive layer on top of the dried primer coat; this adhesive may be then hot- or cold-curing.

Another possibility is to combine a chemical deoxidizing process with a corrosion-preventive treatment such as a phosphoric acid treatment or the Bonder process. The latter not only offers a good adhesion basis for the adhesive but also ensures excellent corrosion resistance for the whole structure.

In judging the adhesion quality of a bonded joint, it should be borne in mind that low adhesion quality shows up strongest after exposure to hot air having a high relative humidity. Testing is best effected after several hundreds of hours at 50°C and 95-100% R.H.

In one case, cold rolled steel had after bonding, preceded only by vapour degreasing, very nearly the same shear strength as after vapour degreasing plus the Bonder process the shear strength figures were 1·97 and 1·99 kg./mm.² respectively. After 30 days at 100% R.H. and 38°C these shear strengths were found to have fallen to 0·27 and 1·67 kg./mm.² respectively.

In the second case the strength reduction of the adhesive layer only was measured; in the first, that of the steel degreased by vapour only, the adhesion had been completely destroyed, mainly by corrosion.

The cohesion strength of the bonded-joint is the result of the curing of the resin following either chemical reaction of the various resin components or a heat treatment process. Compared with adhesion strength, the cohesion quality is relatively easy to control.

Methods are now also available for non-destructive testing of cohesion quality, such as the Fokker Bond Tester System (Biblio. II).

Applications

Load-carrying structures

If it is desired to use metal bonding in steel structures in the same way as in light-alloy airframes, viz. as an indispensable part in a really reliable load-bearing structure, all these advantages can well be obtained but only provided that the various aspects I have noted are carefully borne in mind. Given well chosen materials, good design and execution, very striking technological results can be achieved. In the United States good results have been obtained in the last 15 years with, for instance, large bonded steel inspection covers on diesel-electric locomotives, which with other types of design had previously afforded considerable difficulties.

There remain however numerous other possibilities for adhesive bonding in load-bearing steel structures which have not yet been turned to account. Thus adhesive-bonded joints can add considerably to the rigidity of bolted or riveted truss-structures of bridges etc. Shear loaded bridge webs, etc., can be lighter if the web stiffeners are adhesive-bonded on to the web plates prior to riveting or bolting, where the use of these is retained.

Flange plates on heavily loaded parts of booms of bridge sections can be made thinner when these are bonded instead of riveted. Railway wagons can be made stiffer and lighter and also more pleasing in appearance when stressed skin structures with adhesive-bonded stiffeners are used. Primary adhesive-bonded joints are being successfully used in the manufacture of technical instruments and installations. On the military side use is now being made of the adhesive-bonded joint in the frames of vehicles for land and water transportation. Adhesive bonding is much used in the construction of missiles and artificial satellites. Smooth noiseless adhesive-bonded joints in railway tracts offering in addition electrical insulation between one section and another have been in successful use for some years in the United States. The problem of the maintenance of sufficient adhesion quality has been solved by the introduction of adhesive primers which can be applied at the works after which the final bonding can be carried out in the open air during assembly.

Non-load-carrying structures

There are undoubtedly any number of structures and products incorporating less important joints which can equally well be effected by bonding. Such joints often require only relatively low strengths, e.g. where spot-welded sheet-joints have to be replaced.

It is clear that strength control in the design plays a much less important role. In consequence, there is the risk that no effort will be made during production to obtain higher quality jointing than is absolutely demanded. It must, however, be remembered that reduced surface treatment of the metal and/or reduced curing which may be sufficient initially to fulfill the low standard of quality required very often have very bad ageing characteristics: over a period, moisture may have such a serious effect that the joint fails completely so that the lowest quality requirement is not fulfilled.

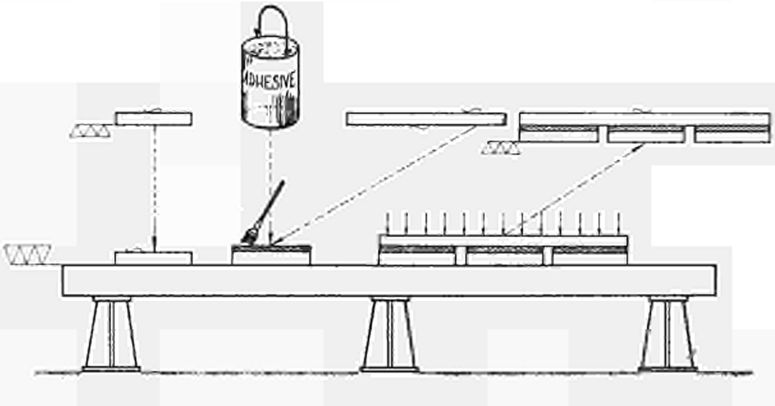
In the motor industry, spot welded joints in various constructions have for some time past been replaced or at least supplemented by adhesive bonding (Biblio. 12 and 13). The view has been taken that the low strength required should be obtained without special pretreatment of the oily steel surface as received from the rolling mill.

In the meantime remarkable results have been obtained with the use of epoxy adhesive pastes which can dissolve the thin grease layer and absorb it into glue layer. Some car manufacturers have in recent years been successfully connecting reinforcement frames to external car-body parts, such as doors, etc., based on incompletely pretreated steel sheets. To lessen the admittedly considerable influence of atmospheric conditions on these bonded joints, they are designed so that exposure to the weather is reduced to a minimum, while in addition good protection is given by the paint spraying.

One important application is the use of adhesive as an insulating joint in, for instance, large transformer cores and electromagnets as employed for nuclear purposes. There are also major openings for the adhesive bonding of various different kinds of steel to one another or to non-metallic meatrials. A good example of the former is the cladding of non-corrosion-resistant steel with a thin layer of stainless steel. With high curing temperatures of up to 290°C and curing times of about 30 sec. such joint strengths have been attained that under certain circumstances deformation of the composite material as one piece was possible.

An important application of steel to non-metals is the bonding of friction material to brake-shoes and coupling discs. These have a much higher capacity and longer life than by the earlier riveted method (Biblio. 12 and 13.).

In the field of machine-tool construction important results have been obtained with gap-filling adhesives for the low-cost production of large accurate flat tables and reference planes of jigs. For this purpose, use is made of a large number os small square steel plates accurately ground on one side only, which are placed with the machined side on an accurate flat table. The un-machined side which has been cleaned beforehand by the Vacublast method, is covered with a thick coat of adhesive, if necessary including several layers of glass-fibre cloth. The less accurate supporting structure is then placed with its pretreated face plates on the adhesive layers. After curing of the adhesive, the ground faces of the steel components form together a plane as accurate as the original flat table.



Principle for the production of accurate planes with the aid of adhesive-bonded steel elements

Conclusion

It is certainly possible to make much more extensive use of adhesive bonding of steel than is the case to-day.

Its introduction has probably been retarded by poor results with secondary joints which by reason of their low quality requirements had been treated so inadequately that the most essential prerequisites for a good bonded joint were not fulfilled.

The premature failure of these secondary joints has deterred many designers from using bonded joints in important load-bearing primary structures.

Where adhesive bonding is efficiently and expertly used by designers and production engineers this can do a great deal to ensure better, stronger and more economic steel structures.

The European Coal and Steel Community can make a contribution by drawing up a classification of adhesive materials to facilitate the choice of material for the designer.

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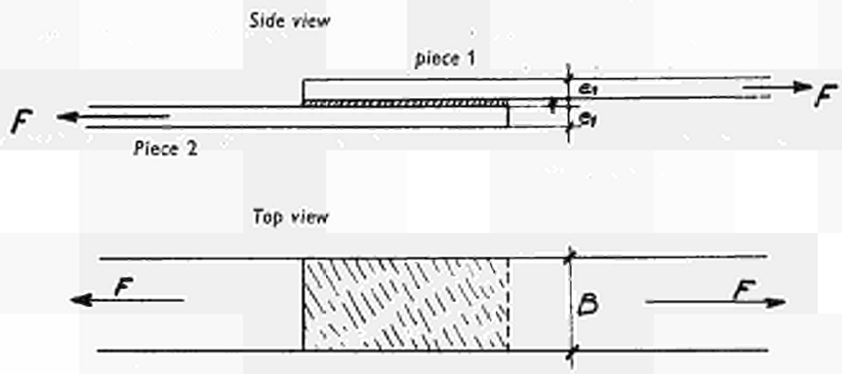
André FANJAT de SAINT-FONT

Stress Distribution in an Adhesive-Bond Joint

(Translated from French)

We shall consider the bonded joint in the following figure



— B *is the width of the two pieces, which have a uniform thickness e*

— η *is the uniform thickness of the bonded joint*

— *l* *is the length of the bonded joint*

— E *is the elasticity modulus (Young's modulus for the adherents)*

— G_c *is the shear modulus of the bond*

We shall make the following assumptions:

a — the sections remain level during their deformation,

b — Hooke's law is still applicable,

c — the elastic modulus E is very large compared with the shear modulus G_c.

We shall assume that the deformation has the form as indicated in the figure below.

Let us consider a prism a b c d a' b' c' d' forming a section in the assembly constituted by the two pieces. After deformation under the action of the two forces + F and − F applied to the assembly, this prism becomes:

a_1 b_1 c_1 d_1 a'_1 b'_1 c'_1 d'_1

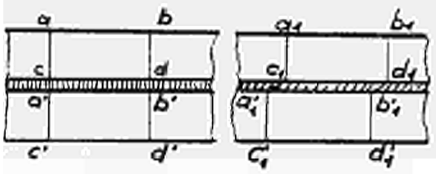
The faces ac, bd, a'c', b'd' are displaced parallel to themselves.

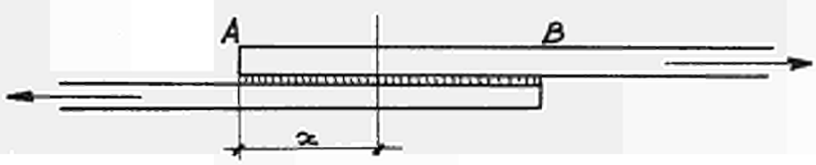
Let σ_1 be the stress in piece 1

σ_2 be the stress in piece 2

τ be the shear stress in the bonded joint.

We shall take as a parameter the abscissa x of the section under consideration, with its origin at the extreme left of the assembly (see right hand figure below).





With all calculations made on these assumptions, we obtain:

$$\sigma_1 = \frac{\sigma_0}{2}\left[\frac{1+e^{-\frac{l}{lc}}}{e^{\frac{l}{lc}}-e^{-\frac{l}{lc}}}\,e^{\frac{x}{lc}} - \frac{1+e^{-\frac{l}{lc}}}{e^{\frac{l}{lc}}-e^{-\frac{l}{lc}}}\,e^{\frac{x}{lc}} + 1\right]$$

$$\sigma_2 = \frac{\sigma_0}{2}\left[-\frac{1+e^{-\frac{l}{lc}}}{e^{\frac{l}{lc}}-e^{-\frac{l}{lc}}}\,e^{\frac{x}{lc}} + \frac{1+e^{\frac{l}{lc}}}{e^{\frac{l}{lc}}-e^{-\frac{l}{lc}}}\,e^{-\frac{x}{lc}} + 1\right]$$

$$\tau = \sigma_0\sqrt{\frac{e_1 G_c}{2 E_1 \eta}}\;\frac{\left(1+e^{-\frac{l}{lc}}\right)e^{\frac{x}{lc}} + \left(1+e^{\frac{l}{lc}}\right)e^{-\frac{x}{lc}}}{e^{\frac{l}{lc}}-e^{-\frac{l}{lc}}}$$

These formulae can be written:

$$\sigma_1 = \frac{\sigma_0}{2}\left[1 + \frac{\mathrm{sh}\,\frac{x}{lc} + \mathrm{sh}\,\frac{x-l}{lc}}{\mathrm{sh}\,\frac{l}{lc}}\right]$$

$$\sigma_2 = \frac{\sigma_0}{2}\left[1 - \frac{\operatorname{sh}\frac{x}{l_c} + \operatorname{sh}\frac{x-l}{l_c}}{\operatorname{sh}\frac{l}{l_c}}\right]$$

$$\tau = \sigma_0\sqrt{\frac{e_1 G_c}{2 E_1 \eta}}\;\frac{\operatorname{ch}\frac{x}{l_c} + \operatorname{ch}\frac{x-l}{l_c}}{\operatorname{sh}\frac{l}{l_c}}$$

Or alternatively :

$$\sigma_1 = \frac{\sigma_0}{2}\left[1 + \frac{\operatorname{sh}\frac{2x-l}{2l_c}}{\operatorname{sh}\frac{l}{2l_c}}\right]$$

$$\sigma_2 = \frac{\sigma_0}{2}\left[1 - \frac{\operatorname{sh}\frac{2x-l}{2l_c}}{\operatorname{sh}\frac{l}{2l_c}}\right]$$

$$\tau = \sigma_0\sqrt{\frac{e_1 G_c}{2 E_1 \eta}}\;\frac{\operatorname{ch}\frac{2x-l}{2l_c}}{\operatorname{sh}\frac{l}{2l_c}}$$

σ_0 is the stress $\frac{F}{B e_1}$

e is the base of Napierian logarithms

l_c is a characteristic length with a value:

$$l_c = \sqrt{\frac{E_1 e_1 \eta}{2 G_c}}$$

Discussion of these formulae

At the two ends of the joint, we have:

A (x = 0)

$\sigma_1(0, l) = 0$
$\sigma_2(0, l) = \sigma_0$

$$\tau(0, l) = \sigma_0\sqrt{\frac{e_1 G_c}{2 E_1 \eta}}\;\frac{2 + e^{\frac{l}{l_c}} + e^{-\frac{l}{l_c}}}{e^{\frac{l}{l_c}} - e^{-\frac{l}{l_c}}}$$

$$\tau(0, l) = \sigma_0\sqrt{\frac{e_1 G_c}{2 E_1 \eta}}\;\operatorname{cotanh}\frac{l}{2 l_c} \qquad (1)$$

B (x = l)

$\sigma_1(l, l) = \sigma_0$
$\sigma_2(l, l) = 0$
$\tau(l, l) = \tau(0, l)$

The curves representing the functions $\sigma_1(x)$, $\sigma_2(x)$, and $\tau(x)$ have the forms as shown in the following figures.

We have the relationships :

$\sigma_1(x) = \sigma_2(l - x)$
$\tau(x) = \tau(l - x)$

The curve $\tau(x)$ is symmetrical in relation to the straight line $x = \frac{l}{2}$. The curves $\sigma_1(x)$ and $\sigma_2(x)$ are symmetrical in relation to the same straight line.

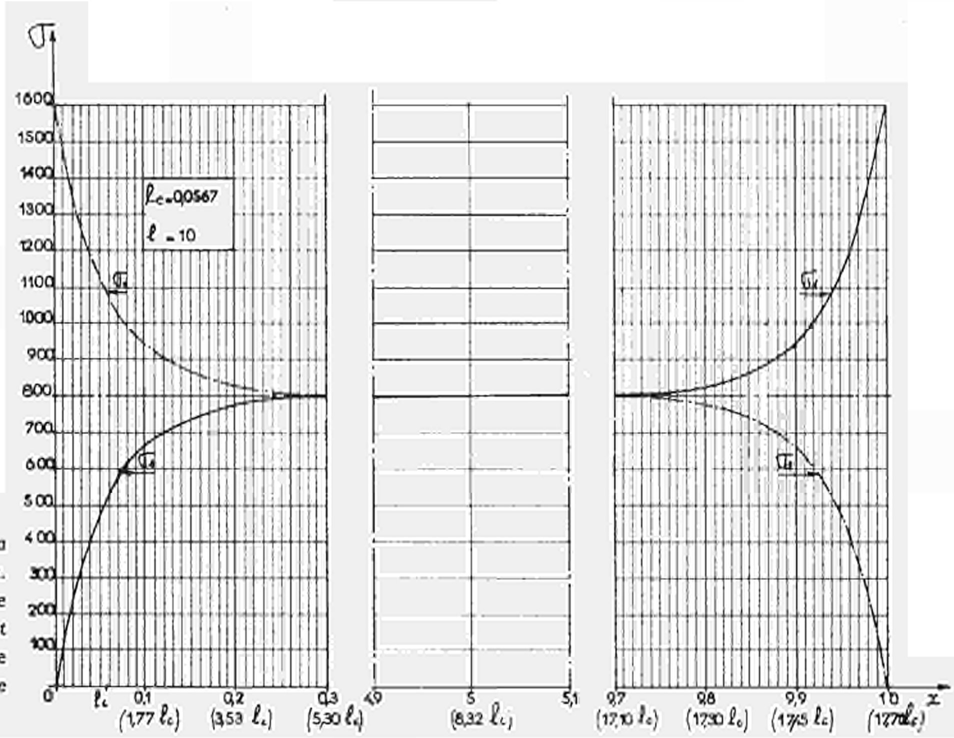
The shear stress τ is a minimum for $x = \frac{l}{2}$.

Then :

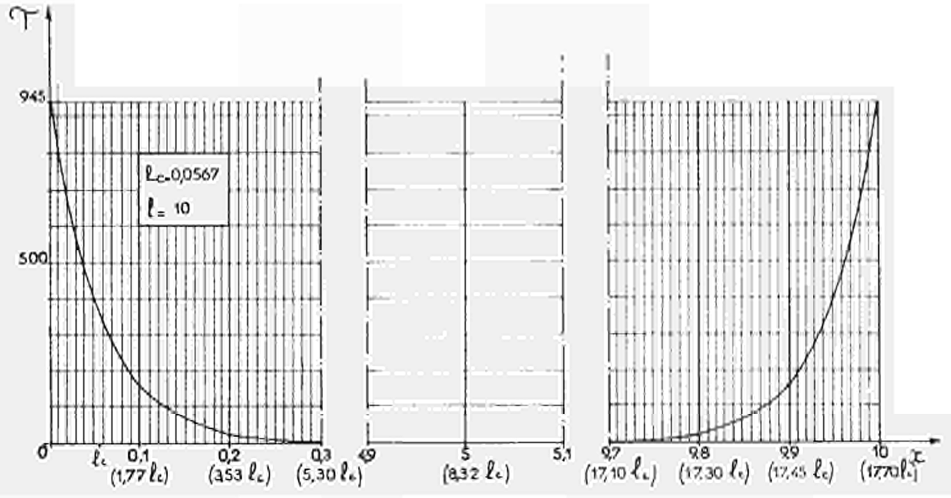
$$\tau\,\text{min.} = \tau\left(\frac{l}{2}, l\right) = \sigma_0\sqrt{\frac{e_1 G_c}{2 E_1 \eta}}\;\frac{1}{\sinh\frac{l}{2 l_c}}$$

Let us calculate the relationship :

$$\frac{\tau(0)}{\tau\left(\frac{l}{2}\right)}$$



Variation in σ_1 and σ_2 as a function of the abscissa x.
N.B. The active parts of the joint are situated at either end over a distance of about three times the characteristic length.



Distribution of the shear-stress in the adhesive joint. The shape of the curve explains that of the functions $\sigma_1(x)$ and $\sigma_2(x)$

We have: $\dfrac{\tau(0,\, l)}{\tau\left(\dfrac{l}{2},\, l\right)} = \cosh \dfrac{l}{2\,lc}$.

When $l \to \infty$, we have :

$$\tau(0,\, \infty) = \sigma_0 \sqrt{\frac{e_1\, G_c}{2\, E_1\, \eta}}$$

$$\tau\left(\frac{l}{2},\, \infty\right) = 0$$

The shear stress at the ends of the bonded joint does not tend towards zero when the length of the joint increases towards infinity. This is explained by the fact that the hatched area in the figure on p. 558, which is proportional to F, must keep a finite value which is not zero when $1 \to \infty$

If we postulate :

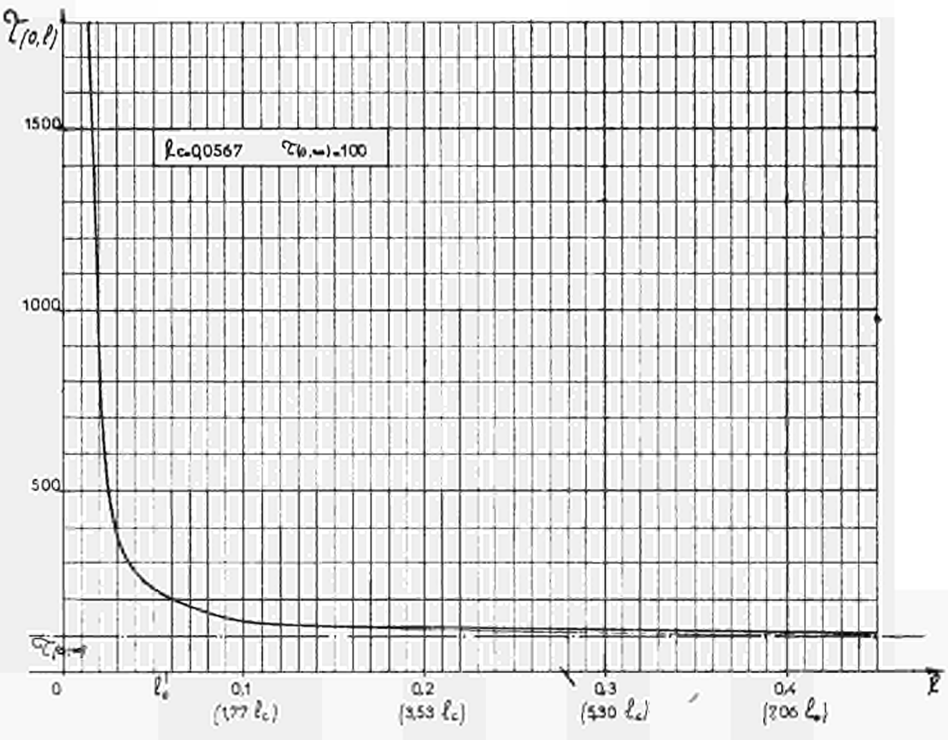
$$\tau(0,\, l) = \tau(0,\, \infty)\ \mathrm{cotanh}\ \frac{l}{2\,lc}$$

the curve representing this function is plotted in the following figure.

Check calculation for a bonded assembly

This operation consists in calculating the stress $\tau(0,\, l)$, and ensuring that it remains less than the permissible shear stress for the joint $\overline{\tau_e}$. This condition can be written:

$$\tau(0,\, l) = \tau(l,\, l) < \overline{\tau_e}$$



Variation in shear stress at the ends as a function of the assembly length. Note that beyond 1·77 times the critical length nothing is gained by increasing the assembly length as regards the maximum shearing stress. Inspection of the two preceding figures shows the permissible assembly load is reached when the optimum length is 10·6 times the critical length.

We deduce the length of l from the equation :

$$\tau(0, \infty) \text{ cotanh } \frac{l}{2\,lc} < \overline{\tau_c}$$

or :

$$\text{cotanh } \frac{l}{2\,lc} < \frac{\overline{\tau_c}}{\tau(0, \infty)} \qquad (2)$$

The hyperbolic cotangent function is always greater than unity, and so the necessary condition is :

$$\frac{\overline{\tau_c}}{\tau(0, \infty)} > 1$$

We deduce from equation (2) the condition :

$$l > lc \text{ L } \frac{\overline{\tau_c} + \tau(0, \infty)}{\overline{\tau_c} - \tau(0, \infty)}.$$

Permissible loadings for a bonded assembly

Replacing σ_0 by $\frac{F}{Be_1}$ and $\tau(0, l)$ by $\overline{\tau_c}$ in the equation (1), we get:

$$\overline{\tau_c} = \frac{F}{B} \sqrt{\frac{G_c}{2\,E_1\,e_1\,\eta}} \text{ cotanh } \frac{l}{2\,lc}$$

or :

$$F = B\,\overline{\tau_c} \sqrt{\frac{2\,E_1\,e_1\,\eta}{G_c}} \tanh \frac{l}{2\,lc}.$$

Conclusion

These formulae provide an explanation for the peeling effect always starting at an extremity of the bonded assembly.

They show that the strength of a bonded joint is very far from being proportional to its surface area, and that for a given area it depends on the ratio $\frac{B}{l}$.

We were able to apply a similar reasoning to bolted connections, and we found that the rupture of such connections also begins at the extremities.

Jacques CAUCHETIER

Protection of Structural Assemblies

(Translated from French)

The protection of structural frameworks assemblies is a matter of controversy among engineers. Should the interface be protected or not? It is almost impossible, in assembling structures by means of bolts or rivets, to achieve dead flat surfaces and to prevent moisture and air from penetrating into this zone, thus allowing the formation of rust and reducing the strength of the structure. It is quite a different matter when assembling the units by means of a continuous weld. Even if the steel components have first been sprayed with zinc or aluminium, difficulties could arise. Tests have therefore been carried out by the French Welding Office with sheets metallized with zinc to different thicknesses. No special precautions need be observed as regards the quality of the weld for thicknesses of up to 80 microns, provided that rutile-clad electrodes are used. This is not the case with basic coated electrodes, when it is advisable to eliminate the zinc before welding. With an aluminium-metallized component, the removal of the aluminium protective coating is essential to prevent the aluminium from diffusing into the metal and so embrittling the joint.

Regarding fabrication by HR bolts or rivets, tests have been undertaken in France by the French Railways and also by the International Railway Union. Tensile strength tests with bolted fish-plates, sand-blasted to different roughnesses, have shown that such assemblies are stronger than similar ones with rough fish-plates in the as-rolled condition, and all the more so since in greatly tightening the bolts, the contact surfaces between the metallic parts are diminished. Similar sandblasted assemblies but painted with red lead, had their strength greatly reduced, the paint serving as a lubricant. On the other hand thin zinc metallization (20 microns according to the German railways) maintained the same strength as the sand-blasted fish-plate. Tests are proceeding to establish whether this thickness of the protective coat could be increased without detrimental effects.

It may be said therefore, that it is today possible to protect steel fabrication and to prevent rust formation from reducing their strength.

Henri M. SCHNADT

Welding of New Steel Qualities: Problems and Solutions

(Translated from French)

I shall confine my remarks to those problems raised by the *phenomena of spontaneous brittle fracture* in large- and medium-scale welded constructions.

This paper is part of the programme of an important congress the purpose of which is to bring up to date our ideas about steel and how it can be used. Authors have been asked to state their thoughts frankly and to express them where necessary in new words.

The phenomena of spontaneous brittle fracture suddenly became apparent in the most spectacular fashion about 1935 with the failure of the Zoo bridge in Berlin and the Hasselt bridge over the Albert Canal. They have continued in evidence without intermission ever since in about a hundred Liberty and other ships, in bridges, boilers, penstocks, metal frames, liquid and gas pressure vessels and in kilometres of pipe-line, resulting in great material damage.

The tanker "World Concord" which broke in two on its maiden voyage in 1954 is another tragic example. More recently there was the case of the *new welded King's Bridge* in Melbourne, several of the principal members of which broke on 10 July 1962, shortly after its opening. An expert committee had been appointed to see to its satisfactory design and its safety.

There have been a number of fairly recent cases of brittle fracture and cracks appearing (but before they were in service) in the shields for atomic reactors. These failures are not only serious but also extremely discouraging. For these are instances of new applications, important new openings, prestige constructions to show off high quality steels and to confirm the reliability of welded construction. They are the very cases where things have gone wrong. Why therefore should we be surprised if certain authorities responsible for atomic power stations now envisage building in concrete not only the safety shields but also the pressure vessels?

The "Sunday Times" of 4 July last devoted a whole page to the subject of the many cracks which appeared in the members of the *welded steel structure* of a large building in London and to the replacement of this structure by one in pre-stressed concrete. The steel was that specified by the new British Standard BS968 which has been in force since 1962 and applied for the choice of steel for, among other things, the great Severn and Tay bridges and for the Wyllfa reactor.

The many cases of fractured or simply cracked welded constructions prove that all these difficulties have their origin in a *single, basic physico-mechanical cause* which seems to escape calculations and official specifications.

It is obvious that some progress has been made in this field, in the last 30 years. But it is equally obvious that the many problems raised by the brittle behaviour of welded construction are far from having been solved and that the serious loss of confidence felt in most quarters as a result of these fractures has not yet been regained.

If therefore we would bring up to date our ideas regarding how steel should be used and if we wish to encourage its use through increased confidence, good quality and low costs, there is only one thing to do: try to discover the scientific truth, to state it openly and unreservedly, whatever may be the temporary consequences.

The following problems have to be solved:

— to make welded structures lighter or to reduce their cost while retaining a 100% safety factor;

— to reduce the weight of these structures by the use of steels with a high or very high yield point and a corresponding increase in the maximum permissible stresses;

— to use steels in great thicknesses and to weld them without defects;

— to know the minimum temperature to which steels must be preheated before welding in order to avoid immediate or later cracking of the heat-affected zones;

— to know whether it is necessary to carry out stress-relieving or whether this expensive operation can be dispensed with;

There is a list of problems the practical solution of which can only lie in the analysis and Cartesian synthesis of the relevant phenomena as well as in the knowlegde of and absolute respect for the multiple laws which interconnect and govern these phenomena. To find a solution it will be necessary to call upon a knowledge of the physics of the solid body and the internal mechanics of welded structures.

It is also clear that the correct quantitive determination of the capacity of a steel to withstand brittle fracture (and of its numerous possible variations) can only be achieved by means both of methods of testing and of properties based on these theories

It is therefore above all on the solid and neutral ground of mechanical properties that steel-makers and constructors should meet and reach understanding and not on the waste and treacherous ground of chemical analysis, of method of manufacture and of grain size which the constructor would be well advised to leave to the appreciation of those who make the steel. To be able to transmit forces and residual stresses, mechanical properties are needed and nothing else. It is for the constructor to say which of these properties are necessary and for the metallurgist to achieve them economically and with complete regularity. Thus each party has full freedom to do what is evident and necessary.

What mechanical properties however are necessary? This is one of the main questions which welded construction still asks every day of steels, good and not so good.

I am therefore going to try to outline very briefly the elements of a scientific reply.

It is a complete illusion to imagine that it is possible to limit by calculation the stresses at the dangerous points of a structure, that is to say, at the points where fracture is likely to be initiated. There are two reasons for this:

(i) the inevitable existence of high *residual stresses* introduced by welding operations;

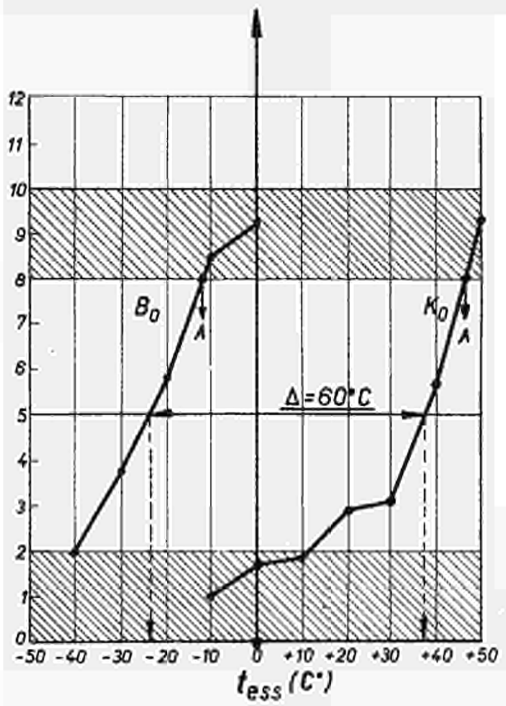
(ii) the fact that at the critical points one always has to deal with a tri-axial state of stress subjecting the steel to tensile stresses in three directions at right angles to each other. The mechanical effect of these stresses, called principal stresses, is generally quite different from that of mono- or bi-axial states which are the only ones which can be calculated.... sometimes! This difference tends to be accentuated with their degree of poly-axiality, that is to say, if the state of stress tends towards the tri-axial isotropic state.

Generally speaking, there is only one way of limiting the value of the highest principal stress at critical points and that is by relieving it by local plastic strain at the moment when, for one reason or another, this stress tends to exceed a certain value, depending among other things on the yield point of the metal at the point in question. For as soon as the steel enters the plastic range the growth of the points of stress slows down and comes to a complete stop, unless in the meantime the steel fractures because it was too brittle under the existing conditions of loading.

The capacity of a steel to deform plastically before fracture in the direction of the greatest principal stress depends on its true elongation to fracture which has absolutely nothing to do with the purely conventional elongation laid down in the specifications. It depends not only on the heterogeneity, the anisotropy, the chemical state and the heat treatment of the steel, but also on:

(i) its temperature, as is well known;
(ii) the degree of poly-axiality of the stresses;
(iii) above all, the plastic straining rate which is not mentioned either in technical commissions or in specifications.

For the present, it is enough to remember that the steels of which we are speaking all have a tendency to embrittlement: 1. when the degree of poly-axiality of the stresses increases; 2. when the temperature of the steel decreases, and 3. when the plastic straining rate increases. The following diagram (which relates to a given state of stress) shows how, for example, the plastic strain to fracture of a Thomas steel varies in relation to the temperature (on the abscissa) and the straining rate, that of the curve B_0 being about 10,000, that of the curve K_0 about 500,000%/s., and therefore 50 times higher. The great difference between these two curves shows how considerable this influence can be.



Effect of deformation rate (impact rate) on the transition curve of resilience of a basic Bessemer steel (coheracy test). Curve B_0: impact rate 100m m./s_0 curve k: impact rate 5,000 mm./s.; Difference of 60°C

The new testing technique which I put forward consistently and systematically brings into play the three fundamental parameters which I have just mentioned as well as their values encountered in practice. These are as follows:

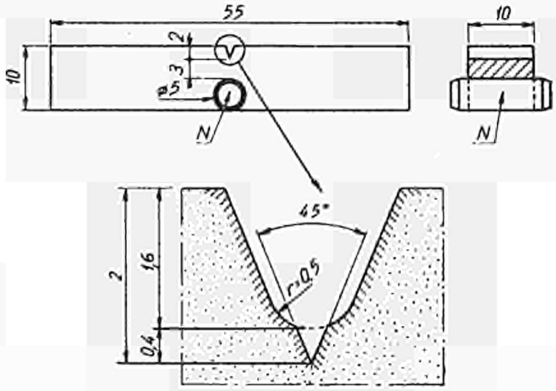
The temperature should in principle always correspond to the lowest temperature encountered in service or when the steel is brought into use.

With regard to the degree of poly-axiality of the stresses, I have shown the necessity to taking into account the so-called "acrotopic" stresses occurring at the very bottom of a natural crack, that is to say at the bottom of a very severe notch. One of the reasons for this is, for example, that the bottom of a crack, as it is initiated or propagated, is never round.

There remain the values which are possible in practice of the plastic straining rate. A clear distinction should be made between the initiation of a brittle crack and its quasi-explosive propagation. The initiation of such a fracture in a steel which is more or less ductile in ordinary tests is, contrary to current opinion, an essentially dynamic phenomenon, even if the stresses are purely static. It is in fact set off by a mechanism which can set in train straining rates of the order of 10.000%/s. On the other hand, this speed can reach 500,000 to 1 million %/s at the propagation of a more or less brittle fracture at linear speeds of up to 3000 mm./s.

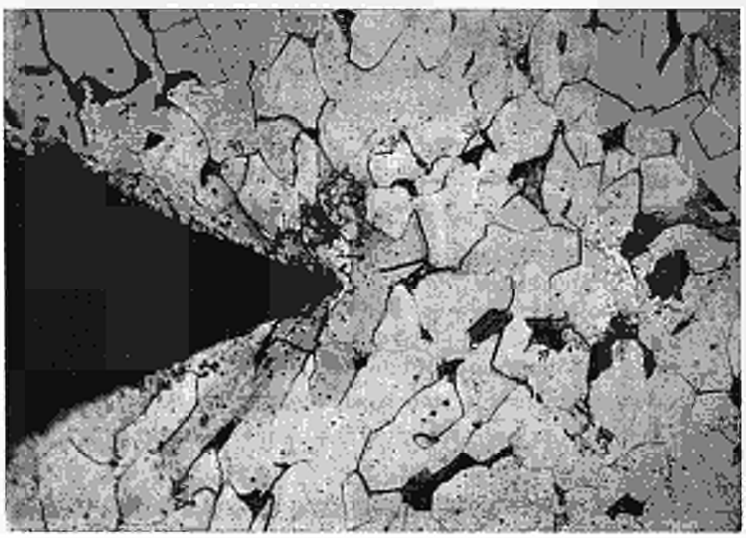
The new testing technique fulfils all the conditions mentioned above. It makes use of a test specimen with an absolutely sharp notch, called a coheracy test specimen which can easily be broken at any temperature in conditions resulting in straining rates for the steel of the order of 10.000%/s and of 500.000%/s, that is to say, speeds of the same value as those reached at the initiation and rapid progapation of brittle fracture. For this reason, this technique is the only one which is realistic and whose practical forecasts have never been proved wrong.

The following figure shows the shape and dimensions of the coheracy test specimen. It is broken as in the case of ordinary impact specimens except that in this case the load is applied at an axis of rotation centered on the notch. For this reason, the steel is subjected only to pure tensile straining without parasitic compressions.



Shape and size of the coheracy test-piece
Detail of notch (milled and pressed)

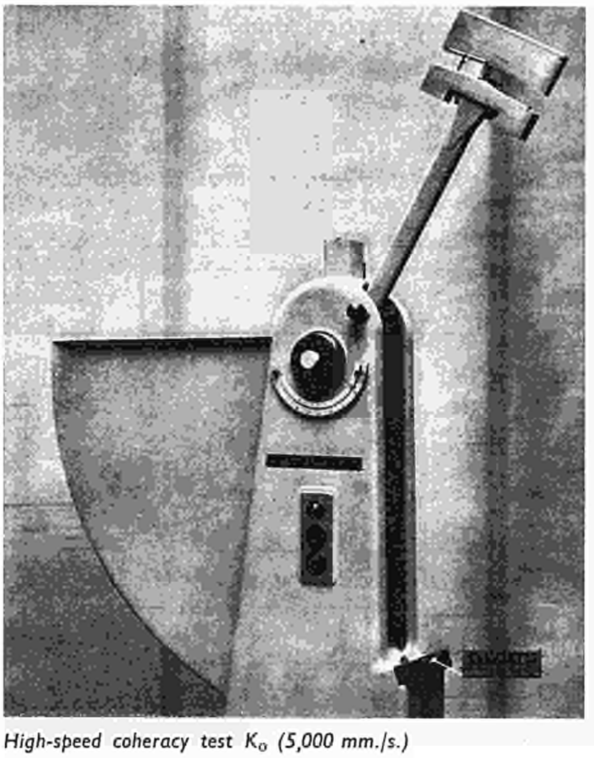
The acute notch is made by pressing at the bottom of a round notch which has first been milled. For this purpose very accurate equipment and special knives are used. The notch made in this way has a radius of less than 0·003 mm. The following illustration provides a comparison, with the same degree of enlargement,



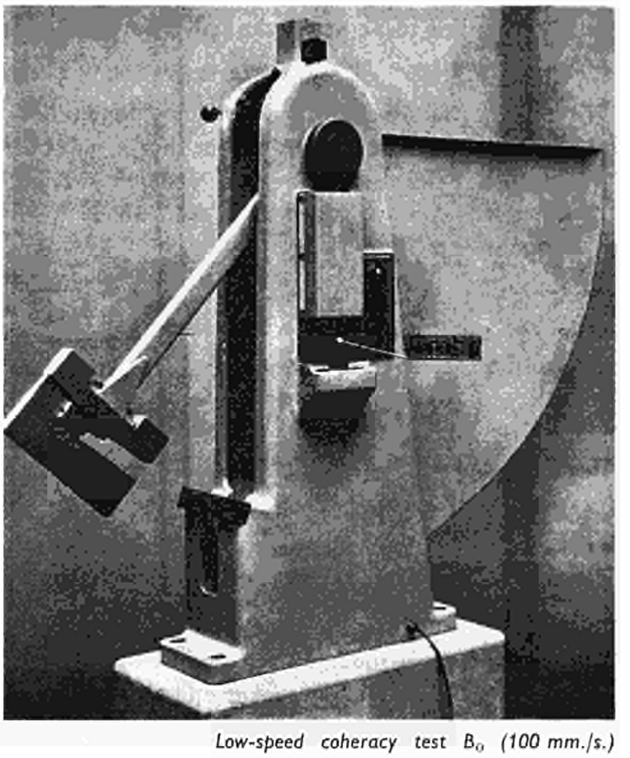
Comparison between the the coheracy notch (r = 0·005 mm.) and the Charpy-V-notch (r = 0·25 mm.)

with the notch of a Charpy-V test specimen which is also called a severe notch. The comparison speaks for itself.

The coheracy test specimen is fractured by means of a new pendulum which strikes the test specimen at two speeds whose ratio is 1 : 50, that is 100 and 5000 mm./s. In the high speed test, called tachycoheracy test, the specimen rests on supports on the bottom; in the low speed test, called bradycoheracy test, it rests on supports at the back and is broken by means of a striker worked by a cam fitted to the suspension rod of the pendulum. The fracture energy, expressed in kgm./cm.², is denoted by B_O in the low speed test and by K_O in the high speed test. This energy varies in direct relationship with the true elongation to fracture on which the relief by plastic strain of the points of tension depends.



High-speed coheracy test K_o (5,000 mm./s.)

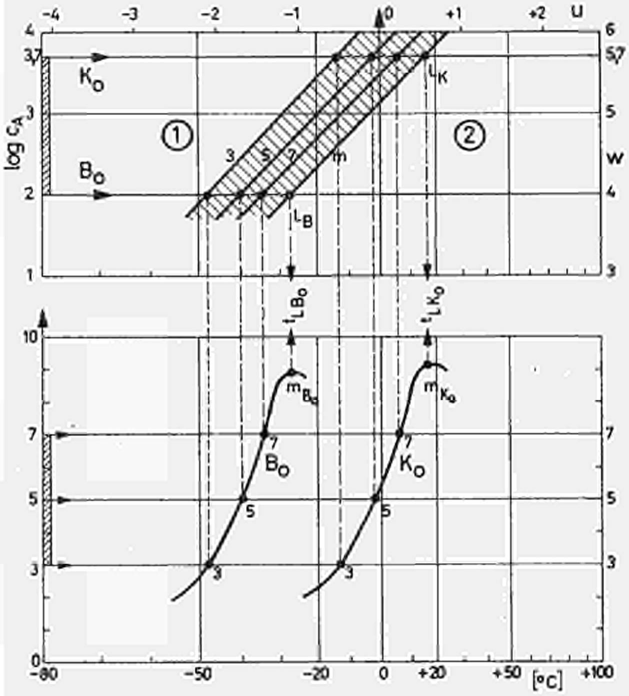


Low-speed coheracy test B_o (100 mm./s.)

The results of the new method of testing are expressed in their simplest and clearest form by the following diagram called the thermo-vectonic diagram showing on the abscissa the test temperature and on the ordinate the logarithm of the impact speed (left scale). Thus the horizontal lines B_O ordinate 2 = log 100/s and K_O ordinate 3·7 = log 5000 m/s correspond respectively to the low and high speed tests.

Using the results of the brady- and tachycoheracy tests carried out at different temperatures, it is possible to plot on this diagram a hatched zone, the boundaries of which are the straight lines 3 and "m", called the thermo-vectonic zone of the steel. A coheracy below 3 kgm./cm.² and, consequently, brittle behaviour of the metal, always correspond to the temperature/impact speed combinations represented by a point to the left of the zone; a shear fracture with a completely dull appearance, showing it to be highly plastic, always corresponds to combinations represented by a point to the right of the zone.

Determination of the thermo-vectonic zone



Definition and experimental determination of the thermo-vectonic zone of a steel by means of low-speed and high-speed coheracy transition curves. $B_0(t)$ and $K_0(t)$ obtained with the new two-speed pendulum
(1) Completely brittle zone
(2) Highly plastic zone

At this juncture, two important points which I have no time to demonstrate should be remembered. The first is that in the bradycoheracy test the straining rate for the metal at the bottom of the notch is about 10.000%/s so that the horizontal line B_O corresponds to the conditions prevailing at the initiation of a brittle fracture. The second is that in the high speed tachycoheracy test this speed is about 500.000%/s, which is to say of the same order as that attained in the quasi-explosive propagation of a brittle fracture. In this latter case the straining conditions therefore correspond to the horizontal line K_O.

From this it follows:

(1) that the potential capacity of a steel to withstand the initiation or the propagation of a more or less brittle fracture is defined by the position, the breadth and the slope of its thermo-vectonic zone, since this zone takes into account the severe notch as well as all the relevant temperatures and straining rates;

(2) that the capacity of a steel to withstand fracture increases as its thermo-vectonic zone moves towards the left;

(3) that the steel is strongly resistant to the initiation of brittle fracture at the temperature of the critical point L_{BO} and above;

(4) that at the temperature of the critical point L_{KO} and above, the steel can arrest a fracture attacking it at high speed from a neighbouring zone where it has been able to propagate freely.

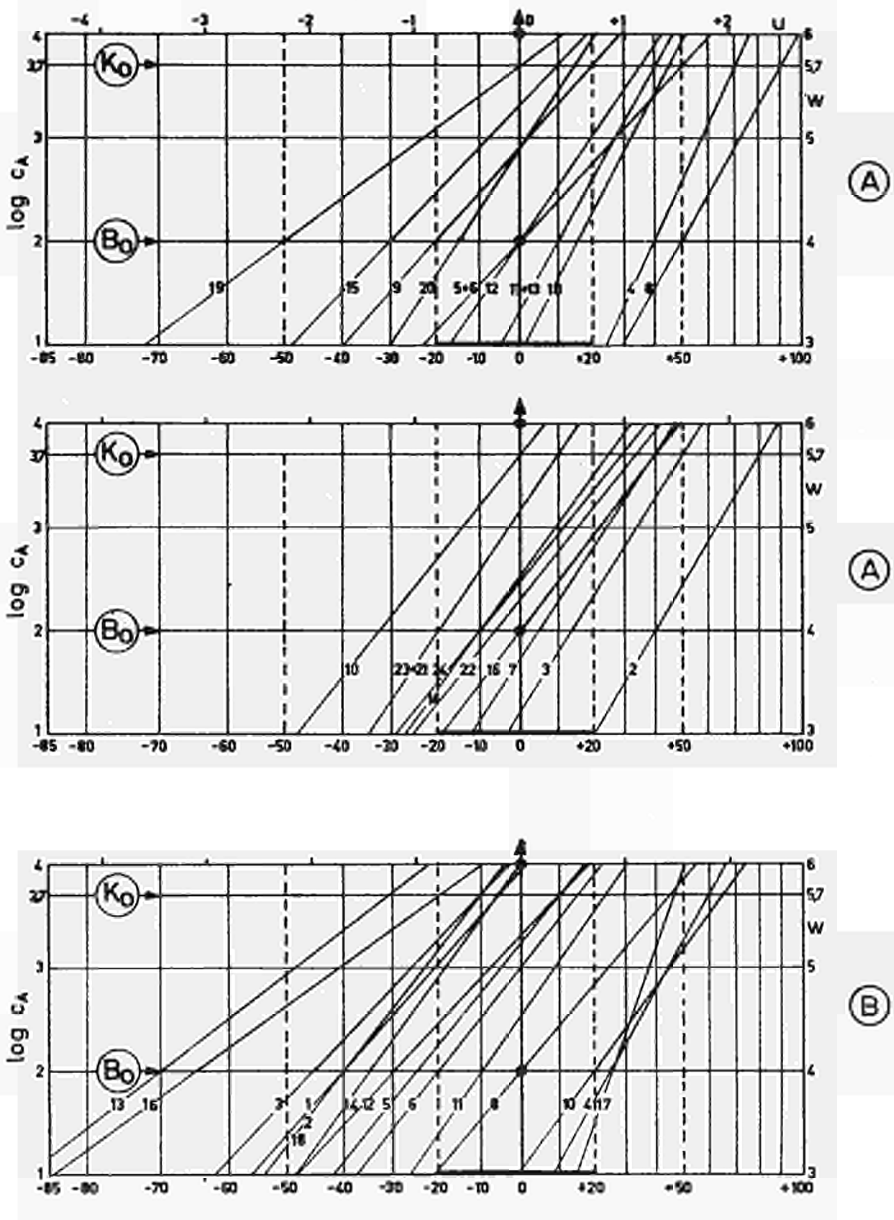
These conclusions apply to all kinds of steels and welds, including the heat-affected zones. They are fundamental and provide the new testing technique with its real practical significance which large-scale tests and industrial practice have always confirmed.

As a result, important progress has been achieved in the design of welded structures: it consists in the local use of strongly tachycoherace steels serving as crack-arrestors for any brittle fractures initiated in parts of the construction made of less expensive steels.

This technique which I put forward on the basis of entirely theoretical ideas was applied for the first time some 15 years ago when the welded Tannwald railway bridge was built in Switzerland and when the world's first large all-welded ship, the tanker "Tank Emperor", was constructed in Sweden (1950).

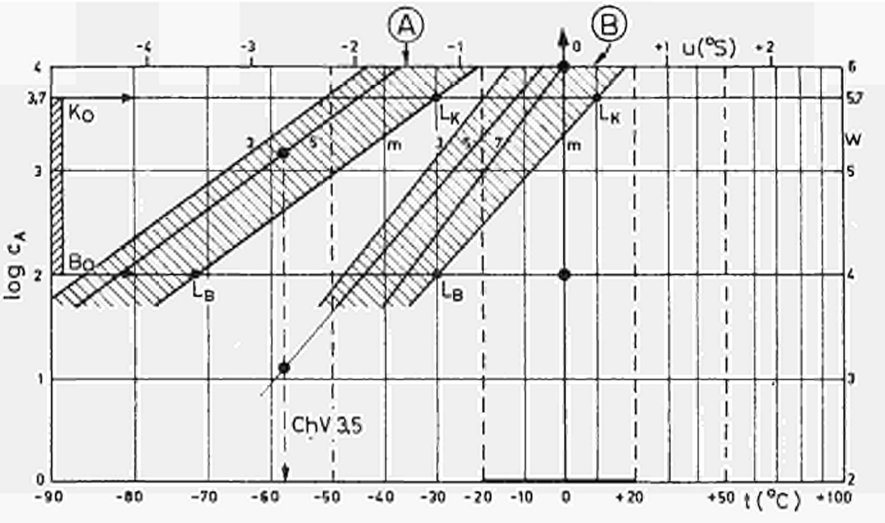
The new testing technique and its practical application in the study of 60 steels from 15 to 100 mm. thickness have been the subject of two articles published in September 1965 in Switzerland and Germany. (Oerlikon: Schweiszmitteilungen, 55/1965).

The following figure shows the position of the shear lines "m" of all the steels of groups A and B of yield strength below 50 kg./mm.². It will be seen that there is no lack of choice and that the steels are not grouped, as is claimed, around certain qualities. The best steel is able to arrest a rapid crack at −30°C, while the worst lets it propagate at about +50°C. Analogous diagrams exist for steels of groups C and D with very high yield strengths.



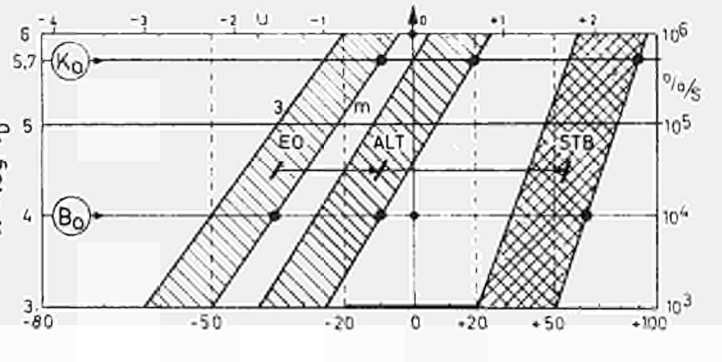
Thermo-vectonic diagram. Straight shearing lines "m" only mild steels (A), semi-mild (B)

The following figure shows the thermo-vectonic zones of two steels of the same price and with the same Charpy-V transition temperature of −58°C. These steels are however completely different from the point of view of their capacity to withstand fracture. It follows that the Charpy-V test is inappropriate for evaluating them correctly and that it may, as in the present case, lead to errors.



Comparison of the thermo-vectonic zones of two steels A and B of the same price and transition temperatures
Charpy V-notch = 3·5 kgm./cm.² (t = — 58°C.)

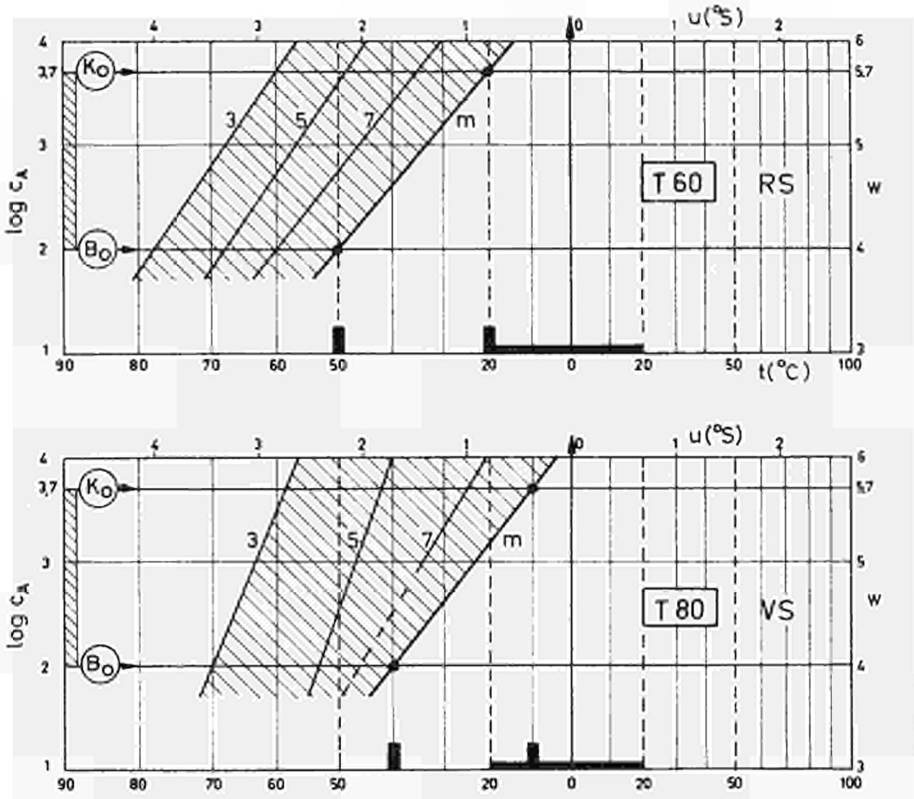
The following figures shows schematically the movement of the thermo-vectonic zone of a steel or a weld subjected to *embrittling effects* such as, for example, ageing, heat effects from welding near the welds, weld hardening, neutron bombardment, over-heating, heat treatment over a long period, etc., the state of initiation being represented by EO. It is obvious that these effects can only be appropriately evaluated by means of the thermo-vectonic diagram. I am sorry that I cannot say more on this subject today, for these effects raise considerable problems both for the metallurgist and for the constructor.



Internal embrittlement (displacement to the right of the thermo-vectonic zone) due to the manufacturing and service parameters

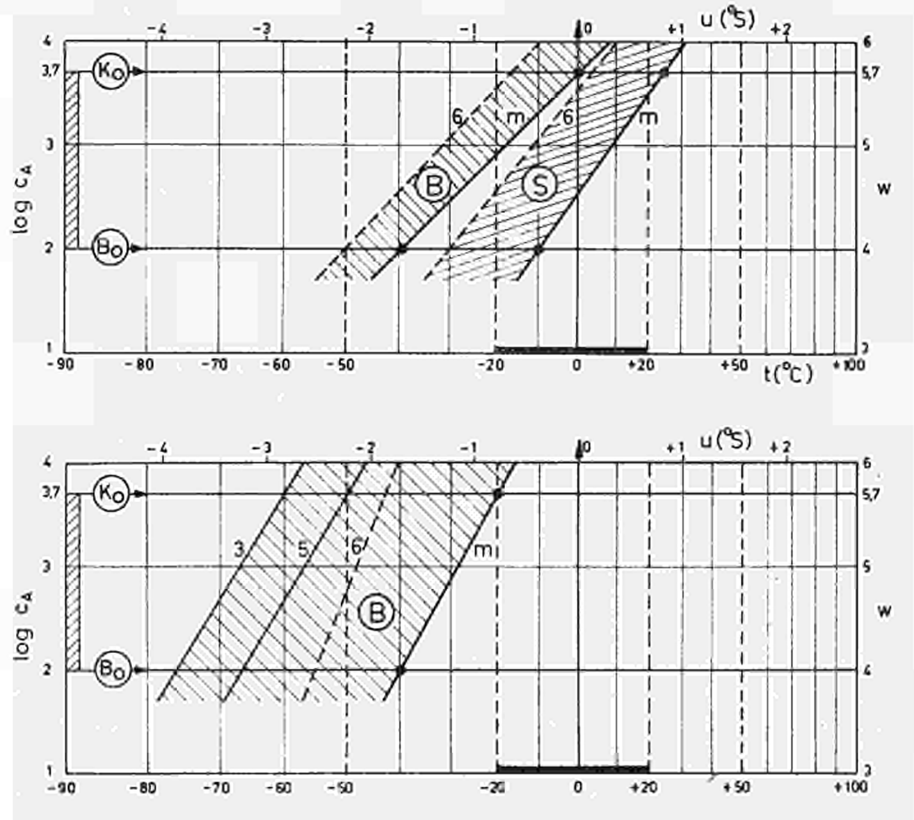
The progress of welded construction depends not only on the development of the steels but also on that of the *welds*, whether manual or automatic. Their tendency to brittle fracture should never be greater than that of the parent steel. This means that their thermo-vectonic zone should practically coincide with that of the parent steel or be further to the left. The coincidence of the zones is shown in the following figure where the thermo-vectonic zones of the welds cover the darker zone of the parent steel. This example is taken from a welded road bridge.

The next figure relates to manual welds made on low alloy high yield point steels. It will be seen that these welds have the remarkable quality of arresting an explosive fracture up to temperatures of about —30°C. Thus their thermo-vectonis zones more or less cover those of the majority of current structural steels. Not so long ago there was, from, this point of view, a fairly considerable difference between manual welds and automatic welds, the latter being far from attaining the ability to withstand fracture values of the former. This situation has changed greatly since the appearance on the market of basic-type fluxes which are used



Thermo-vectonic diagrams of hand-welds of low-alloy high-tensile-strength steels

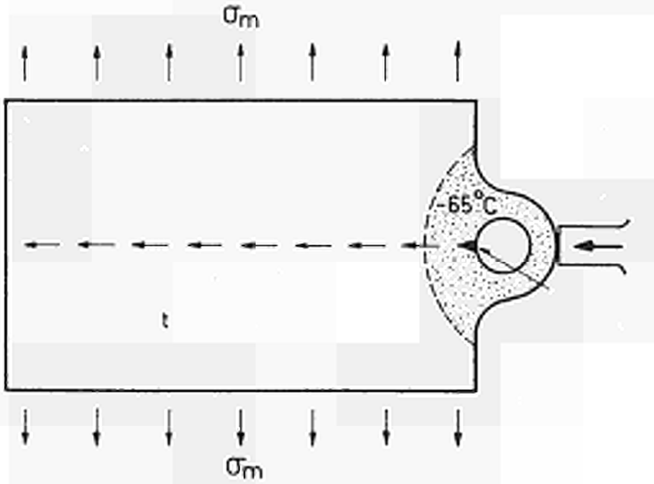
in combination with low-alloy filler wires. This is shown, for example, in the following figure in which, in the upper diagram, the thermo-vectonic zone of a weld made with an acid-type flux is compared with zone B of a weld made with a basic-type flux. The termo-vectonic zone in the lower diagram closely corresponds



Thermo-vectonic diagrams of flux welds
S = Acid flux,
B = Basic flux

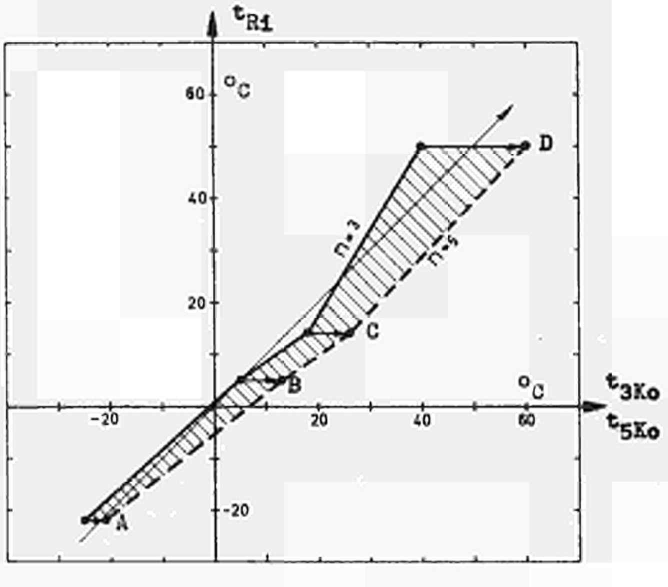
with the best which can at present be obtained with automatic welding. These welds are more or less equivalent to those obtained with the best manual electrodes and they thus open entirely new possibilities for the automatic processes, including the welding of hardened and tempered steels with a very high yield point. This development would be more rapid if it were not hampered by the fact that the European steel industry can only with difficulty produce the necessary welding-wires. It is most desirable that this paradoxical situation should end as soon as possible.

The last part of my paper is intended for those who are only convinced by theoretical considerations to the extent that they are confirmed by tests on large-scale specimens which are claimed to be more representative of actual construction. For this I have used the so-called Robertson iso-thermal test, the principle of which is explained in the following figure. It consists of subjecting a steel specimen to a uniform tensile stress equal to that which it is to undergo in service. A special tensile machine is used which in this case had a maximum capacity of 2000 tons. The notch is made by a saw-cut inside a ring which prolongs the actual body of the specimen.



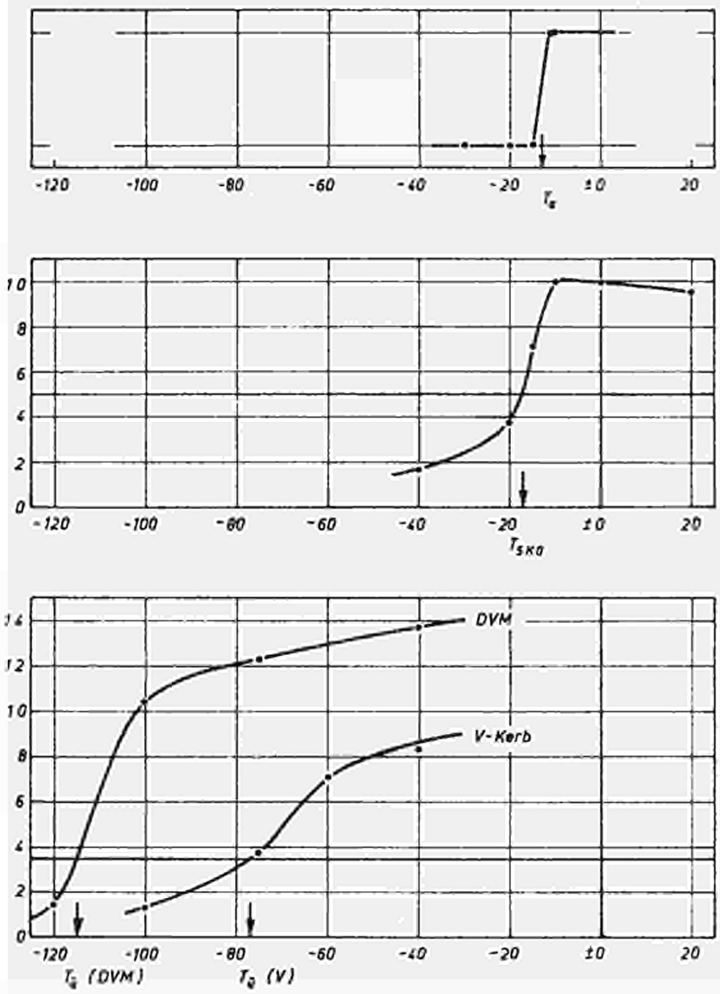
Robertson isotherm test
σ_m = *mean tension,*
t_{test} = *testing temperature*

While the latter is kept as nearly as possible at the test temperature, the notched part is rapidly cooled by means of liquid nitrogen in order to make it completely brittle. As soon as a sufficiently low temperature is reached, a small riveting gun is used to deliver a hard blow in the direction of the arrow on the ring. This blow initiates a fracture which propagates itself in the direction of the small arrows. This fracture may then either cross the specimen from one end to the other or be arrested at the point where it reaches the appreciably less cold zone of the test temperature. The lowest test temperature at which the crack is arrested is called, for the given tensile stress, the Robertson iso-thermal crack arrest temperature of the steel.



Ratios of the tri- and pentacoheracic temperatures t_{3KO}/t_{5KO} *and the final Robertson isotherm temperatures* t_{RI} *of four 75 mm. and 80 mm. steels*

The following figure is based on results obtained, in collaboration with the United Kingdom Atomic Energy Authority, from tests on large plates. It deals with four plates of 70 and 85 mm. and of very different qualities and it proves the existance of an almost linear relationship between the critical tachycoheracy temperatures (on the abscissa) and the Robertson iso-thermal crack arrest temperatures (on the ordinate). This excellent concordance is again confirmed in the following figure relating to a Mn Ni Va steel 40 mm. thick subjected to tensile stressing of 30 kg./mm.². It shows (upper diagram) that the Robertson crack arrest occurs at a temperature of — 15°C and this temperature (middle diagram) exactly corresponds to the temperature at which the tachycoheracy is at its maximum, as it should do in theory.



Robertson test

Coharacy (kgm./cm.²)

Impact value (kgm./cm.²)

Comparison of transition curves obtained in the Robertson isotherm, high speed coheracy $K_0(t)$ and Charpy notch and German notch tests. Semi-hard 40 mm. steel.

The bottom diagram gives the temperature transition curves obtained from *DVM and Charpy-V impact specimens* used in accordance with present specifications. The transition temperatures are —90°C and —75°C for an energy level of 3·5 kg./cm.². Two facts will be noted: (a) these temperatures do not correspond to any special behaviour on the part of the Robertson test and (b) brittle fracture may occur in the steel tested at the temperature of —20°C at which it still has a DVM impact value of 14 and a Charpy-V impact value of about 9 kgm./cm.².

In closing, I would like to say something about a particularly interesting application of the new theories, the economic importance of which is obvious. This is the local use of tachycoherace welds to arrest the quasi-explosive propagation of a fracture initiated in part of a structure made of non-tachycoherace, and thus cheaper, steel. The experimental test in this very important field, consisted in subjecting to a Robertson iso-thermal test two specimens containing in the middle a butt weld, the direction of which was perpendicular to that of the propagation of the crack. The test temperature was at 0°C. In both cases the parent steel was brittle at this temperature. The same was true of the weld shown in the first figure and the crack therefore crossed it without encountering any resistance. In the second case the weld was made with electrodes depositing a steel which was strongly tachycoherace at 0°C. The crack was arrested at the moment when it reached the weld.

These tests, which are of quite a new kind, supplement the preceding ones as an absolute and definite confirmation, which had to be demonstrated, of the theoretical claims. In conclusion some general comments. I think that the only value of past errors is to serve as lessons for the future. If there is any lesson to be learned here, it is necessary to tackle without further delay the problems discussed above in an entirely new spirit. It is time for everything to go up a storey.

My report has only opened slightly the great door leading to the science of steel and steel constructions. In this field new and immediately usable knowledge goes much further than what I have tried to expound and allows us for example to evolve equations linking certain essential properties.

Whether these new theories are understood or not, they will continue to exist and to govern all the time the behaviour of steels and welds at all stages of their development, production, testing and service.

At a time when steel must seriously try to fight back against keen competition from concrete, glass fibres and light alloys, there is no choice between the daily errors of empiricism and the eternal laws of the physics of metals.

For this reason, steel must first become scientific if it is to be rejuvenated and become more dynamic. This necessity is inevitable. It is also my response to the main objectives of this conference.

Henri HERBIET

and

P.-E. LAGASSE

Brittle Fracture of Structural Steels — The Metallurgist's Point of View

(Translated from French)

During the last 20 years basic investigation and experimental research into the mechanism of brittle fracture has figured prominently and continuously in technical literature on metallurgy and metal structures throughout the world.

Research workers in all fields — metallurgists, physicists and engineers — have vied in ingenuity in their efforts to establish, on a valid theoretical basis, the most adequate criteria for a definition of the brittle fracture strength of the various steels.

A remarkable example of these endeavours has just been set before us by Mr. H. Schnadt, whose viewpoint is that of solid mechanics and whose theory is a very interesting adaptation of the Hencky and Von Mises plasticity criteria in the case of brittle fracture.

Whilst this graphic representation of the mechanisms of brittle fracture is not the only one of its kind, it does have originality, and above all, as you have seen, it helps to make clearer the external parameters of brittle fracture : state of stress, notch sharpness, and, more particularly, the rate of deformation.

It might however be wondered whether these numerous and varied basic investigations have succeeded in giving the metallurgist the answer to the practical problem of classifying steels by their brittle fracture strength.

Mr. Schnadt thinks his thermo-vectonic chart will give a complete definition of the brittle fracture behaviour of steel used at a given operating temperature and hence its suitability for a particular structure.

It must not be forgotten however that the characteristic values of the thermo-vectonic chart are relative and conventional. Although Mr. Schnadt's experimental method provides us with certain data on the effect of the rate of deformation, it is impossible to establish an absolute relationship with the operating behaviour. An experiment with a test-piece of any kind cannot reproduce exactly the same complex stresses to which a welded structure is subject.

This may be exemplified by the following :

(1) The dimensional effect of thickness and other geometrical structural factors directly affect the rate of plastic deformation. For instance, all other conditions such as macro- and microstructure being the same, the risk of brittle fracture in a steel sheet will increase with increasing thickness. This dimensional effect is not taken into account when using a small test-piece.

(2) A small test-piece taken from a steel product can never give a true indication as to the product's overall behaviour throughout its thickness because no account is taken of its microscopic and structural heterogeneity.

Finally, we feel bound to state that whatever type of small test-piece is used and whatever test method is applied for defining the characteristics of a steel, the structural engineer should always estimate the brittle fracture risk that can be safely allowed; he should bear in mind the extent of metal fatigue during use, and should take into account the dimensional effect of his structure in relation to the brittle fracture characteristics of the steel in small test-pieces.

Hence, with the passage of time and seen from the point of view of the manufacturing metallurgist, it is necessary to define a relative order of quality for steels independently of external factors affecting brittle fracture which are bound up with the design of the building and its construction. The remarkable fact about all the research is that, although reached along quite independent paths, the outcome in each and every case is a single common expression characterising the brittle fracture strength properties of a given steel, viz: "A steel's metallurgical brittle fracture strength is expressed by a certain capacity for local deformation in line with a crack."

Simple though it may appear, this physical quality cannot be directly measured and used as a criterion of quality. Among the main reasons for this is, as Mr. Schnadt has so clearly shown, the fact that the capacity for plastic deformation in the presence of a crack depends to a very large extent on the acuity of the crack, the state of the applied stress, its velocity, and temperature.

It is precisely in the most satisfactory expression of this property that the differences persisting to-day between these theories and specialists' viewpoints lie.

The following traces, very roughly, the evolution of ideas on this question :

Early theoretical research was based upon the notion of mechanical balance between the work of initiating and propagating the crack and the elastic energy released by the fracture.

The well-known Griffith and Orowan theories were the forerunners of this research and are the basis of many developments both in crack initiation research at microscopic level (Cottrell-Petch laws.) and in macroscopic instability research (Boyd, Irvine, Krafft, Schnadt, Pellini, Puzak).

All these highly scientific theories support the classification of steel by a toughness criterion, i.e. one of "energy absorbed by the fractures."

The choice of toughness, the Charpy V-notch test-piece and its use as a criterion of quality has often been criticised for its arbitrary and conventional character.

In actual fact the choice of toughness is upheld by energy theories on brittle fracture which take into account both the elastic strength and the ductility of the metal and it is only the experimental parameters of the toughness measuring operation (type of notch and velocity of impact) which, inevitably, have a conventional character, as have all test-pieces.

It is obvious today that the brittle fracture strength of a steel cannot be defined without reference to its mechanical strength and that therefore the most general expression of brittle fracture strength is essentially an energy function in which the metal's capacity for elastic deformation may compensate that for plastic deformation.

We cannot but recognize, therefore, that the Charpy V-notch test, chosen for the general classification of welding qualities of steel on the basis of industrial tests and experimental observation of steels that had been the source of accidents in service, is not in contradiction with the latest theories.

Moreover, no-one would dispute that it has been by observing the behaviour of steels in such toughness tests that steelmakers have been enabled to make considerable improvements in the resistance to brittle fracture of their products, improvements which have been reflected in the performance in service of the assembled structures.

The classification was initiated in 1959 by document 22 of the International Welding Institute (Institut International de Soudure), entitled : "Recommendations on the choice and classification of structural steels intended for constructional assembly by arc welding." The field of application of these I.I.S. recommendations is that of rolled products such as heavy plate, section, bar and strip in mild or carbon-manganese structural steel corresponding to the 34-37-42-47-52 Kg/mm.² minimum tensile strength grades, used for bridges, structural frames, road and railway structures, ships, railway installations, storage tanks and machine frames, all of which are structures working at service temperatures governed by normal climatic conditions. This list is sufficient to illustrate the vast field of application of these recommendations.

The I.I.S. Recommendations dealt with four classes of steel, termed A, B, C and D in rising order of weldability, whose conditions of use are indicated in a very rough fashion. The purpose of Mr.Bierett's paper (see p. 515), is to categorise the choice of these classes of steel in relation to the classification of welded structures.

What is the basis of the classification of steels for welded structures adopted in these recommendations?

The main criterion is the notch strength of the steel in the state in which it is delivered by the steelmaker. It is based upon the 20 ft/lb (3·5 kgm./cm.².) energy level on a Charpy V-notch test-piece. This criterion is supplemented by limitations on chemical composition and steel homogeneity.

The following table gives the general characteristics of these four quality classes as laid down in IIS 22-59 document.

Quality	Grade Kg./mm.²	Cradle analysis Chemical composition in %					Charpy V-notch toughness test on product as delivered. Longitudinal test-piece.
		C max	S max	P max	Mn max	Si max	
A	⩽ 52	0·22 (¹)	0·06	0·08	—	—	—
	> 52/65	—	—	—	—	—	
B	⩽ 52	0·22 (¹)	0·05	0·06	—	—	(²)
	> 52/65	0·22	0·05	0·06	1·50	0·55	
C	⩽ 52	0·22 (¹)	0·05	0·06			20 ft/lb or 2·8 kgm. or 3·5 kgm./cm.² (at) 0° C
	> 52/65	0·22	0·05	0·06	1·50	0·55	
D	⩽ 52	0·22 (¹)	0·05	0·05			20 ft/lb or 2·8 kgm. or 3·5 kgm./cm.² (at) −20° C
	⩾ 52/65	0·22	0·05	0·05	1·50	0·55	

(¹) If this maximum content of 0·22% C is complied with, special welding precautions are unnecessary.
For 0·22 to 0·27% C for qualities A and B and 0·22 to 0·24% C for qualities C and D, special welding precautions may be necessary.
If these latter limits are exceeded then special welding precautions will be necessary.

(²) For some B quality steels and for certain applications it may be useful to take into consideration either less severe notch toughness requirements than for quality C or nitrogen content limits.

A final, highly important comment is contained in these IIS 22-1959 Recommendations :

The chosen level of energy and the test temperatures recommended for brittle fracture tests should not necessarily be considered to have any direct relationship to service behaviour. These criteria serve purely to classify steels by rising order of brittle fracture strength.

Let us now see what the practical effect of these Recommendations has been on national and international standardisation on the one hand and on the service performance of welded structures on the other.

National and International Standards

A critical comparative study of these standards is not possible within the scope of this report. We shall simply make a comparison of the number of classes of welding steels and their brittle fracture characteristics in relation to the IIS 22-1959 Recommendations.

As regards chemical composition there are, generally speaking, slight differences in C, S and P contents between the standards of the different countries. Also, some countries have introduced, for certain qualities, a maximum nitrogen content or a limitation on the refining or deoxidation processes.

For a detailed and exhaustive comparison we recommend the excellent critical study of Messrs. Delbart and Rousseau, published in the June 1965 issue of *Métallurgie* under the title "Etude de la Normalisation des produits sidérurgiques en France et à l'étranger" (Iron and Steel product standardisation in France and abroad).

(a) *Belgium:* NBN 631 - 1965

4 welding steel classes: A, B, C and D characterised from the point of view of brittle fracture as in the Recommendations

except that, for Class B, a 3·5 Kgm/cm². Charpy V-notch toughness at +20°C is guaranteed.

(b) *France:* Afnor: A 35 - 501 - 1963

3 or 4 welding steel classes according to product grade and type, characterised from the point of view of brittle fracture as in the Recommendations except that, for Class B, a Charpy U-notch toughness value at ambient temperature is guaranteed.

(c) *Germany:* DIN 17100 - 1965

3 or 4 welding steel classes according to grade characterised from the point of view of brittle fracture as in the IIS Recommendations except that, for Class B, a Charpy 3·5 Kgm/cm². V-notch test at +20°C or a 8 Kgm/cm². test on an aged DVMF specimen at +20°C is guaranteed. For classes C and D values of 7 and 9 Kgm/cm². respectively at 0°C may be guaranteed on the DVM test-piece instead of the 3·5 Kgm/cm². at 0° and −20°C respectively on the Charpy V-notched specimen.

(d) *Italy:* UNI 5335 - 64

4 welding steel classes : A, B, C and D characterised from the point of view of brittle fracture as in the IIS Recommendations except that, for Class B, a 3·5 Kgm/cm². Charpy V-notch toughness at ambient temperature is guaranteed.

(e) *Sweden and Scandinavian countries:* SIS 1314/11-12-13-14

4 welding steel classes of which the last two are characterised from the point of view of brittle fracture by a Charpy toughness of 3·5 Kgm/cm². at 0° and −20°C on a V-notched specimen.

(f) *Great Britain:*

1. BS 2762 Notch Ductile Structural Steels for general uses. 4 welding steel qualities, ND I, II, III and IV characterised as in the IIS Recommendations by a notch toughness of 3·5 Kgm/cm². but at temperatures scaled from 0° (ND I) to −15° (ND II), and −30°C (ND III) to −40°/50°C (for ND IV).

2. BS 968 - 1962: (High-yield-stress structural steel — welding quality).

One quality with a brittle fracture characteristic of 3·5 Kgm/cm². at −15°C.

(g) *E.C.S.C.:* Eur. draft 25-65 April 1965.

Final edition for the most part.

4 welding steel classes: A, B, C and D characterised from the point of view of brittle fracture as in the IIS Recommendations except that, for quality B, a Charpy 3·5 Kgm/cm². V-notch toughness at +20°C is guaranteed.

(h) *ISO:* ISO draft TC 17 No. 705 - March 1965.

4 welding steel classes characterised from the point of view of brittle fracture as in the IIS Recommendations except that quality B may be specified with a Charpy V-notch toughness of 3·5 Kgm/cm². at ambient temperature.

(i) *Joint Specification of the Marine Classification Societies.* (Lloyd's, Veritas, Norske Veritas, Registro Italiano, ABS)

5 welding steel classes for the 41-50 Kg/mm². grade, listed as classes A, B, C, D, and E, the last two being rated, as to brittle fracture, at 6 Kgm/cm². (35 ftlb) at 0°C for Class B and 7·7 Kgm/cm². (45 ftlb) at −10°C for Class D.

Note that Classes B and D are non-effervescent steels and Classes C and E are completely killed, fine-grain steels.

(j) *ASTM:*

There is no toughness test requirement in the standards on "structural steels." Deoxidation and heat treatment conditions are however laid down for certain qualities and thicknesses.

From the comparative study of these various national and international standards it may be concluded that, generally speaking, the classification of welding C and C-Mn structural steels used at climatic temperatures, if not exactly the same, is in the same spirit as that put forward by the IIS 22-1959 Recommendations. This similarity is particularly striking in the case of the Western European countries and in the ECSC and IIS drafts.

What are the prospects as regards the extension of this classification and in particular the choice of brittle fracture strength as a criterion, to the field of low and ultra-low temperatures, very thick products and high and ultra-high elastic limit steels? We think that in the light of knowledge now revealed by the study of brittle fracture phenomena, a review of the choice of energy and/or temperature level will be necessary but the Charpy V-notch "energy" criterion will still remain the basis of the classification. Steps in this direction are already being taken in various countries.

The same will be true of C, or C equivalent, content in high elastic limit welding steels to prevent the risk of cracking in the welded joint. This task is now being tackled by Committees IX and X of the Institut International de la Soudure.

Behaviour of welded structures in service

Sub-Committee D of Committee IX of the I.I.S. has been engaged during recent years in an international enquiry on service failures of welded structures due to brittle fracture. At the Annual General Meeting of the IIS in 1964 in Prague the Sub-Committee presented an interim report which has just been published in full, in the review "Soudage dans le Monde" No. 2, 1965. This report covers detailed examination of 30 cases of brittle failure in ship and boiler construction. The highly interesting conclusions in this report relate to the influence of geometrical factors, that of stress conditions and lastly that of the characteristics of the steel employed.

In regard to this latter point the report states that, on the whole, the characteristics were found to correspond to those of old steels prior to the IIS 22-1959 Recommendations; these steels for the most part may be compared with steels of classes A and B in that document, as is shown by the following table giving the transition temperatures found in these steels, i.e. transition temperatures corresponding to the 20 ftlb (3·5 Kgm/cm².) level on a Charpy V-notched test-piece.

Tran. Temp. range TT Kv	—39/—20°C	—19/0°C	1/+20°C	+21/90°C
Number of cases	3	2	12	13
IIS Class	D	C	B	A

The majority of these cases, it should be remembered, relate to mild steels of grades 37 and 42 Kg/mm²., some being of the 52 or 54 Kg/mm². grade.

It is interesting to note that, in 28 cases out of 30, the temperature of the failure was lower than or equal to the transition temperature (3·5 Kgm/cm². or 20 ftlb) of the steel at the initiaton point of the failure.

In its progress report to the 1965 Annual General Meeting of the IIS in Paris, Sub-Committee "D" of Committee IX states that, after detailed examination of 10 new cases, (for the most part related to welded frames and mechanical parts) the conclusions in its first general interim report will probably remain largely unchanged.

Finally, the same Sub-Committee "D" of Committee IX of the IIS considered it necessary to consult the bodies charged with the verification of welded structures in order to learn whether the judicious use of the welding qualities now available has produced the favourable results anticipated from structures in service.

In particular the Sub-Committee wished to find out whether, since new welded steel specifications have been brought into use, these welded construction control bodies have reported failures the nature of which reflected either on the quality of the steel or the design or assembly of the structure.

Most of the important marine classification bodies have responded to this vast survey. Replies have also come in from boiler and pressure vessel control bodies and from public administration departments such as "ponts et chaussées" etc.

It is not possible to give you a complete analysis of these replies to-day; this is the task of Sub-Committee "D" of the IIS for the 1966 Annual General Meeting.

We can however, with the approval of the Chairman of this Sub-Committee, to-day acquaint you with the main lines of the results of this survey :

1. the number and seriousness of brittle failures in service has fallen considerably;
2. this improvement in the performance of welded constructions is due on the one hand to the use of welding steel qualities conforming to current standards and on the other to improvements made in design, execution and verification methods for welded structures. It is, however, not possible to distinguish with accuracy between the roles played by each of these factors.

To conclude, we hope we have convinced you that the C and C-Mn welding steels developed by steelmakers and supplied to-day to the various countries of Western Europe on the basis of specifications derived from the IIS-22-1959 Recommendations, have contributed to the general improvement of welded construction. Their judicious and logical use, related to the difficulty of the design and execution, leads to a real saving in the cost of material in welded structures and helps in a positive manner the promotion of the use of steel.

Franco BONOMO

Investigation of the Influence of Phosphorus on the Welding of Some High Elastic Limit Steels

(Translated from Italian)

The tests I am going to speak about were carried out in order to obtain primary data regarding the influence of phosphorus on the welding properties of steels with high elastic limits and resistant to atmospheric corrosion.

It is well known that the presence of P generally tends to improve the material's corrosion resistance, but it is possible for it to have a negative influence not only on transition temperature but also on welding properties. Current literature does not contain all the data required for a quantitative assessment of the influence of this element on the welding process, and it was therefore considered useful to carry out welding tests on a number of experimental plates.

This first series of tests was made on a steel with approx. 0·1% P and at the same time, for comparison, on another steel of similar analysis but with a low P content (0·01%).

Base material used

Two types of experimental steel were used, both being made by the Italsider Company with the chemical composition and mechanical properties as given in the two tables below: the thicknesses concerned were 12 and 20 mm.

Chemical Composition of Base Material (in %)

	C	P	Mn	Si	Cu	Nb	S	Notes
High P steel	0·10 + 0·1	0·094	0·74	0·06	0·27	0·017	0·020	semi-killed
Low P steel	0·12 + 0·13	0·010	1·25	0·35	0·24	0·023	0·020	killed

Mechanical Properties of Base Material

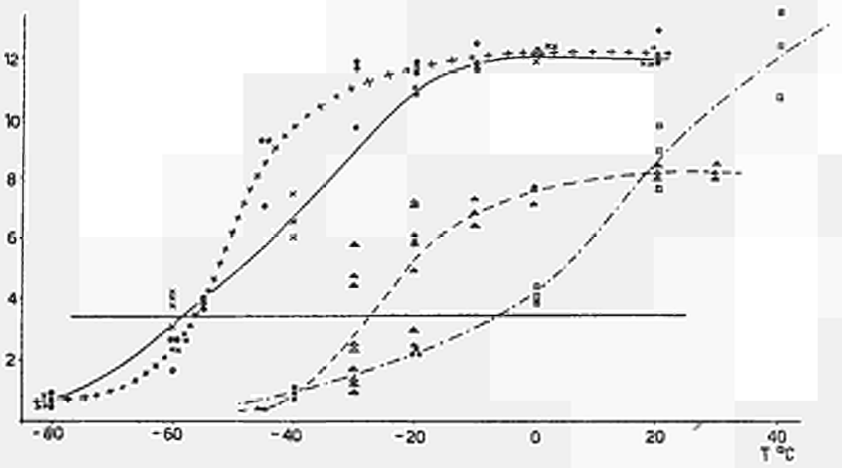
Type of steel	High P				Low P			
Heat treatment	As rolled		Normalized		As rolled		Normalized	
Thickness mm.	12	20	12	20	12	20	12	20
Yield stress kg./mm².	41	38·8	34·9	33·7	42	41·6	35·2	36·1
Fracture kg./mm².	51·5	51·3	47·8	47·9	55·8	52·0	50·8	49·2
Elongation A5%	26	30	29	33	25·5	27·5	28	28·5

As can be observed, the material produces tensile strength values between those of Fe42 and Fe52 steels: the high-tensile properties are due to the presence of Nb. All the tests described were carried out on the material in the as-rolled condition.

In making these steels, particular attention must be paid to the pouring technique which should be such as to keep inclusion formation to the minimum: in some plates in particular, due to the presence of elongated silicate-type inclusions, a noticeable fall in tensile strength in the direction of the thickness has been encountered which, in a certain number of welding tests with T-shape and cruciform specimens, has resulted in the material showing a marked tendency to open up of itself due to the effect of shrinkage stress.

Finally, on the basis of the transition characteristics found in the steels tested, the following observations could also be made :

(a) The presence of P raises the material's transition temperature appreciably: taking the normalized steels as an example, the temperature rises from −27 and −6°C with the high P type to −56 and −57°C with the low P type, for 12 and 20 mm. respectively. These figures relate to an energy level of 3·5 kgm/cm², the transition curves concerned are shown in the following figure.



△ *High phosphorous steel sp. 12*

□ —·—·— *High phosphorous steel sp. 20*

O ×××× *Low phosphorous steel sp. 12*

× ———— *Low phosphorous steel sp. 20*

Transition Curves Kv of steels with a high and low phosphorous content in the normalized state

(b) any variation in the rolling conditions may, in the case of the high P type, cause appreciable changes in the transition temperature; in, for example, two plates from the same heat, the 3·5 kgm/cm². Kv transition temperature rose from −15°C in the case of the 12 mm. thickness to +30°C with the 20 mm. thick plate; particular care thus has to be exercised in rolling these steels;

(c) normalizing, even with the high P type, has a beneficial effect on transition temperature which is reduced from −15 to −17°C for the 12 mm. and from +30 to −6°C for the 20 mm. (energy level: 3·5 kgm/cm².)

Welding tests
Investigation of the fusion zone

Square butt-welded specimens - Test procedure

These welding tests were carried out in order to examine mechanical properties in the fusion zone and, in general, to assess the aptitude of the metal to be welded with joints free from blowholes and hot cracks.

"Submerged arc" and "CO_2 shielded spray-arc" processes were employed under conditions and after preparation designed to result in considerable penetration of the base material.

Six 750 × 600 mm². specimens were made up for each steel, two in "CO_2" (one for the 12 mm. and one for the 20 mm. thick plates) and four by submerged arc (covering the two thicknesses and two types of wire-flux combination).

Welding conditions and preparation are given in the table below.

Tests made on welds and examination of results

All welded joints were examined by the X-ray method and subjected to bend, transverse tensile and kV toughness tests. Examination of the results proved the absence of faults in the fusion zone and good mechanical strength in the tensile tests: in two cases however, fracture occurred away from the weld, and in these two cases a strength of 56 and 57 kg/mm². was obtained, which is fully satisfactory.

The toughness values showed that, in the fusion zone, P has an unfavourable effect and can raise the transition temperature appreciably; in particular, inacceptable results are possible if suitable wire-flux combinations are not selected.

Conditions of square-butt weldirg tests

Process	Plate thickness	Preparation α = angle of V d = gap a = shoulder	Number of runs	Welding conditions 1 - Amp. V - Volt v - Cm/1		Filler material
				1st run	2nd run	
Submerged arc	12	straight d — o	2	I — 650 V — 34 v — 40	I — 730 V — 34 v — 40	1st wire-flux combination: 5 mm. diam. 2% Mn wirew ith appropriate slagtype flux.
	20	Y α — 60° a — 10 mm. d — o	2	I — 625 V — 34·5 v — 40	I — 865 V — 31·5 v — 27	
Submerged arc	12	straight d — o	2	I — 650 V — 34 v — 40	I — 730 V — 34 v — 40	2nd wire-flux combination: 5 mm. diam. 1% Mn wire with appropriate slagtype flux.
	20	Y α — 60° a — 10 mm. d — o	2	I — 625 V — 34·5 v — 40	I — 865 V — 32 v — 27	
CO^2 Spray-arc	12	Y α — 60° a — 5 mm. d — o	2	I — 360 V — 32 v — 37	I — 360 V — 32 v — 30	1·6 mm. diam. wire. Composition: C - 0·09 Mn - 1·57 Si - 1·12 S - 0·013 P P - 0·024 Cu - 0·10 (0·14)
	20	Y α — 60° a — 3 mm. d — o	4	I — 380 for all runs V — 32 for all runs v — 43 at base of V v — 30 for final run		

The following conclusions may be drawn from these tests :

(a) high and low P steels, 12 mm. thick, which are considered to be of type C, can be welded as such both by submerged arc and in CO_2; in fact it was possible, using a suitable wire-flux combination, to arrive at KV toughness values in the fusion zone and at 0° C over 3·5 kgm/cm². (3·7 and 3·95 for high P and 7·35 and 5·10 for low P for submerged arc and CO_2 processes respectively in each case) ;

(b) if toughness values at 0° C do not happen to be important for the purposes of the service conditions of the structure, it is possible, even with wire-flux combinations which do not produce satisfactory toughness values at that temperature, to make sound welds in these circumstances without porosity or hot crack formation occurring (whether at the root or interdendritic) and without inadequate mechanical characteristics arising, such as tensile strength and ductility in the fusion zone;

(c) the presence of P in the fusion zone lowers toughness appreciably: by way of example the Table below shows the values obtained at 0° and −20° for the two steels in the 12 mm. thickness; in the same table are shown the percentages of P encountered in the corresponding welding beads.

Some toughness values in the fusion zone (average of three)

	Submerged arc			CO_2		
	kgm./cm² 0° C	kgm./cm² —20° C	% P	kgm./cm² 0° C	kgm./cm² —20° C	% P
High P steel	3·70	1·70	0·059	3·95	2·00	0·054
Low P steel	7·35	2·60	0·018	5·10	3·40	0·025

DIN and Fisco specimens - Method

The object of these tests was to assess the extent of the hot-cracking tendency of the material.

For the DIN tests (two-bead T-shape cracking test specimens made as prescribed in UNI 5132 point 9) three specimens were made of each type of steel in the 12 mm. thickness using 4 mm. diam. basic electrodes.

For the Fisco tests (cracking tests on plates spaced and welded as prescribed by the author, M. Schnadt) a first series of specimens was made from the two steels in question and from Aq 42 using 4 mm. diam. basic electrodes and with gaps of 1, 2, 3 and 4 mm. between the ends without practically any signs of cracks. To increase the severity of the conditions in these tests, two rutile and one acid type electrodes were used in succession, all 4 mm. in diam.; the gap, moreover, was kept at 4 mm.

Finally, to enable a comparison to be made, Fisco tests were carried out with the same electrodes on a special plate selected by the Registro Italiano Navale for cracking homologation tests of the acid electrodes ("Rina-acid" plate).

The chemical compositions of the Aq42 and "Rina-acid" plates used in these tests were found to be the following:

Aq42 : C = 0.20, P = 0.018, S = 0.021, Mn = 0.91, Si = 0.04, Cu = 0.09.

Rina-acid : C = 0.23, P = 0.027, S = 0.044, Mn = 0.83, Si = 0.22, Cu = 0.10, Cr = 0.11, Ni = 0.08.

Examination of results

On visual examination the DIN specimens were completely crack-free.

The f4 values for the Fisco tests are reproduced in the Table below. This parameter is equal to the ratio between the total length of the cracks and that of the beads, with a 4 mm. gap, expressed as a percentage. The figure on p. 579, by way of example, shows a series of tests carried out with a rutile type electrode.

It will be seen that even with electrodes that are particularly prone to hot cracks (such as the acid and rutile types) the test turned out fairly well for high and low P steels, the f4 parameter being either not much higher or, in certain cases even lower than the 25% figure recommended by the author.

f4 values in the Fisco tests

Steel / Electrode used	Low P	High P	Aq42	"Rina-acid"
Rutile A	17·0	22·9	18·0	78·0
Rutile B	13·2	25·0	30·8	78·0
Acid	18·2	28·5	36·3	91·0

A — "Rina-acid" steel
B — Aq42 steel
C — High-phosphorous steel
D — Low-phosphorous steel

Fisco tests example of a series of tests carried out with a brittle electrode

Generally, the cracking properties of the high P steel can be considered good having proved practically equal to those of Aq42 and decidedly better than those of Rina-acid.

The low P steel proved to be slightly less prone to hot cracking, which would tend to indicate a certain negative influence by P even as regards hot cracking, not however great enough to cause alarm since it is generally good practice to use electrodes with basic coatings for welding high elastic limit steels.

Investigation of hardening — Cruciform specimens

Procedure

The cruciform specimens were made in order to make sure, by hardness testing, that the heat-affected zone did not present any marked hardening phenomena even under particularly critical welding conditions.

The test-pieces were made of a continuous central plate (measuring 500 × 600 mm².) and two "wings" (each one measuring 500 × 300 mm².) welded to both faces of the former at right angles to it so as to form a cross; a bead of suitable dimensions was deposited at each corner.

Four test-pieces were made for each type of steel, two with the 12 and two with the 20 mm. thickness, using the "CO_2 Short-arc" process and with the parts at an initial temperature of 5° C for each bead; the welding conditions and positions and sizes of the beads are shown in the table below.

Welding conditions for cruciform test pieces made by the "Short-arc" process and with 1·2 cm. diam. wire

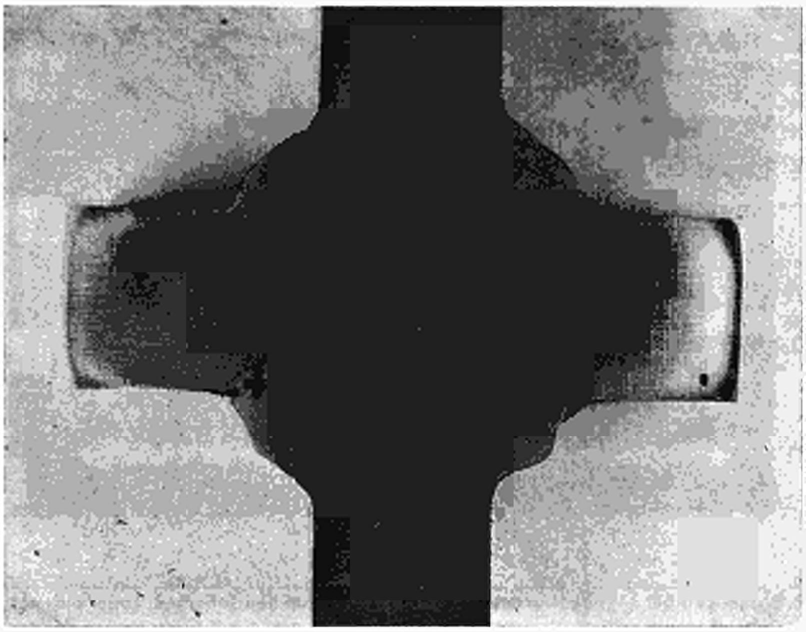
Plate thickness	Position	Bead dimensions	Welding conditions	Heat input kWh/m.
12	vertical downward	5 × 5	I = 150 V = 22	0·32
12	vertical upward	6 × 6	I = 190 V = 21·5	0·48
20	vertical upward	8 × 8	I = 190 V = 21·5	0·83
20	level forward	10 × 10	I = 150 V = 22	1·20

Examination of results

For each test-pieces hardness was measured on two sections, one at the start and one at the end each test piece, at the points shown in the macrograph in the following figure.

The following table shows the maximum, minimum and mean values for the heat-affected zone of each section measured.

From a study of the results it can be seen that there is no marked difference between the mean values for the two different positions of the same test-piece; on the other hand it is clear that, for equal plate thickness, hardness, as expected, increases with decreasing heat input; in particular it should be remembered that the heat input of 0·32 is very severe associated with small beads deposited with the downward technique which is inadvisable in practice on



Example of a measurement cross-section of cruciform test-pieces and hardness check-points

Hv hardness in the heat affected zone of cruciform test pieces

Plate thickness	Heat input	Type of steel	Position of section	Min.	Max.	Ave.
12	0·32	High P	start	214	285	248
			end	223	275	248
		Low P	start	287	348	317
			end	275	366	328
12	0·48	High P	start	204	247	226
			end	194	263	228
		Low P	start	225	294	266
			end	225	263	246
20	0·83	High P	start	206	278	237
			end	218	247	234
		Low P	start	218	291	261
			end	223	315	277
20	1·20	High P	start	206	232	219
			end	206	247	226
		Low P	start	223	275	241
			end	223	275	243

high elastic limit steels. It will be further noted that the low P steel proved slightly more susceptible to hardening than the high P, probably because of the higher Mn content.

Finally it may be concluded that, since the mean hardness values never reach the 350 Hv limit considered critical, even in the most severe conditions, the material is very unlikely, under normal welding conditions, to be subject to serious hardening phenomena or cold cracking risks in the heat-affected zone.

Investigation of heat affected zone — Square butt welded test-pieces with half-V preparation

Procedure

The object of these tests was to see whether any base material embrittlement phenomena occurred in the zone affected by the welding heat.

Only the high P steel in the 12 mm. thickness was considered.

The half-V type of preparation prevented one part of the test piece (that prepared with the straight edge and from which the toughness specimens were taken) from having zones differently affected by the wave of heat; with normal preparation, indeed, the tests would possibly have lost their significance in so far as the cutting of the toughness test pieces, particularly when close to the welding bead, would have crossed zones subject to varying heat cycles. Three processes were used: "manual arc, level," "manual arc, vertical" and "submerged arc", so as to have three different heat input values: the level, manual arc weld made with six runs represents the coolest technique reasonably usable in practice with a 12 mm. thickness, single run submerged arc welding represents the hottest, whilst the manual vertical method with four runs represents an intermediate stage. During the making of the manual welds, care was taken to observe an appropriate distribution of the runs so as to keep the heat input for each of these equal on the straight edge of each test piece.

The welding conditions of the three tests are shown in the following table.

Welding conditions of half V butt-welded test pieces and positions at which notch toughness specimens were taken

Process & Position	Number of runs	Diameter of electrode or wire	Preparation. α — angle of level a — shoulder d — gap	Welding conditions I = amp. V = volt Q = Kwh/m.	Distance from the straight edge at which the toughness specimens were cut
Manual arc level	6	4 3·25	1/2 V with support α — 45° a — 0 d — 6 mm.	I = 160 (130) (¹) V = 24 (26) (¹) Q = 0·47	1 — 3 — 5 — 8 18 — 23 — 200 mm.
Manual arc vertical	4	4 3·25	1/2 V with support α — 45° a — 2 mm. d — 7 mm.	I = 140 (120) (¹) V = 24 (26) (¹) Q = 0·74	1 — 2 — 6 — 12 22 — 38 — 55 — 200 mm.
Submerged arc	1	5	1/2 V with support α — 30° a — 0 d — 4 mm.	I = 910 V = 31 Q = 1·77	2 — 8 — 20 — 40 60 — 90 — 140 — 200 mm.

(¹) The values in brackets refer to runs made with 3·25 mm. diameter electrodes.

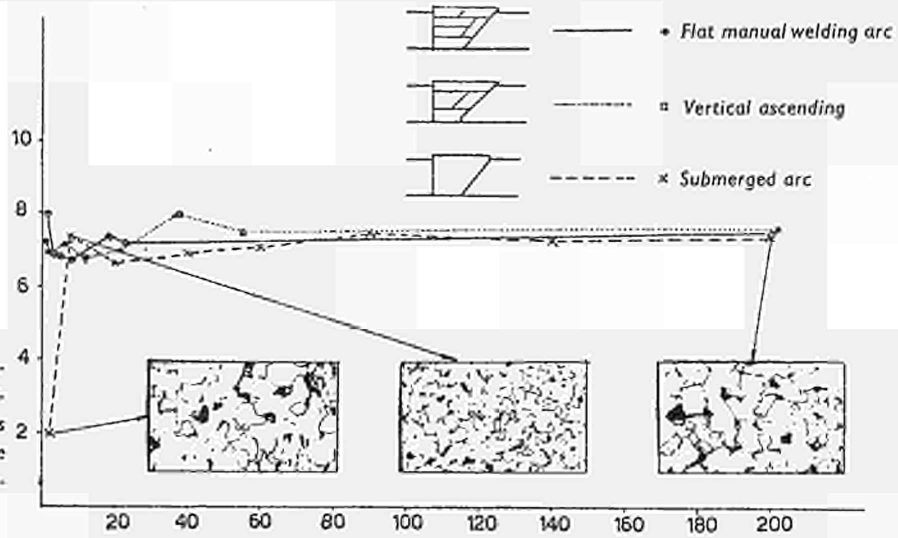


Diagram showing values found in test-pieces with 1/2 V preparation. Distributions of the passes. Dimensions (×200) of the grain found at three typical distances in submerged arc-welded test-pieces.

Tests carried out and examination of results

Eight groups of three Charpy V-notch toughness specimens for each test were taken from the part of the test piece prepared with a straight edge at varying distances from the bead and crosswise to the joint. The positions were chosen with a view to examining the whole of the zone adjacent to the joint where it was to be assumed that 200° C were exceeded; an attempt was also made, on the basis of theoretical work of Nippes and Savage, to choose points for the three test pieces corresponding to approximately the same temperature; lastly, for each test piece the intervals between one group of notch-toughness specimens and the next were made larger and larger with increasing distance from the joint and, therefore, with falling temperature gradient.

All the toughness tests were carried out at ambient temperature except for some special points in which low temperature tests were also made.

The last column of the table shows the distances from the straight edge at which the various groups of toughness specimens were taken.

Lastly, the figure on p. 581 summarises the results of the tests.

It will be seen that, except for the case of the submerged arc in the zone bordering the fused edge where the grain is coarsened, the base material has suffered no ill-effects.

In all three test pieces there are apparent, at a certain distance from the weld, minor toughness minima, i.e. at 8 mm. for the level manual arc process, 12 mm. for the vertical manual arc and 20 mm. for the submerged arc; supplementary tests at —10°C were carried out for these points (and also at 0°C in the case of the submerged arc) to find out whether there were excessive changes in the transition temperature in relation to that of the unaffected base material (—15°C). From these tests it was possible to state that the transition temperature at these particular points proves to be less than —10°C for level manual arc, about —10°C for vertical manual arc and between —10 and 0°C for submerged arc. In this latter process, it is important to note that there is a clear-cut drop in toughness two millimetres away from the straight edge where the steel showed appreciable coarsening of the grain on micrographic examination (see the figure on p. 581). This drop in toughness does not, however, occur in ordinary carbon steels or in high tensile steels welded in a similar manner by submerged arc.

From the results provided by these tests it may be concluded that, with the multipass technique and low and medium heat input, the steel may be welded without ill-effects, retaining the characteristics of a C steel even in the heat-affected zone; more caution is, however, necessary before adopting submerged arc welding, with its high heat input for high phosphorus steels, particularly for structures subject to impact at low temperature.

Conclusion

The tests described represent the first stage in a broader plan of research which will take in other sorts of P steel with different composition ratios; the conclusions reached, therefore, may be subject to some alteration. It seems however that we can already deduce from these tests that a high P content (up to 0·1%) in steels of the type investigated in the present research does not have an unfavourable influence on hot crack susceptibility in the weld or cold crack susceptibility in the heat-affected zone; there is however, a certain unfavourable influence, in some cases, on the toughness values of the fusion zone and the heat-affected zone, for which the proper choice of welding process seems important.

DISCUSSION

M. EL GOZHI

(Translated from French)

I would like to mention a somewhat specialized, but very valuable steelmaking process ensuring high-strength welded structures, namely the addition of alloying elements such as chromium, molybdenum and vanadium.

Some years ago, at the request of the Aeronautical Department, a steel was developed which enabled welded structures of a strength above 100 kg./sq. mm. to be fabricated without heat treatment.

This steel is the subject of technical recommendations FE-PL-525 of the "Association Internationale des Constructeurs de Matériel Aérospatial" on which ten European countries are represented.

Is has found many different uses in aeronautical engineering and rocketry; for engine frames, flight controls, landing gear, liquid and solid propellant rocket-engines, skirt joints and especially the rocket casing of the "Diamant" rocket launcher.

This outstanding high-strength welding property is no longer confined to aerospace applications; plates of much greater thickness have also been produced, formed and welded; for instance plates of 9, 10 and 23 mm. thickness for cylindrical high-pressure gas-storage tanks. Welding tests have shown R > 100 kg./sq. mm., E > 80 kg./sq. mm., A > 10%, Kuf > 7 kg./sq. cm.

Among its various uses, I would mention parts for high-speed centrifuges, excavator jibs, girder spans, bascule bridges, etc., and in the field of oceanographic research, a bathysphere, the Deepstar 400, constructed under the direction of Cdr. Cousteau of the French Department of Underwater Research. This bathysphere has a diameter of more than 2 m. and consists of two 70 mm. stamped plates. The sphere was ordered by the United States for descents to depths of over 4,000 m.

These applications are prototypes, but they have opened up the way for other industrial uses, for instance, the French Electricity Board is interested in this steel for pressure conduits.

There is also a range of weldable steels of ultra-high strength (above 150 kg./sq./mm.) in the as-welded condition. It has not been possible to weld such steels until the advent of the Sputnik. Among the steels considered more especially for rocket casings are 5% CR - 0·4% C - 1% Mo - 0·5 Va steel, which is being increasingly used in France, not only in astronautical engineering, but also in aeronautical engineering, and it will probably also be used in automobile engineering, in bolt and nut manufacture, etc. It is currently welded in thicknesses of 0·6 to 5 mm. and with air-hardening and double tempering it can be given a strength of 160 kg./sq. mm. with excellent resistance to high temperatures.

In recent years also, a new range of 18% Ni steels has been evoking interest. These are the steels with a tensile strength and yield point which can be doubled by heat treatment (for 3 hours at 480 C°), while retaining a good elongation and good reduction in area. In France, 5 m. plates, several millimetres thick, have been rolled of this type of steel and welded succesfully. Various tests are now in progress with the object of discovering further uses for these steels.

Wilfried MARFELS

(Translated from German)

Among the examples Mr. Schnadt has given us of brittle fracture, he mentioned one which occurred in a containment of a nuclear reactor. This could be highly disquieting news, since the containment is a safety vessel enveloping the reactor to protect the population from radioactive contamination in the event of damage to the reactor itself.

Mr. Schnadt has confirmed that the structure he was referring to was in fact the one which I had in mind. From detailed knowledge of this structure I would inform the Working Party that brittle fracture has not in fact occurred, nor has it been observed in any other containments constructed to date in Europe.

The problems arising in the construction of welded sheet containments have been competently dealt with by the specialist firms responsible, and there is therefore no danger of future brittle fractures in containments. Fine-grained steel is, of course, employed in making them.

I make this point in order to offer reassurance as to the reliability of welded sheet safety vessels.

L. CAPEL

Semi- and Fully-Automatic Welding Techniques for Low-Alloy, Alloy and Stainless Steels

(Translated from Dutch)

Just as in almost every branch of industry, automation is gaining ground, we find the same efforts being made in the field of welding. Automation can help to increase production and at the same time aims to stabilise quality by the elimination of imperfections in workmanship.

In our western society, in which prosperity increases constantly together with all the human problems, the need for higher production per man hour will need more and more attention.

The services sector is demanding more and more manpower which must be drawn especially from industry, and personal output per man is limited by a universal labour shortage.

Welding is basically a typical craft, which demanded craftsmen at a time when crafts were being lost in other technological fields.

We are witnessing then in this youthful art of welding, which is only 40 years old, revolutionary developments, in which more rapid progress is being made than in the age-old callings of forging, casting, turning, planing, fitting and so on, which have developed more traditionally and by evolution rather than revolution.

Welding is a method of joining used in industry, whereby parts of workpieces can be permanently joined together. It has replaced riveting and has, by its nature, enabled articles that were usually assembled by casting or forging to be put together from sheet metal or tubes. This has given welding an influence in other types of construction and interaction has taken place. The transitional period is now over, i.e. that of welded, riveting or casting constructions, and the potentialities of welding are known as such; in other words the development of forms of construction is based on the concept of welding.

The steel manufacturer plays an important part where special steel grades are demanded. The co-operation of the steel processer and the steel producer is obviously of prime importance.

There are plenty of examples, such as those of low-alloy and high-alloy steels, plated steels, and bi-metals, in short, products developed on the basis of welding. In our modern society, in which the chemical industry is developing rapidly, the problems that this branch of industry sets the metalworker cannot be solved without the joining element-welding. The same applies to practically all other metal consumers.

Automation involves a number of factors, such as:

(1) *Technology*: Technical possibilities for the design and control of apparatus.

(2) *Reliability*: Can the apparatus developed be used with the necessary safety and regularity without breakdowns?

(3) *Economy*: Is automation an economic proposition? Increased productivity is naturally always attractive; we must consider whether the total cost of the product is also reduced. Automatic plant is often expensive and has a short life, involving rapid depreciation.

(4) *Quality*: The quality of the product must be judged. Where welds always form joints that share in the load of the structure, no concessions may generally be made in so far as the quality of the joint is concerned. Although perfectionism must be avoided, the quality of the joints must regularly be supervised. The attitude that the quality need be only just good enough to prevent the likelihood of trouble may be permissible in unimportant cases, but it is suspect in my opinion for fully loades structures.

(5) *Time*: The time factor is closely linked with economy. In series and mass production these factors go hand in hand. In individual manufacture we must no doubt consider the advantage in connection with delivery dates to the purchaser or assembly firm and the factory output.

(6) *Men*: Last but not least, the human factor is probably the most important which must be considered. It is true that the craft of welding is becoming more and more a matter of machine operation. "Thinking with the hands" is changing into "thinking with the head"; frequently, the same men are not involved. We should like to see our automatic welding apparatus operated by a welder; in many cases this must be entrusted to experts in other fields. At the same time maintenance and plant repair demand other provisions. Finally, is the modern specialist prepared to do this sort of work? The latter point may raise conflicting problems. On the one hand workers no longer want to act as unconscious and unknown cogs in the machinery; they want to join in the process both physically and mentally and play their part in it. On the other hand, modern society demands more products in which a degree of standardisation can be recognised. The Taylor moment is passing and the era of switching-on is beginning.

All the above factors influence the automation of welding, although total automation, especially in the heavy welding industry, is not yet a reality. The method of operation still demands supervision of the welding technique, even though the work is done by machine.

If we deal with the first beginnings of electric welding and make a start with the position as it was in the thirties, we see attempts to replace manual electric welding with electrodes by the mechanical melting of electrodes.

The first form of automatic welding was the Elin-Hafergut process, whereby an electrode was simply placed in the joint to be welded and melted. Then came the Sarazin system; this used coiled wire with covering and armouring for the passage of current. The machine imitated the welding movements of advancing, wire feeding and turning.

The advantages were a uniform supply with constant resistance of the current-carrying part. Rather more current can be given so as to increase the quantity melted. In addition, no time is needed for replacing electrodes and touching up heads and craters.

Many variations on this automatic method have been developed, but it has not been very much used in practice on account of its unreliability.

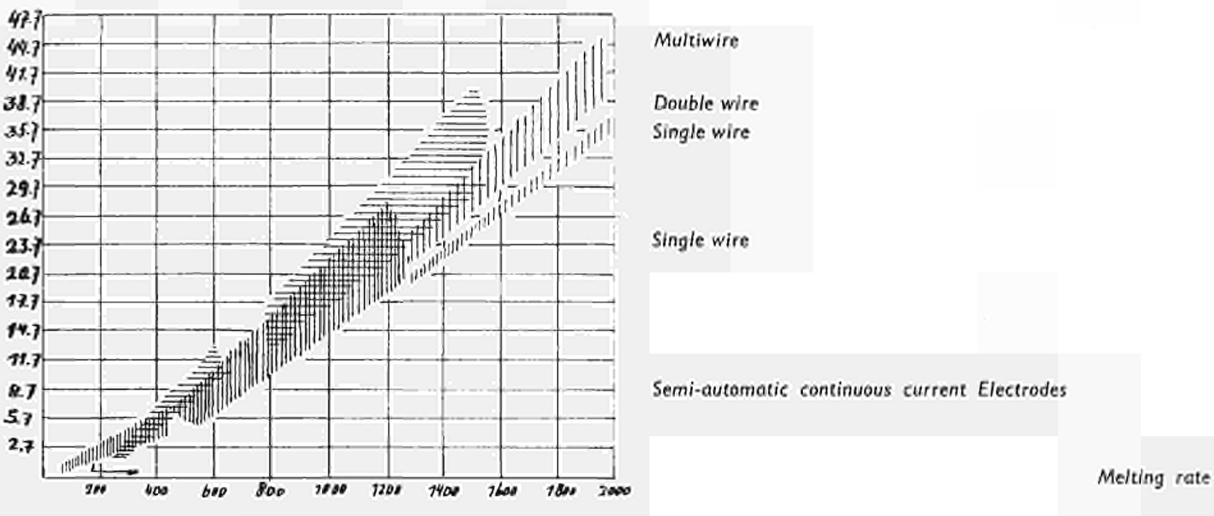
This was not the case with the Kiellberg automatic welding apparatus, which used standard electrodes.

Two electrodes relieved one another, which resulted in continuous welding with no heads or craters and productive time was not lost by replacement, as this was done during welding. At the same time there was a free choice of electrodes. These automatic devices were used a great deal from 1938 to 1950.

In the years before the Second World War two automatic and also semi-automatic welding processes were developed, which have ultimately had a lasting effect on the automation of welding and with all their further developments and special applications have enabled alloy steels to be mechanically welded on a large scale. We refer to submerged-arc welding and welding in a shielding gas.

Submerged-arc welding

In this method, which was introduced in the thirties, an arc is automatically maintained between a continuously fed bare wire and the workpiece. The arc and its immediate surroundings are covered by a welding flux, which is also fed continuously. The arc is usually advanced mechanically along the seam. Submerged-arc welding is one of the most efficient and rapid methods available. The most important advantages result from the applicability of high current intensities and densities, as the current can be fed to the bare wire at a short distance from the arc. Current densities of up to more than 10 times those obtainable with manual welding are used. This results in deep penetration and rapid melting rates. These are the most essential advantages of this welding process. The following figure shows quite clearly the high melting rate as compared with welding with a covered electrode :



The melting rate given is calculated for a 100% duration of application. The melting rates actually obtainable are not so good and depend on the duration of application obtainable. In many cases this is a smaller percentage in manual welding than in submerged-arc welding, so that the latter process is relatively more economical. Non-alloy steel can often be submerged-arc welded in a number of layers, that is with a maximum current intensity, and in many layers with a considerably lower current intensity per layer. The choice of the method to be followed depends on the demands that the weld and the transfer zone have to satisfy. The mechanical properties decline with the number of layers.

The application of heat treatment after welding however, enables mechanical properties to be improved. It has been found preferable with alloy steels to use the multi-layer technique, especially with fairly thick plates, as the correct heat treatment frequently cannot be given afterwards.

Nowadays we have a choice of two methods for the welding of alloy steels, i.e. welding with alloy wires and neutral or practically neutral fluxes, and welding with a non-alloy wire in combination with an alloy flux.

Both methods have their advantages and disadvantages and both are used. The types of flux are classified according to the methods of manufacture into fused and agglomerated fluxes. Fused fluxes are prepared by fusing the constituents completely at high temperatures during manufacture. This produces a glassy material which is ultimately ground down to the desired fineness of grain. Metal, alloying and yield-raising constituents cannot be added in this way.

Agglomerated fluxes are obtained by sintering previously finely ground and mixed starting materials at a much lower temperature than the fusion temperature. An important advantage of this method is that metal constituents cannot be separated as in the fusion process. They are thus bonded in with the non-metal constituents. This enables high percentages of metal ingredients to be finely distributed in the flux, and these, on welding are yielded to and uniformly mixed with the pool.

A special form of submerged-arc welding, which has been developing recently, is that of welding with a strip of say 60 × 0·5 mm. as filler material instead of a wire. The great development of alloy welding fluxes has enabled strip welding to be studied again. It has already been found that in combination with alloy welding fluxes this process may now be regarded as a practical proposition (figure 1, page. 597).

Quite apart from the fact that the melting rate is considerably higher than is the case with wire welding, melting rates of 10 to 16 kg. of weld metal an hour being obtainable, several other properties distinguish this method from wire welding. There is a high degree of uniformity and the depth of penetration and therefore mixture with the underlying metal is much less, while the appearance is frequently so good that subsequent machining is unnecessary. This shows immediately that strip welding is very suitable for providing large areas with a specific layer in a short time. This applies both to plating with special irons with a view to resistance to corrosion or oxidation and to wear-proof layers. In the chemical industry and reactor construction use is frequently made of designs having thick walls which cannot be made of plated steel. Strip welding is an economic proposition here. The use of a current source with a flat voltage characteristic is also worth recommending for other automatic or semi-automatic welding processes. For with this system the arc voltage is constant, which promotes quiet welding and improves the appearance. The melting rate is directly corrected by variation of the welding current.

Investigations have shown that the arc moves to and fro in strip welding, resulting in the partial melting of the strip by an arc and partial melting in the liquid slag. This explains the high melting rate at a relatively low current intensity.

A welding method which does not involve an arc between the wire and workpiece is vertical welding under a liquid slag. This method has been specially developed for the rapid welding of thick-walled structures. The amount of metal melted in this case amounts to 25 to 30 g./ah., which corresponds, with a current intensity of about 550 amp, to about 15 kg./h. Flux consumption is very low compared with submerged-arc welding with a wire.

The heat of the arc, which is alone present at the start, melts the flux which is overheated and conductive and in which the electrode or electrodes are placed. The high electric resistance of the slag keeps the latter at a high temperature.

The pool is shielded by the two edges of the parts to be welded and by two water-cooled copper shoes, which rise with the pool. This method has produced a highly uniform weld in a single layer. The standards of construction, particularly with regard to the toughness of the melted metal, sometimes necessitate heat treatment, which is necessary for the production of fine grains. Non-alloy and low-alloy steel grades of great strength can be welded vertically under melted flux.

The welding process can be used for welding with unalloyed and alloy wires, and for welding with filled wires, the desired alloying elements being worked into the filling. It is not possible to use sintered fluxes with the object of transferring alloying constituents from them to the bath.

Submerged welding with electrodes

TIG and MIG welding of non-alloy and low-alloy carbon steel has never found wide fields of application, mainly owing to the high price of the argon gas. Various cheaper gases have been tried but only CO_2 gas has been a success. In 1926 this was used as a shielding gas, but the weld was porous, and the mechanical properties were unsatisfactory owing to the brittleness of the weld metal. CO_2 gas decomposes at high temperatures and the oxygen liberated had to be bound by the addition of small percentages of deoxidising elements to the melting wire. This was done for the first time in 1952. Only 0·3% Mn and 0·3% Si were sufficient to obtain a dense weld under favourable circumstances with a CO_2 gas shield. In practice these favourable circumstances are only present sporadically, so that several times these percentages of Mn and Si are necessary to achieve the desired results.

The presence of oxygen in CO_2 welding also means that satisfactory TIG welding in this atmosphere is impossible owing to the rapid oxidation of the tungsten electrode.

The transfer of drops in welding in a CO_2 atmosphere is not the same as in an argon atmosphere. The drops are larger and the arc crackles more. For the welding of non-ferrous metals argon is usually used as a gas shield, while for ordinary steel grades CO_2 is principally used, and sometimes a mixed gas consisting of, for example, argon, CO_2 and oxygen. Certain circumstances and, in particular, standards have permitted austenitic Cr-Ni steel grades to be welded in a CO_2 atmosphere. The composition and resistance to corrosion demand careful attention in regard to the effect of the CO_2 gas on the pool.

The development of present current sources and the wire-feeding mechanism have also contributed greatly to the wide use of welding in a CO_2 atmosphere.

Because of the pronounced arc-damping properties of CO_2 gas, resulting from the fact that the molecule contains several atoms, direct-current equipment of the rectifier type, with silicon or selenium cells, or transformer type must be used. The electrode is generally connected to the plus pole.

The most important method used at the present time for accurate adjustment of the arc is the regulating system with a self-adjusting arc. This method has almost completely ousted the system in which the arc length is mechanically regulated.

Self-adjusting arc regulation is obtained by using constant-voltage direct-current equipment, the current being a direct function of the wire-feeding rate. The wire melts at the rate at which it is fed and the arc length remains constant. Any variation in the length of the arc is immediately corrected by changing the current intensity.

A great deal of research is being carried out on drop transfer in the arc, and films with 3,000 to 5,000 exposures a second show this drop transfer in detail. Fine atomisation of the metal drops is observed, for example, in the welding of aluminium in an argon atmosphere. A condition is the maintenance of a given minimum current density, which is usually the case with aluminium. In a CO_2 atmosphere there are two important and distinct forms of transfer, i.e. spray transfer, where the operation is carried out above the threshold current, and dip transfer, where use is made of current intensities below this threshold value.

Until a few years ago only spray transfer was possible, but improved current sources have now made it possible to use dip transfer. This improvement is expressed in particular in the control of the short circuit, which always occurs when the drop comes into contact with the pool. A current source with a flat characteristic, which at the same time enables the short circuit current peak to be reduced, produces a quiet arc without explosive action in the pool. In contrast to the spray-transfer technique, which is suitable only for manual welding in view of the large pool, it has become possible to weld in situ and join thinner material, whenever welding is carried out with the drop transfer method. A much wider field of possibilities can now be covered with the same wire diameter. Thus, it is quite feasible to weld in situ with a 1·2 mm. wire with a current intensity of about 150 amp and with the same wire, but then apply manually a current intensity of about 300 amp.

With regard to the mechanical properties of the melted metal, the CO_2 process may be regarded as suitable for high-quality welds, as only a small amount of hydrogen is liberated, while good protection against oxygen and nitrogen from the atmosphere is provided.

Alloy steels can be welded with CO_2, with alloyed wires as filler material.

The number of g./A. min. is characteristic of the melting rate of an arc-welding method; the following table gives a few average values:

Standard electrode	0·17	g./A. min.
Contact electrode	0·24	g./A. min.
Submerged-arc welding	0·24-0·30	g./A. min.
CO_2 welding	0·30-0·40	g./A. min.
Electric slag welding	0·50-0·60	g./A. min.

After the development of CO_2 welding with bare wires, many variations of this welding method have been proposed. They may be divided into two groups, i.e. those in which slag powder is added and those in which other gases are added to the CO_2 gas.

A long-established example of the first group, i.e. with a flux filling in the wire, is the Arcos composite wire. This wire is used for semi-automatic and automatic welding with a CO_2 shield at fairly high current intensities. Welding in position is therefore impossible.

The development of folded wires is moving in the direction of smaller diameters, such as 2·4 mm. and 2 mm., which are still intended exclusively for manual welding. The manufacturing technique for the fluxes and the filling of the wires has improved so that alloy constituents can be added to the flux if alloy steels have to be welded and whenever heat-resistant, corrosion-proof and wear-proof layers are needed.

The higher melting rate of the filled wire, especially for semi-automatic welding, will give this technique a place beside CO_2 welding with solid wire and welding with high-yield electrodes.

Both solid bare wires and wires filled with flux are used for automatic vertical welding. The welding process is carried out in exactly the same way as with electric slag welding, a CO_2 gas atmosphere and an open arc being present. High welding rates are achieved as the seam is filled in one layer, while the mechanical properties of the weld are usually satisfactory so that subsequent heat treatment is unnecessary (figures 2, 3 and 4, pp. 597 and 598).

Welding in an inert gas atmosphere

To distinguish between active and inert gas shields, the generally accepted abbreviations MAG and MIG for "Metal Active Gas" and "Metal Inert Gas" respectively are now used. Welding with a melting electrode in a CO_2 atmosphere is thus designated MAG, while MIG is the abbreviation for welding with a melting electrode in an argon or helium atmosphere.

Welding in an inert gas with a non-melting electrode is designated TIG (Tungsten Inert Gas).

The TIG welding process is a method in which heat is evolved by maintaining an electric arc between a non-melting electrode (tungsten or tungsten + thorium) and the workpiece in an atmosphere of a separately supplied gas.

Any necessary filler material must, as in autogenous welding, be fed to the pool separately from the current-carrying electrode. The great advantage of this method is the high degree of purity and uniformity of the melted material resulting from the absence of fluxes and coating materials. The weld therefore contains no flux or slag, so that corrosion due to residues of flux or coating material cannot occur. Great heat concentration and splash-free welding also characterise the process. TIG welding is clearly very suitable for joints whose welds must satisfy a very high standard of density and, as regards composition, conform to very narrow analysis limits.

With TIG welding, ionisation in the arc space cannot be increased by the addition of certain substances and in particular the arc cannot be maintained in alternating-current welding; high-frequency voltages are therefore applied during and after the striking of the arc. The welding transformer, converter or rectifier can be used as a source of current. The modern double-current welder is a welding transformer combined with a welding rectifier. In general aluminium-containing alloys are welded with alternating current and all other materials with direct current. Some jobs can only be carried out in practice by the TIG process. Examples are the welding of thin plates of stainless steel, titanium and aluminium, and the welding of tubes in a tube sheet for a heat exchanger. To prevent fissure corrosion in the latter case, the welded joint must be made on the other side of the tube sheet. This can only be done by the TIG process if it is carried out completely automatically.

The current source, welding gun and especially the starting current adjustment and crater filling must satisfy very high standards, as it is not so easy to repair a welding defect in such a case. TIG welding can be made completely automatic, when a separate supplementary wire which does not carry current may be used. This makes it possible to weld very small profiles without filler metal, long seams with filler metal and tube-tube sheet joints, also with filler metal (figure 5, p. 598).

Welding in an inert gas with melting electrodes

In MIG welding (Metal Inert Gas) a direct-current arc is maintained between the workpiece and a melting electrode, this electrode, the arc and the pool being surrounded by a shielding gas.

The filler metal is fed at a constant rate through a welding tip. Current transfer takes place in the latter. This method was originally used in particular for relatively large wire diameters and high current intensities, where only manual welding was possible.

Aluminium, stainless steel, copper and its alloys, etc. are MIG-welded with good results. The MIG method is frequently used as a fully automatic welding process, especially in view of the high current intensities, which make it more difficult to control the pool.

The specific advantages of this process are as follows:

The absence of fluxes and coating materials, giving the melted material a high degree of uniformity and enabling high melting rates to be achieved through the high current density.

The development of current sources and feeding mechanisms for CO_2-welding (MAG) has at the same time enabled the MIG process to be applied according to the atomizing and short-circuit arcs.

This development is thus entirely parallel with that of the CO_2 process. Nowadays MAG and MIG welding may easily be carried out with the same current sources and wire-feeding unit. In addition to the use of pure argon for welding non-ferrous metals, MIG-welding proper, steel can be welded by means of the following gases: argon +3 to 5% O_2; argon +25% CO_2; CO_2 (MAG-welding proper); CO_2 + 5 to 10% O_2 and argon +15% CO_2 +5% O_2.

The latter mixed gas is sold under various names. Each gas or mixture of gases influences the welding process in its own way. Vertical welding can be carried out with the short-circuit arc.

Finally, here are some practical examples of the various welding methods discussed.

The submerged-arc welding of thick plates

We have already referred to the multi-layer technique which is preferable for the submerged-arc welding of thick plates of alloy steel.

Here are some figures for the welding of 200 mm. plate, which is used for example in the nuclear industry. An extensive investigation has shown that good results are obtained with the following plate quality:

Composition of plate material (1·2 *MDO* 7)

C = 0·18% max.	Mn = 1·15%
Si = 0·35% max.	Ni = 0·5%
S = 0·04% max.	Cr = 0·2%
P = 0·04% max.	Mo = 0·45%
	Al = 0·02-0·05%

The mechanical properties obtained by special rolling and heat treatment are as follows:

σ_V = min. 35 kg./mm.^{2}

σ_2 = 52·5 — 65 kg./mm.^{2}

elong. = 20%

Composition of filler material

Welding of this quality is carried out with a non-alloy wire with an appropriate sintered flux (Record S 56). (This is a basic low-alloy flux containing Cr, Ni and Mo).

Analysis wire "A"

C = 0·06%

Mn = 0·45%

Si = 0·1%

S = 0·02%

P = 0.02%

If the multi-layer technique is applied with this combination of plate, wire and flux, the following composition is found in the melted material of the weld joint:

C = 0·037%	S = 0·023%
Mn = 1·12%	Cr = 0·20%
Si = 0·52%	Ni = 1·34%
P = 0·021%	Mo = 0·28%

It has been found that optimum results are obtained with normal adjustment of current intensity, voltage and advance rate. These are as follows:

Wire diameter	5/32"
Current intensity	620 ampères
Voltage	28 volts
Advance rate	16 inches/minute
Number of beads	107

Heat treatments

The preheating temperature during welding is 200°C, while the maximum inter-pass temperature is 300°C.

Whether intermediate annealing, to prevent the occurrence of beads, is carried out depends among other things on the constructional rigidity and the welding sequence.

The cycle of thermal stress-relieve is as follows:

Heating rate from 300°C to 625°C = about 25°C/hour.
Annealing time at 625°C = about 8 hours.
Cooling rate from 625°C to 400°C = about 11°C/hour.

Mechanical properties

The degree of uniformity of this welded joint can only be effectively determined by means of ultrasonic tests.

The following three tables summarise the mechanical properties.

Tube-tube sheet joints

With tube-tube sheet joints, the welding of the tubes onto the tube sheets is becoming more and more automatic.

The most important technique employed here is automatic argon arc welding without filler material.

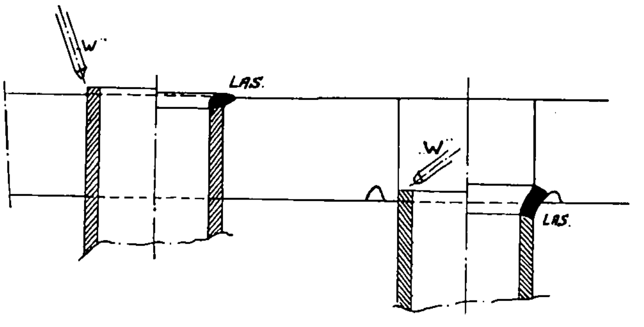
Automatic equipment however, using filler material is also on the marktet. This type of equipment can also be used for welding carbon-steel heat-exchangers, as it is well known that the argon-arc welding of carbon steel without the use of filler material leads to difficulties.

More recent techniques are being developed in this field. As there is an ever-increasing demand for heat-exchangers and evaporators in which fissures do not occur between the tube and tube sheet.

Fully loaded stretched rod 12 mm. diam. - dp 5	Yield point kg./mm.^{2}	Tensile strength kg./mm.^{2}	Elongation L_o = 5d	Contraction %
Welded state				
Top of weld	46·8	57·9	22·5	57·7
Middle of weld	52·6	61·4	20·0	56·8
Bottom of weld	57·2	68·0	20·8	56·8
Annealed state				
Top of weld	43·8	54·6	28·4	59·2
Middle of weld	46·8	56·5	24·2	60·8
Bottom of weld	51·2	61·9	23·4	57·7

Transversely stretched rod 10 × 25 mm. - dp 5	Yield point kg./mm.^{2}	Tensile strength kg./mm.^{2}	Location of break
Welded state			
Top of weld	48·0	59·2	Outside weld
Middle of weld	40·0	54·8	Outside weld
Bottom of weld	48·8	62·4	Outside weld
Annealed state			
Top of weld	44·8	55·8	Inside weld
Middle of weld	45·2	54·2	Outside weld
Bottom of weld	44·0	58·8	Outside weld

Notched rod 10 × 10 × 55 mm.	Impact strength (notched) in kgm./cm.^{2}	
	V-notch at —10° C	Average
Welded state		
Top of weld	3·5 — 3·4 — 4·5	3·8
Middle of weld	3·5 — 3·8 — 3·5	3·6
Bottom of weld	2·0 — 2·2 — 3·3	2·5
Annealed state		
Top of weld	8·8 — 8·3 — 7·8	8·3
Middle of weld	4·1 — 9·4 — 2·4	5·3
Bottom of weld	4·6 — 5·0 — 5·9	5·2



In the chemical industry, fissure corrosion is prevented in this way. One of these more recent techniques is internal bore welding. (figures 7 and 8, p. 599). The welding procedure consists in attaching the tube by means of the tube bore to the rear side of the tube sheet.

In the above figures, at left the conventional method is shown and at right the internal bore welding system.

DISCUSSION

Albert COMBE

(Translated from French)

As Mr. Capel pointed out in his paper, the inert-gas-shielded welding process has many advantages, including:

— absence of flux and covering materials,

— possibility of obtaining good compact welds, high fusion rates.

Because of these advantages this process is being more and widely used in France for mild steels (in terms of metal welded, it has caught up with the solid-flux welding process) — 70% of bare wire being melted using gaseous mixtures of the argon-CO_2 type.

On the other hand, despite its advantages, the MIG process has hitherto been used only on a small scale for stainless-steel structures, for the following principal reasons:

— with helium, argon or argon-oxygen mixtures it is difficult to obtain a state of steady fusion by arcs;

— with CO_2 and mixtures of high CO_2 content, which allow arc fusion it is not possible to obtain total transfer of the noble elements of the filler rods; moreover, carbon enrichment is observed in the deposited metal.

Furthermore, the welds are oxidised on the surface, and one often notices projections which add to the finishing work after welding.

Thus, starting from the three principles that:

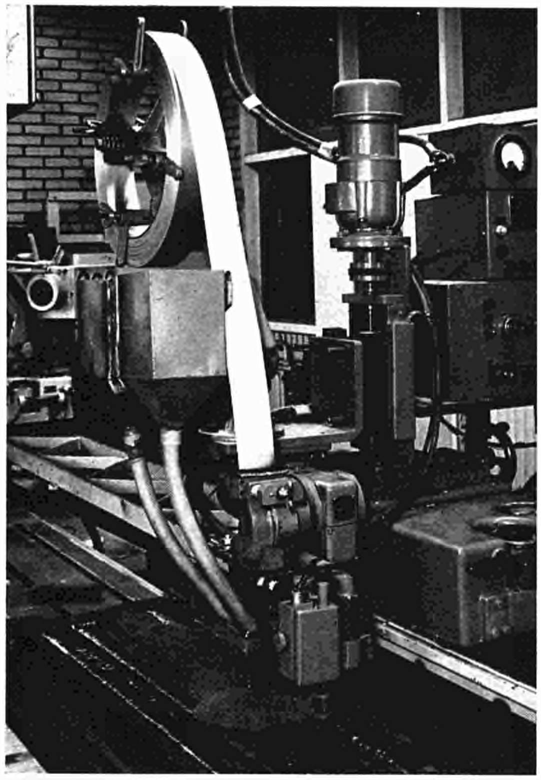
(i) in-position welding requires some kind of arc fusion;

(ii) the quality demands as good a transfer as possible of noble elements with minimum carbon enrichment of the deposited metal;

(iii) the construction calls for compact welds which are not oxidised externally and have no projections.

Our company has developed a special gaseous mixture for welding of stainless steels. This mixture enables all the advantages of inert-gas-shielded welding to be applied to stainless steels.

List of illustrations



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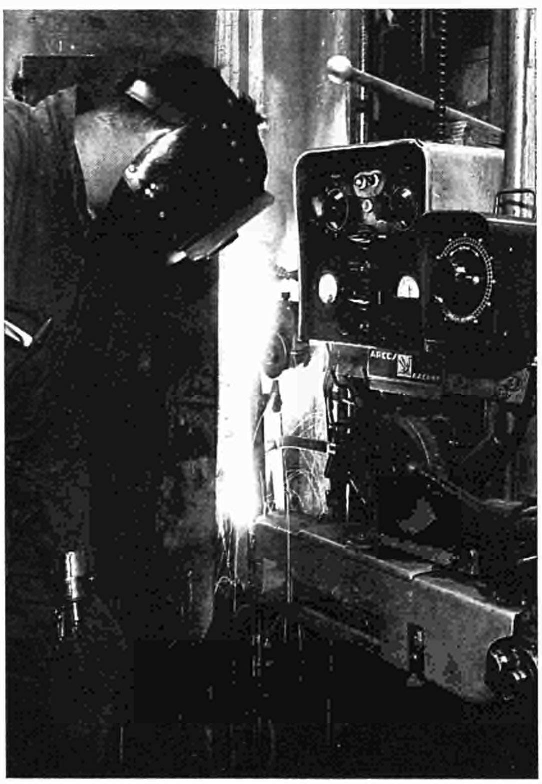

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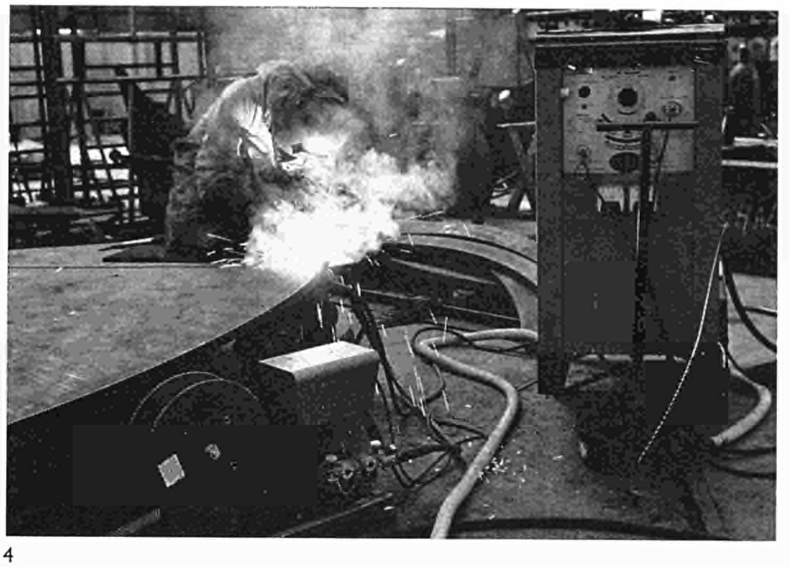

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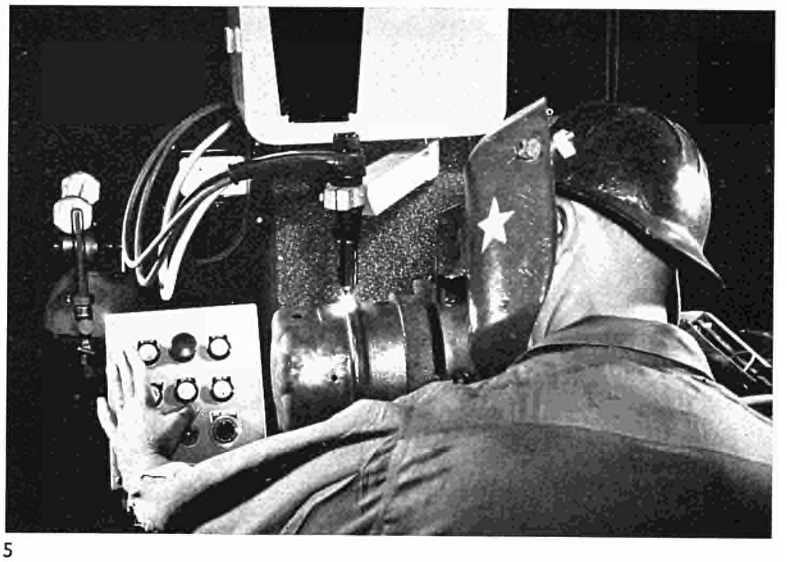

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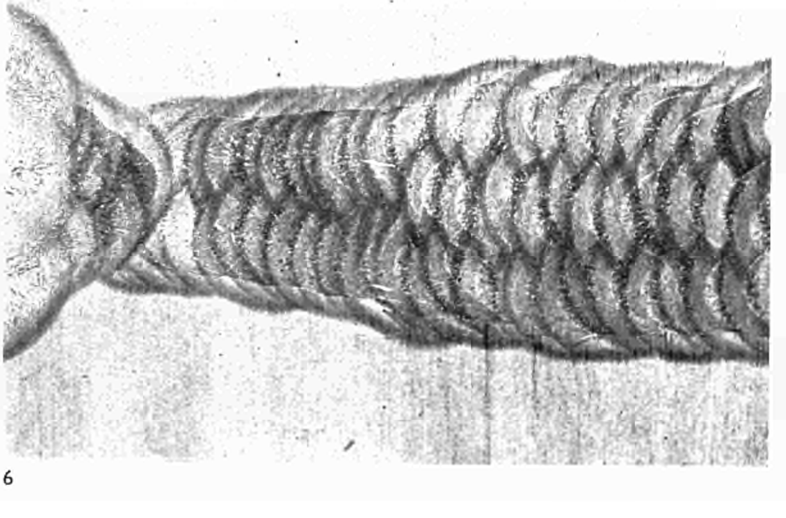

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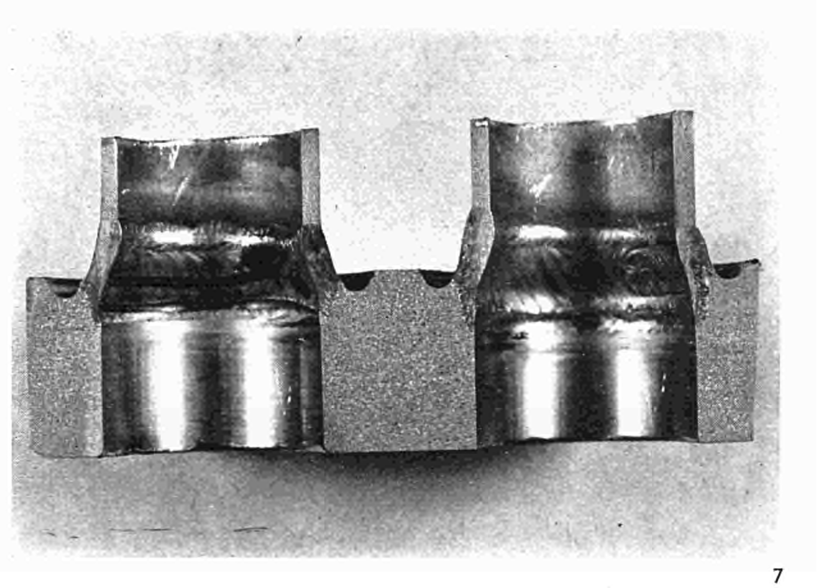

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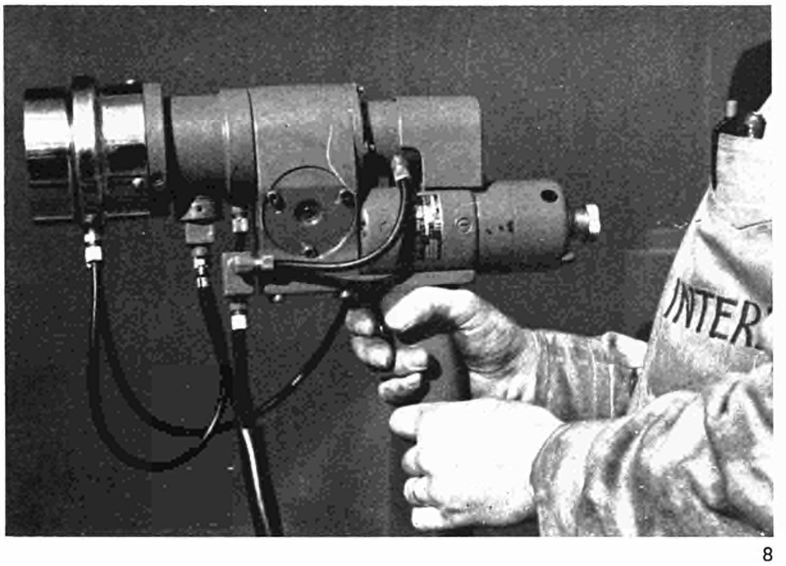


8

André GAUBERT

Welding Techniques for Thin Sheet Steel

(Translated from French)

It is sometimes said that the welding of thin sheets does not give rise to any problems. From the metallurgical point of view this assertion is largely true if it implies that the very diverse methods offered by the numerous welding processes available enable satisfactory results to be achieved. On the other hand, from the practical point of view, if account has to be taken both of economic requirements (which are often related to the investment needed for the production and productivity envisaged) and of the many desiderata which the fabrication is expected to meet: strength, weight, general appearance, state of the welded surface, soundness, capacity to resist corrosion, etc., many other problems are raised. Only a detailed knowledge of the possibilities offered by the many welding processes enables these problems to be solved satisfactorily. In arriving at a solution, account must be taken of the availability or otherwise of the power sources required for the chosen process.

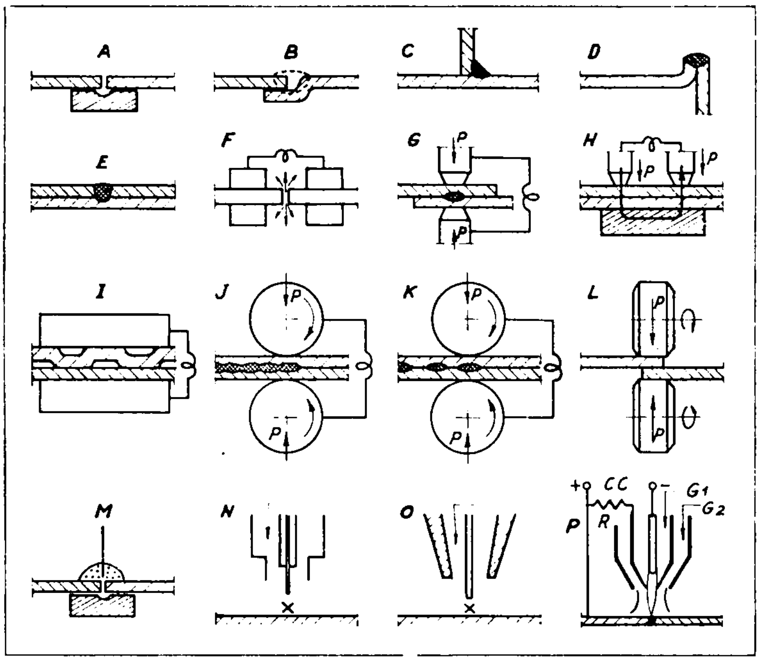
A look at some examples, in a short general review, will illustrate some of the possibilities offered by the various welding processes. We will not, in principle, take into account the manual processes of gas welding and arc welding with covered electrodes because, though they are used and often present certain advantages, their possibilities are well known. Also, to avoid repetition, the fabrication of tubes by welding will not be mentioned and the majority of the examples cited will relate to the joining of normal mild steel components.

General considerations on the welding of thin sheets

The thickness of thin sheets fabricated by welding is generally 3 mm. or less. The constituent parts of sheets which have been cut, stamped or cold drawn, are generally in rimmed steel and the state of their surface is satisfactory, i.e. free from rust and oxide.

It may be that they are welded before being formed and in that case the joint is subjected to the necessary forming operations. This sometimes occurs with the rims of vehicle wheels which are profiled after the hoop has been closed by welding; we shall mention one other example among many others.

Simple preparations are required for the majority of the types of assembly we shall meet. These types are: the butt-welding of sheets with square edges or with a slight root gap (see following figure), fillet welds (C) and edge welds (D). The fusion welding processes used for the butt welding of thin sheets frequently necessitate the use of a backing-bar which prevents the collapse of the edges and facilitates the formation of a seam with regular penetration. We shall see however that there are welding processes which allow the input of energy to be so precisely controlled and the heating effect to be so localized that the fusion of the



Schematic views of the various welding assemblies and methods

edges may be achieved without recourse to a backing-bar. If, however, a backing-bar is necessary, it often consists of a grooved copper strip (A). This traditional type cannot however, always be used. For instance, removal from inside after welding may be impossible in the case of a hollow object (a butane cylinder for example). In that case, an alternative device is necessary: some makers use a backing-bar which can be destroyed after welding, for example by fusion in the course of subsequent heat treatment; others get round the difficulty by using a sleeve joint of the spigot and socket type (B).

Finally, there are lap joints which are frequently used in the resistance welding process.

Difficulties of quite a different kind may arise from the characteristics of the base metal whose effervescent character may become evident in the weld metal, giving rise to blow-holes or porosity in the joint. We shall see that each welding process has its own means of combatting, within certain limits, the formation of this type of defect.

Automatic oxy-acetylene welding of radiators

The constituents are made up of two mild steel half shells of 13/10 mm. thickness formed by means of a mechanical press, brought into contact and welded round the edge with an oxy-acetylene blowpipe. This is an example of edge welding of the type shown D in the above figure, and is carried out without filler metal. The welding operation being automatic, fusion is very regular and a smooth edge of uniform appearance is obtained. With this method of fabrication, one may expect to achieve lightness and elegance of form, strength (because of the remarkable impact strength of the steel), low thermal inertia and a smooth surface which facilitates maintenance operations in service.

A machine fitted with 15 burners enabling the 15 elements of a radiator to be welded simultaneously is shown in figure 1, (p. 609). Its extreme simplicity should be noted. Each burner furnishes 150 l./h. of aceytlene, the total combustion of which is equivalent to a thermal power of about 2·3 kW. The welding speed is 0·33 m./min. and the assembly of the 15 elements is achieved in about 6 mins. The reducing character of the oxy-acetylene flame ensures sound welds and each radiator is submitted to severe hydraulic tests.

Resistance welding

In these welding processes, the passage of an electric current through the components to be assembled provides, through the Joule-effect, to the necessary heat input. The application of pressure effects the weld. It is obvious that, since the heat effect only occurs within the components to be assembled, it is usually possible to obtain very rapid heating, so that the period during which the assembly is subjected to the fusion or forging temperature is very short, which is advantageous from every point of view.

The resistances of the elements in contact are evaluated in hundred thousandths of an Ohm, the welding currents often reaching some tens of thousands of amps.

The heating times are sometimes so short that it is convenient to evaluate them in the number of periods of alternating current at 50 cycles delivered by the mains.

If the energy output of the operation is to be acceptable, the welding circuit must be of very low resistance. In these conditions, their reactance may assume a comparatively high value should mechanical requirements necessitate an increase in the extent of the circuits.

Correspondingly, the apparent electric power of the machines can be so high, and the power factor fall to such a low level, that the problems raised by the power supply for such machines from the mains may be a decisive factor with regard to the final choice of the welding process to adopt.

Flash butt welding of strips

In this technique, the strips, gripped by jaws which form electrodes (in the above figure), are required to carry an electric current of a few volts. One of the strips is stationary; the other is moved forqward at a very slow pace (5 cm./min. for example). When the first contact between the two occurs, only a very small number of surface projections are usually involved, say 1% of each of the opposing surface areas. These projections heat up and globules of molten metal are quickly produced and are expelled in a shower of sparks as a result of the forward movement and of the generation of vapour which almost always accompanies fusion and the partial volatilisation of the edges.

This succession of imperfect contacts, continuously repeated, results in a very localized generation of heat; when the upset occurs to effect the weld it finally brings into contact the full areas of the edges which have been cleaned by the expulsion mechanism which has itself been shielded from attack by the air. The upset metal (or flash) is inconsiderable in volume and consists primarly of metal particles and oxides. It is easy to dress off and leaves a joint of excellent quality, able to withstand all subsequent forming operations.

This process is frequently used both in the production of steel strips, between rolling operations for example, and in the joining together of the finished products.

The same method is employed with the machine of the mechanical cam movement type with direct flashing which is shown in figure 2 (p.609) and which is used for making a butt weld between the edges of large sheets. In particular, it enables sheets of 12/10 mm. thickness and of 1·5 m. width to be welded. The flashing time, properly speaking, is 2·25 seconds and the maximum power required from the mains may reach 400 kVA. at the moment of upset; it is essential not to interrupt the current before forging takes place so that air is prevented from returning into the plane of the joint faces. The upset force is 15,000 daN. and the machine is built on the assumption that it will operate not more that 100 times an hour.

Spot welding

The principles of single spot welding are shown in G of the above figure. As a general rule, the practice adopted today for the spot welding of thin sheets presupposes rapid welding, necessitating short welding times, powerful currents and high pressures. The choice of such a method makes possible the localization of the heat input and the reduction of its magnitude.

The spot is at welding temperature while the surface metal is still cold, the heating of the elctrodes is reduced and they therefore last longer. The spot is of excellent quality and the visible traces on the surface very small.

This welding technique makes it possible to produce 200 spot welds a minute on 12/10 sheet. With certain types of fabrication, the present tendency is to increase this rate, and even to double it, but this means acceptance of a reduction in weld quality.

To reduce the assembly time, multiple spot welding machines have for long been used, to a large extent, for example, in the fabrication of car bodies. These machines, designed to make a particular part, consist of as many welding heads as there are spot welds to be made on the assembly. To avoid the necessity for very complicated electrical circuits which would require correspondingly higher power, the method of the series spot shown in H of the above figure is fairly widely used. Since the transformer is placed immediately above the electrodes, the secondary circuit is particularly short and all transformers can be located so as to follow the contour of the components to be assembled. This method of welding has the additional advantage that the weld is invisible on the surface of the sheet in contact with the backing electrode.

Multiple spot welding machines, which are very widely used in the fabrication of car bodies for the welding of the doors, of the floors to the chassis and even of the water channels to the side panels, have found new application in the welding of the frames of the front and back openings.

The machine shown in figure 3 (p. 609) is a good example. It welds the 60 spots which join the frame of the front opening to the body, the 10 spots on the back rail of the body and also the 36 spots which attach the two reinforcing arches to the internal face of the body. Because of the very special work schedule of this machine, the transformers are placed both on the rotating arm for the welding of the frames and also on the sliding carriage on which the body rests for the welding of the reinforcing arches. To limit the electrical power required to about 300 kVA., welding takes place in three cycles and all operations from the loading of the constituent parts to the ejection of the body and the welded frames are entirely automatic.

Projection welding

Another process which enables economies to be made in assembly time is that of projection welding, the principle of which is outlined in figure I on p. 602.

One of the sheets is formed to provide a number of projections and the parts to be assembled are placed between the platens, which constitute the electrodes, of a press type machine. In addition to a high production output, this welding process has the following advantages:

- Projection welding gives very clean work; there is no mark of welding on one of the faces and, on the other, only minute and regular depressions remain;

— The weld spots can be close together and spaced in the best possible way to meet the stresses applied in service;

— It is easy to locate the position of the parts to be assembled;

— Wear and tear on the electrodes is slight.

Finally, the projections may have many different forms.

On the other hand, projection welding has the disadvantage that it demands much electrical power; machines of 1000 kVA. are sometimes necessary.

Seam welding

To increase the possible rate of welding when the joint is effected by successive spot welds, cylindircal electrodes can be replaced by electrode wheels, as shown in of the figure K. When the pitch is reduced, the spots overlap, giving finally a continuous weld seam, as shown in J. (See figure on p. 602.)

An example of the application of this process, a welded petrol tank, is given in figure 4 (p. 610). To prevent corrosion, lead-coated sheet is used, generally 12/10 mm. thick. The tank comprises two shells, previously tack welded together, the seam welding being carried out round the periphery on the raised edges. The speed of welding is about 2·5 m./min.; the production rate being about one unit per minute. About 100 kVA. are required.

Mash seam welding

With this process, large electrode wheels are used and the parts to be welded are slightly overlapped as shown in L (figure on p. 602). The forging or crushing (mashing) action brings the two parts onto the same level during welding if the overlap of the sheets is equal to about one and a half times their thickness. By comparison with flash welding, this process requires lower maximum power and does not necessitate any dressing operations.

Figure 5 on p. 610, shows the continuous welding by this process of mild steel cylinders with the following dimensions: length 700 to 950 mm.; diameter 440 to 585 mm.; thickness 0·6 to 1·5 mm. The preformed cylinders pass open into the arm connecting the upper electrode wheel and the frame, and are then led into a forming device which guides them throughout the welding operation. The output is about 300 to 400 cylinders per hour. As these cylinders are used in the fabrication of drums after cold rolling and insertion of the bases, it is essential that the edges should be perfectly true. Thanks to a special electronic device, the current is automatically reduced as the electrodes start and finish so that none of the metal is forced out at the ends. Finally, to even up the wear and tear on the electrodes, they are displaced by some tenths of a millimetre at each pass.

Submerged arc welding

The principle of this welding process is shown in M of the figure on p. 602. A coiled electrode is fed into the area where welding is taking place which is entirely covered by a layer of conducting flux. Fusion thus takes place protected from the air and is quite calm; noise, light, fumes and spatter thus being prevented. These circumstances make possible the use of current densities five to ten times higher than could be used with arc welding using covered electrodes. The molten flux becomes a current conductor and the Joule-effect in the wire, the flux and the workpiece contribute to the heat input required. However, as current and voltage oscillograms have shown, an arc mechanism occurs only intermittently. For the relatively low currents suitable for the welding of thin sheets, this mechanism occurs every three to five periods. In other words, an arc occurs each time that the pressure of the gases is sufficient to displace the molten flux and this arc is established within a sort of "bubble"; the "bubble" bursts and the resistance mechanism is resumed. During this process the wire and flux contribute reducing and compensating elements which enable joints of a satisfactory quality to be obtained.

This welding process, originally developed for the welding of medium and thick plates, has gradually been adapted to the welding of thin sheets. Its excellent productivity in terms of heat utilised (about 0·3 g. of wire per amp. per minute are melted) and the high degree of localization of the heat input made possible under the insulating covering of the flux fully justify this extension. The welding of butane cylinders has already been mentioned; another example, chosen from among many, is shown in Fig. 6 (p. 610). This is the welding of a sealed unit (motor-compressor) for use in domestic refrigerators.

The casing is made up of two half shells in 3 mm. thick sheet which are butted together, their raised edges being in perfect contact. The weld is therefore an edge weld made in the horizontal-vertical position, the edges being fused as shown in D (see figure on p. 602). With a wire of 2·4 mm. diameter and a current (DC) of 320 A, the casing of 248 mm. diameter was welded in a single revolution. A second pass was made to guarantee absolute soundness. The total welding time was 72 seconds, the power required being about 25 kVA. in three-phased belanced current.

Inert-gas metal-arc welding

In this welding process, a relatively fine coiled electrode of 8 to 20/10 mm. is used, as shown in N (fig. on p. 602). Essentially, fusion occurs as a result of an arc struck within a protective atmoshpere, in fact, argon. If a sufficient current density is used, that is to say, above a certain range, for example of the order of 130 A./mm.^{2} for a mild steel wire of 12/10 mm., the metal transfer occurs across the arc in a special way if the electrode is the anode: the drops are regularly detached and form a chain which remains in the axis of the wire, the spatter being practically non-existant. The transfer of the metal is known as axial spraytype transfer. If all the conditions mentioned above are satisfied, the resulting process is conventionally called the MIG-process (metal-inert-gas).

The MIG-process is very widely used both in the welding of light alloys and alloy steels. Two difficulties stand in the way of its extension to mild steels. The first is the cost of the gas, the consumption of which is about 15 to 25 l./min., the second the particular shape of the weld seam which tends to be undercut. The addition of 3% oxygen to the argon provides a solution: axial spray transfer is retained, an impure, and therefore less expensive, argon can be used and a slight formation of oxydes alters the phenomena of surface tension so that generally deposits of good appearance and excellent mechanical characteristics are obtained.

The MIG-process thus has characteristics which make it indispensable for certain applications, even with mild steel sheets. An example is shown in figure 7 (p. 611).

This example deals with the fabrication by automatic welding of sections for metal furniture. The illustration shows both a section of complex form with two attachments which serve as a support for a strap and also the strap itself, which is 2·5 mm. thick, under two MIG welding heads. The double head makes it possible to weld two fillets (C in the figure on p. 602) with a leg length of 3 ± 0·2 mm. The use of the MIG process was necessitated by the following requirements: a perfect surface free from spatter, dimensional accuracy and good mechanical characteristics which were absolutely essential because these sections had to undergo the further processes of forming and straightening. Naturally, the special electrode of 12/10 mm. diameter contained the necessary reducing elements; the currents were about 350 A, the electric power about 36 kVA. in three-phase balanced current and the speed of movement of the sections about 2·7 m./min.

Gas shielded arc welding

In principle, this process is very similar to the last, the electrode being the anode, but in this case the atmosphere is not inert. It is in fact generally oxidizing, but free from nitrogen and hydrogen. For the welding of mild and low alloy steels, use is made normally of dry carbon dioxide (dew point below —40°C) or a mixture containing argon, about 15% of CO_2 and a little oxygen, or in certain countries, particularly Japan, a mixture of CO_2 and 20% oxygen. To distinguish this process from the MIG process, the abbreviation MAG (metal-active-gas) is sometimes used by analogy.

In active atmospheres there is no limit for the density of the current and metal transfer never occurs by spray but, whatever the current density, in large drops. These escape in a more or less irregular free flight or even sometimes flow, thus forming a liquid bridge between the electrode and the molten pool, and short-circuiting, for a brief instant, the plasma of the arc. The dissociation of the carbon dioxide into carbon monoxide and oxygen gives rise to reactions of oxidation. This should result in serious disadvantages and in effervescence causing a great deal of spatter; but the use of special wires rich in reducing elements, the composition of which depends on that of the gas used (for example CO ·12% max., Si 0·3-1%, Mn 0·9-1·9%, Al 0·3-0·6%) and an arc kept systematically very short (1 to 3 mm.) makes it possible to reduce the losses during deposition to a perfectly acceptable level.

Apart from the use of a less expensive gas, the MAG process has other advantages such as the possibility of welding on unprepared sheets, wide and deep penetration, etc. In the welding of thin sheets however it is probably the fact that it is exceptionally easy to use which has contributed to the development of this process; it is easy to use primarily because it is possible to adjust accurately the extent to which the Joule effect plays a part in the fusion of the electrode and of the sheets and in making the transfer of metal by short-circuits systematic. For this reason, sheets of mild steel of about 0·4 mm. thickness can be welded automatically.

Just how easy it is to use manual semi-automatic welding is illustrated by figure 8 (p. 611) in which an operator can be seen welding downwards in the vertical position the upper and lower closure of the fins, in 1 mm. sheet, of the tank of a transformer. The gas used is the argon-CO_2 mixture mentioned above, the electrode is 8/10 mm. diameter, the welding current is from 60 to 70 A., the welding speed is about 1m./min. in spite of the fact that the joint edges do not fit together particularly well, having been formed by hammering.

Figure 9 on page 611, shows another example of automatic fillet welding — the assembly of the handle-bar tube to the members of the frame of a mo-ped. The members are in mild steel sheet of 15/10 mm. thickness, butted, bent and spot welded along a raised external edge. They are fitted to the handle-bar tube, of 30-34 diameter, by a restrained part having two lugs approximately parallel and about 20 mm. apart. The two welding heads will be noted; they act simultaneously and symetrically to give two weld seams which effect a perfect junction at the side where the maximum stresses occur in service. With an 8/10 mm. electrode becoming molten with a current of about 130 A. and protected by the argon-CO_2 mixture mentioned above, the welding time is about 12 seconds, with a three-phase, balanced power of about 5 kVA.

Inert gas welding using a non-consumable electrode

With this process, the arc is formed between a tungsten-electrode and the parts to be assembled, pure argon being supplied as shown in O (see figure on p. 602); for this reason the initials TIG (tungsten-inert-gas) are used to designate this process. The electrode being the cathode, the TIG process is perfectly suitable for the welding of alloy steel sheets and it takes over from the MIG process for thicknesses below 3 mm. It is considered very valuable because of a very gentle arc and a very localized heat input which prevent distortion, give good weld surfaces and enable very thin sheets to be welded (e.g. automatic welding of 0·2 mm. sheets in 18 Cr, 8 Ni austenitic steel). These very qualities make this process particularly useful with mild steel and it is sometimes employed for special work on car bodies. It also enables spot welds to be made on mild steel sheets with a thickness of up to 18/10 mm. for the thickness traversed, as shown in E (figure on p. 602).

Conclusion

This paper on the welding methods available for the joining of thin sheets is far from being exhaustive. For example, the battle against corrosion phenomena, which is so important in lap joints, is not without its effect on welding techniques but it has not been possible to touch upon it here. However, in this battle the welder has his weapons: he may use coated sheets (zinc, galvanizing, etc.) or he may interpose between the sheets protective coating which are compatible with welding. It has also been impossible to discuss the welding of ultra-thin sheets; this, however, can be done and the plasma torch shown in P (figure on p. 602), which works on the principle of the constricted and transferred plasma jet, will, with a current of 2 A, produce a stable and fine micro-flame particularly useful where 0·05 mm. thick stainless steel sheets are butt-welded together. New perspectives are being opened up today with electron beam welding with which the flexibility of adjustment and the localization of energy are quite exceptional. There is no doubt that, in the field of the welding of thin sheets, technology is far from having said its last word.

List of illustrations

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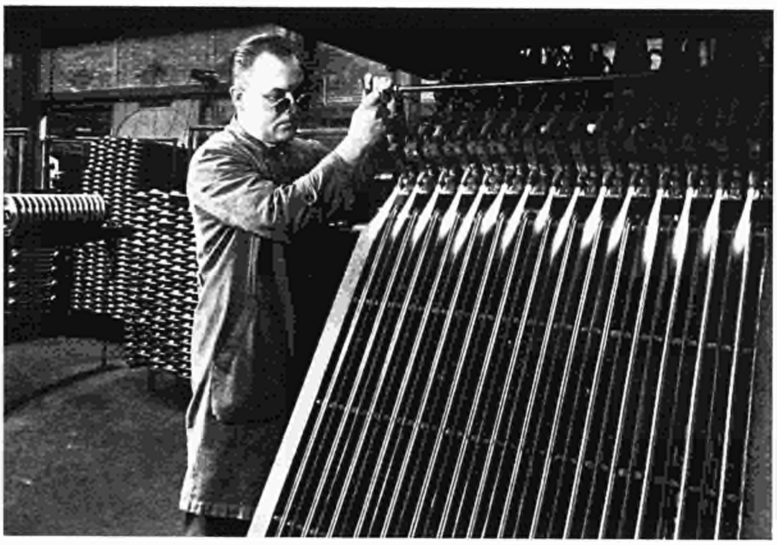
5 — Machine for roller-electrode welding by flattening.
6 — Submerged flux welding of sealed units.
7 — Automatic Mig welding process.
8 — Manual semi-automatic welding.
9 — Automatic MAG welding of the main frame section by means of two symmetrical heads.



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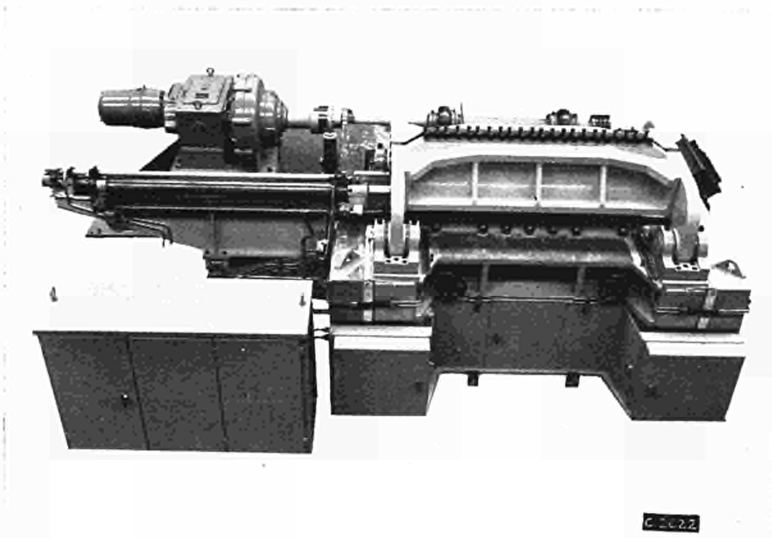

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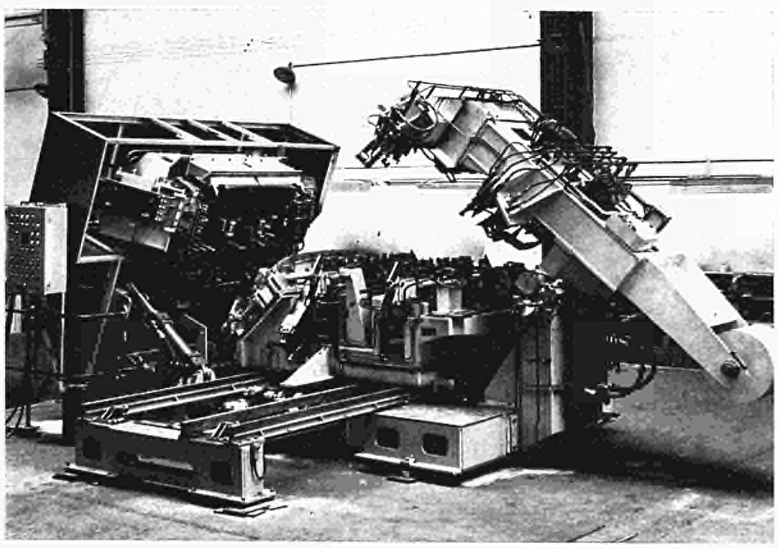

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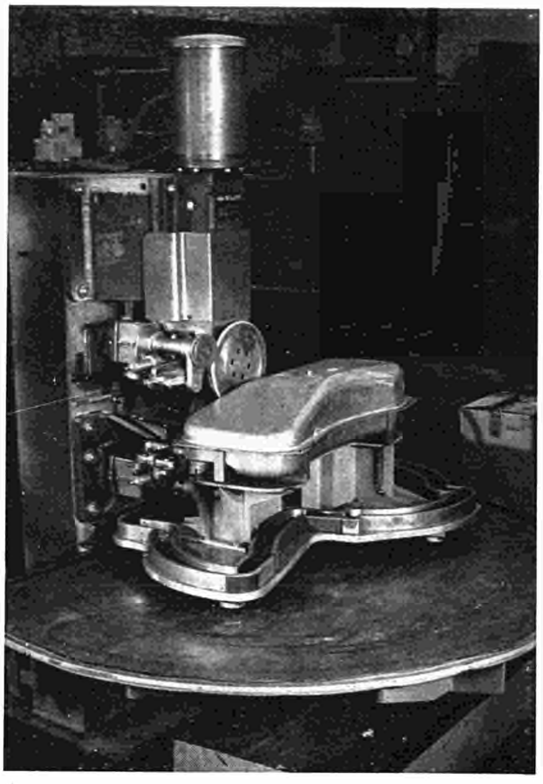

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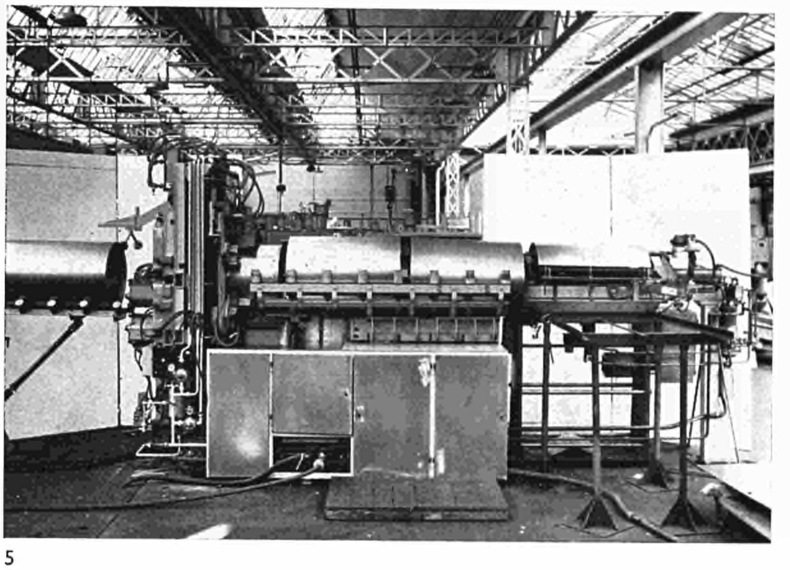

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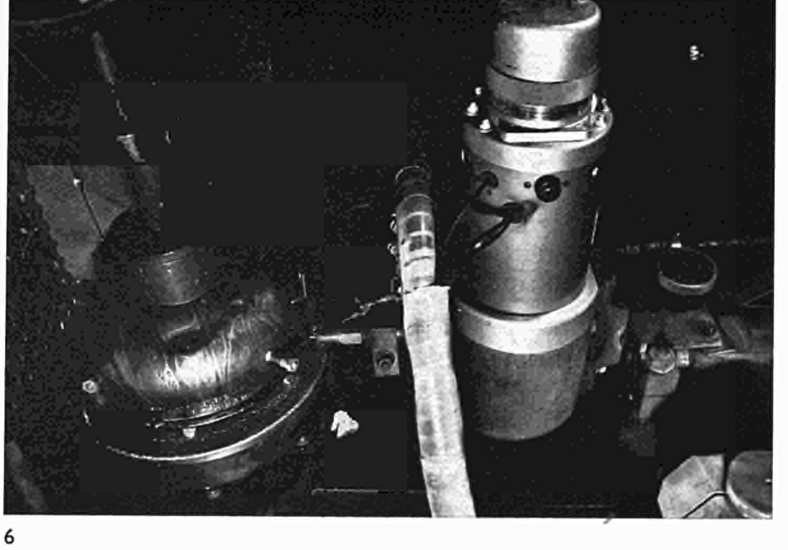

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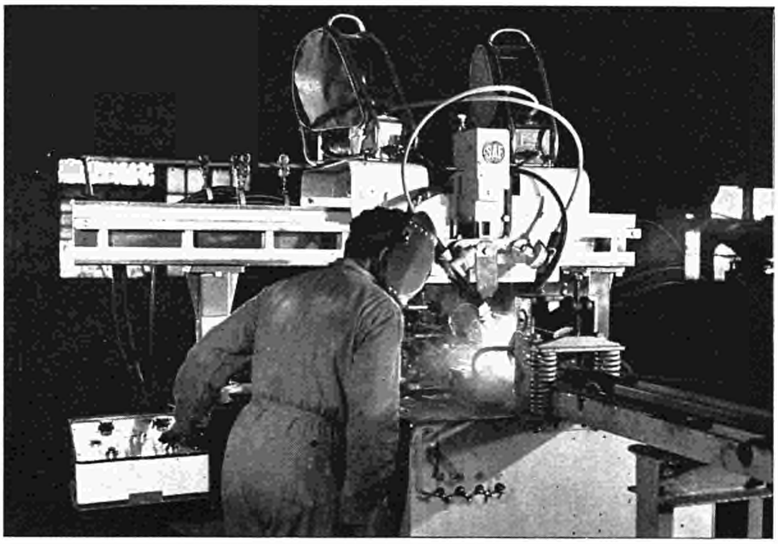

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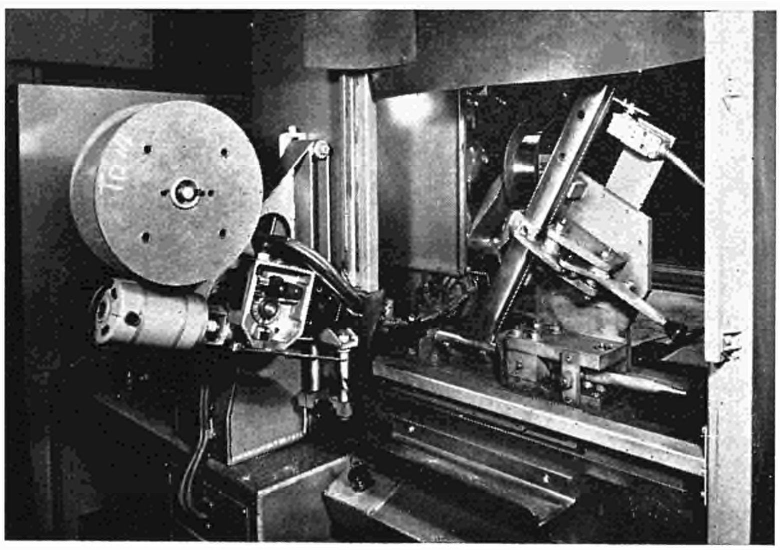

9

Umberto BIFFIGNANDI

and

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Welding of Steel Tubes (Ordinary and Special Steels)

(Translated from Italian)

Reference to steel tubes includes their use as structural components, for pressure pipelines, and similar applications. The paper deals with welded connections and their continued development to meet various requirements. After indicating steel types most widely used, welding procedures applied in particular cases are considered with particular reference to first pass butt joint welded connections for tubular forms. Illustrations are given of applications to industrial production.

General

The problems arising in connecting steel tubes are substantially different in character from those of joining non-tubular material. This applies both to the case of tubular steel structures and to tubes used for conveying fluids under pressure. In the structural field particularly, the best joints are achieved by abandoning traditional methods of joining steel sections. Tube jointing procedures must therefore have reference to geometrical and static characteristics to achieve the widest reliance on welded connections. The successful development of tubular construction is largely dependent upon rapid progress in welding technique.

In pressure pipelines too, as with tubular fabrications such as cylinders, manifolds, and special pressure vessels, continued development of welded joint techniques permits their wider application in meeting increasingly severe conditions.

Jointing of tubular structures

When tubular structures were introduced for towers, electricity pylons, gangways, and buildings, it was not difficult to exploit the rational, aesthetic, and weight-saving advantages of this form of construction. On the other hand, difficulties were encountered in providing effective joints. The idea of riveting was discarded and it was decided to make maximum use of welding, with bolted connections where subsequent dismantling might be necessary. Habitual use of steel sections however, and lack of confidence in welding, at first induced designers to provide flat surfaces in structural tube for traditional methods of jointing, but the wide use of connecting plates and flattened tube ends almost transformed the structure to angle section design.

One of the first important tubular structures was the Park Tower in Milan, constructed in 1935 exclusively with Dalmine tube. Considerable use was made of connecting plates, flanges, profiling of tube ends, etc., as shown in the figure 1 on p. 643, which shows this to be an interesting example of early tubular construction technique. In spite of this, the tower demonstrates the rational and aesthetic character of a tubular structure exploiting the static, aerodynamic, and geometrical advantages obtainable. Rational form also applies to jointing, which permits perfect convergence of the lattice axes to the junctions and perfect axial loading of each lattice.

With the continued extension of welding processes in shipyard prefabrication workshops, greater faith in welding, simplification of joint design, and the introduction of new automatic equipment for tube end profile cutting, welded joints developed a separate entity from traditional forms and resulted in the present direct union of lattices shown in fig. 2 on p. 643.

Besides being more simple and economic, these structures have better static and dynamic characteristics due to improved distribution of internal stress and the absence of stress concentrations as compared with angle section structures. Dynamic load tests carried out by the Dalmine Company on tubular lattice girders have shown the different fatigue behaviour of direct welded connections, the specimens tested having supported 7 million cycles against those with connecting plates which fractured at about 400,000 cycles. Figure 3 (p. 643) shows a typical fatigue fracture at a connecting plate.

In addition to these transverse connections, axial connections along the straps are simplified and improved. Constructional practice and laboratory experiments conducted to eliminate stiffening by internal or external sleeve couplings, plug welds, flanges, or similar connections, have led to increasing application of butt joints in both fabrication shops and erection yards. Many firms concerned assembly and prefabrication are now equipped for welding and it is considered that tubular forms of construction are the most advanced in this field and include:

(a) structures 100% welded;
(b) works prefabrication within the limitations of transport;
(c) welded assembly conserving typical character and behaviour wherever possible.

The application of these techniques to large scale production requires modern methods and equipment as well as specialized labour. Strict inspection and production control are also necessary in workshops and erection yards. In addition, greater care is required in general design and constructional detail with a correct indication of welding processes to be carried out. This also applies to material type, preparation, erection procedure, tolerances and inspection.

Before leaving this subject, it may be appropriate to mention what is considered to be the most interesting application of tubular construction to large structures. I refer to marine platforms for oil drilling at sea and flexible structures for tanker mooring, loading and discharge in open waters. In both cases, tubular construction is ideal, both for supporting columns subjected to stresses from the above-water structure and those due to sea waves, while the upper section must support unexpected stresses and offer the best possible conditions for protective covering. In structures subject to accidental impact by ships, tubular construction offers high yield qualities and is able to absorb impact energy with minimum structural weight. In some cases, impact energy may be of the order of several hundred ton/metres acting in any direction. These large structures are nearly always welded, prefabricated in workshops on the coast, and subsequently towed to the operating site. Cathodic protection provides against corrosion of underwater sections. These considerations combine to provide a simple robust structure which is the basis of technical and economic success with such projects.

Pressure pipeline connections, special fabrications, and pressure vessels

In the last 30 years, the use of welded joints for pipeline sections has increased continuously as a result of the introduction of new procedures and materials. The so-called "Irák Joint" will be well known to those familiar with oil pipeline construction, since at one time it was considered essential to safe operation. An internal coupling sleeve was inserted into the cupped pipe ends and the joint effected by welding together pipe and sleeve. This and other types of pipe connection have been superseded by butt welding of pipe extremities chamfered according to material thickness. In regard to the latter, wall thickness of high temperature and pressure steam pipe may be as much as 50-80 mm. Steam pipe joints are required to sustain the most exacting and complex operating conditions with temperatures up to 500-600°C, high internal pressure, and bending stresses due to temperature variations. The special alloy and stainless steels employed in large power station installations, and pipe systems conveying fluids at high velocity require joints without reduction of internal section.

Such uses call for the widest application of prefabrication, the most modern welding techniques, and close production control. The necessity for precise evaluation of exact operational conditions and the stresses associated with them calls for elaborate calculations in the design stage and the principal firms concerned employ electronic computers for this work. Over a wide field, welded joints have superseded those made by flanges, couplings, threaded connections, and expanded or cupped joints.

Reference has been made to welded jointing of large and medium diameter pipes of considerable thickness and the same considerations apply to tube connections for terminal points to cylindrical vessels, and branched pipe systems. Various applications are employed in the latter case, but in general, the tendency is towards maximum design simplification by the use of special extrusions and unions. In the case of pressure system joints, appropriate regulations are issued by control authorities in various countries.

Another application of welded joints is to small and very small diameter thin-walled tubes employed in large heat exchangers. There is also the case of mechanical applications, where welded joints in thick tubes of alloy steel are specially suitable for machinery subject to complex dynamic stresses.

Steel types

The wide field of employment referred to here requires the use of both ordinary and special types of steel. As well as the ordinary low carbon steels of not more than 55 kg./mm.^{2} tensile, the following are used:

(a) High tensile carbon or carbon-manganese steels having a yield stress of not less than 36 kg./mm.^{2} employed for tubular structures, oil pipelines, gas lines and high pressure water mains, of types Fe 54 UNI, St 52 DIN, and X 52 API standard 5 LX;

(b) High yield point carbon-manganese steels with small additions of niobium, nickel, chromium, and vanadium, having in general a yield stress of not less than 42-45 kg./mm.^{2} of types 144 D by an Italian firm, X 60 American and others, for special constructions and very high pressure oil pipelines.

(c) Carbon heat resisting steels for operational temperatures up to about 430°C of types C 14 and C 18 UNI 5462 corresponding to St 35·8 and 45·8 DIN.

(d) Low alloy steels up to 1·5% for temperatures up to 525-550°C, types 16 Mo 5, and 14 Cr Mo 3 UNI, 15 Mo 3, 13 Cr Mo 44 DIN, T_1, T_2, T_{11}, T_{12} ASTM.

(e) Medium alloy steels 2-4% to cover the temperature range 525-575°C, types 12 Cr Mo 910 UNI, 10 Cr Mo 910 DIN, T_{22} ASTM, or higher alloy steels for employment in refineries, type T_5 ASTM standard.

(f) Nickel steels for employment in low or very low temperatures such as 3·5%, 5%, and 9% nickel steels.

(g) Chrome-nickel austenitic steels for employment in temperatures exceeding 560°C or for very low temperatures.

Welding

Welding of the type of joints previously described merits special attention, especially regarding modern pipe joint butt welds. Whilst structural applications generally call for corner joints or fillets, plant component details usually require a predominance of butt joints. It is now possible to achieve a joint efficiency equal to that of the pipe wall material. That is, we expect that a melted bead display mechanical, physical and chemical properties identical with rolled or forged steel. It must be recognized that welding technology has achieved a substantial success in meeting this requirement when it is considered, for instance, that castings are designed heavier in thickness than the correspondent stampings.

Substantial difficulties were first encountered in regard to tube form, since plate connection permits welding on both sides and this is rarely possible in pipe welding. Moreover, correct technique is difficult since the welding position is constantly changing, passing from the overhead to the vertical and the horizontal position while the operator proceeds round the curve. Without dwelling on the operational aspect, it may be interesting to explore the first difficulty concerned with making tube joints: the first pass has to be free from defects, because there is no possibility of scarfing it and rewelding on the other side.

The first pass in pipe butt welds

This is a delicate operation, when it is remembered that successful joint completion is dependent on the first run, and this applies in a measure directly related to metallurgical difficulties and the magnitude of bead stresses.

Requirements

(a) The first pass should achieve good penetration to provide an effective internal bead.

(b) Correct bead profile, well radiused, without corners or undercuts.

(c) Absence of excess of penetration, pockets, and undercuts at edges; weld surface must be even at stopping and restarting points. There must be no lack in continuity, the worst of which could be cracks.

Predominant factors

Many factors influence good quality of the first pass in pipe joint welding:
Operational factors such as pressure variation in gas welding, voltage and current in electric arc welding, rod

diameter and coating, or gas shielding conditions, relative position of pipes being welded and their degrees of freedom or restraint, bevel geometry, and form of assembly. Operator ability, welding speed, careful approach to procedure qualification, etc., are other factors affecting good welding. Otherwise, from a scientific point of view we can distinguish among physical, physico-chemical, metallurgical, and thermal aspects, mixed up in a complex process. Among the physical aspects, contraction on solidification and cooling is most important. The physico-chemical aspect is concerned with kinetic and thermodynamic equilibrium of the molten metal, slag or oxide, and gas phases. Metallurgical considerations permit clarification of complex relations between phases in the solid state and their variations during abrupt temperature changes. Thermology assists understanding of heat input effects in the molten area and consequent local temperature distribution and cycles during welding and treatment operations. These considerations are particularly important in studying material behaviour assessment during manual, automatic and semi-automatic welding procedures. By examining these quite scientific aspects we must not forget the practical point of view in optimizing both quality and economy of welding procedure.

Practical solutions

A study of parameters, defined as before, may effectively contribute to a practical solution of any complex problem. A brief review of typical cases and examples of application may be of interest. The most common traditional process for joining tubes is the oxy-acetylene welding procedure which is suitable for diameters up to 75 mm. and a material thickness of 1-5 mm. Using the gas torch and a welding rod of appropriate diameter, the bevelled tube ends are first tacked together, and then welding is carried on by melting the groove edges, bridging them with drops taken from the filler metal, taking advantage of material surface tension. Besides taking the necessary heat input for melting, the torch flame provides a protective shield while providing thrust to form a regular bead and appropriate thermal conditions in the material. Control of the process is completely in the operator's hands and application to low alloy steels exceeding 1% alloy content is unadvisable. Characteristic applications of this procedure are found in boiler installations such as economizers and low pressure superheater sections. For tube diameter and thickness larger than indicated, other more modern methods, better adaptable to industrial series production, are preferred. Mild and high yield stress steels requiring good penetration are best welded by manual electric arc procedure with cellulose type coatings. A typical example is shown in figure 4 (p. 644), and this is the classic method of jointing long distance pipeline sections. Figure 5 (p. 644) shows gas duct laying with two operators welding simultaneously.

A method recently introduced and still in the development stage is the short-arc semi-automatic process. Heat is provided by electric arc and protection of the weld pool is by gas emitted from the torch which also carries a continuous electrode, automatic feed being controlled by electronic means. There are innumerable applications, but reference is limited here to the example of special fabrications for mild steel water mains.

It is interesting to note that in all the methods so far considered the bead contraction is relatively free to develop because of the gap left between the groove edges in assembling the tubes. This gap is related to electrode or wire diameter and also to the welding procedure adopted. The vertical down hill method for example, requires a smaller gap than the vertical up hill method. For practical reasons of procedure in special cases, the bevel profile normally used is abandoned, a typical case being the "V" form adopted for shop or field welding of pipe in 5 G position and up hill procedure; in this case an angle of 37° 30' (ASA) is more practical for first pass than the 30° API standard.

First pass for alloy and stainless steel pipes

The most striking development in the past ten years has been the introduction of the so-called TIG method according to universally recognized denomination. In this case the electric arc is struck in a protective inert gas shield (He or Ar), between a thoriated tungsten electrode and the base material. For welding alloy and stainless steel tubes, the process has found various applications and completely replaced coated electrode arc welding for the first pass in the high quality field. It is often used instead of the backing ring procedure despite the simplicity of this method which requires a simple filling operation. It does not lend itself to rigorous radiographic inspection however, since internal profile is poor and may require a costly reaming process, or a special form of ring and precision is essential and very costly. The TIG welding procedure is adaptable to apparently contrasting assembly conditions. For instance, pipes with a gap of 2 mm. and an edge face of 0·8 to 1·6 mm. may be butt welded. The procedure is then similar in operation to oxy-acetylene welding: the internal bead is however protected against oxidation by the inert gas, it solidifies evenly, resulting in good but never excessive penetration and in well radiused bead section. As an example, the figure on p. 645, shows a thermal power station steam manifold. High alloy steel welding (see e, f, and g on p. 616 and 617) poses a number of metallurgical problems and therefore deeply affects the operational conditions with particular requirements such as preheating, controlled inter-pass temperature, immediate reheating. Appropriate welding procedure must be developed and qualified. Nickel and austenitic steels are typical examples of special processing requirements. In these cases, the temperature interval between the liquid and solid lines in the phase diagram is sufficiently great to permit separation of grain formation due to shrinkage before all fused metal has solidified and the material shows a marked tendency to hot cracking, even in the absence of impurities. This difficulty can be met by small deposits per run and moderation of heat input.

Another solution can be to close assemble the groove edges to be joined by fixing them securely in position without gap. The filler material quantity is then small and dilution considerable. Shrinkage seems to be prevented: however provided the root face is kept very low, the unmolten base material will yield plastically under stress. Problems in welding austenitic steel items for the 600 MW. thermo-electric power referred to in the following table were resolved in this way.

Details of thermoelectric and thermonuclear power-stations where pipework has been installed in the past few years

Construction Year	Capacity MW	Main Steam Pressure atm.	Temperature °C	Tube Material
1959	150	147	540	ASTM A335 P 11
1959	70	133	540	ASTM A335 P 22
1959	75	140	540	ASTM A335 P 22
1959	150	188	540	ASTM A335 P 22
1960	40	132	520	10 Cr Mo 910
1961	20	65	500	13 Cr Mo 44
1961-62	210 (1)	62·5	399	St 45·8/II
1963	40	115	520	13 Cr Mo 44
1963	220 (1)	72·8	288	ASTM A106-B
1963	220	147·7	540	ASTM A335 P 11
1963	80	135	540	ASTM A335 P 22
1963	180	230	540	10 Cr Mo 910
1964	2 × 220	174	540	ASTM A335 P 11
1964-65	160	136	540	ASTM A335 P 22
1964-65	300	177	552	ASTM A335 P 22
1965	80	140	540	10 Cr Mo 910
1965-66	2 × 600	270·7	540	ASTM A376 Tp316H

1) Thermonuclear power-station.

Yet another solution is to employ a welding insert of appropriate form (the so called "electric boat"). The insert is put in the joint which is molten down by TIG torch only, without the use of additional filler metal. This provides an almost perfect internal bead profile, but the process requires very careful setting up and hence, greater total cost. The high pressure reactor heat exchangers shown at figure 7 (p. 645) were assembled and welded in this way: the metallurgical problems involved, included ferrite control in the austenitic bead and ensuring welding efficiency in a type of steel very sensitive to micro-cracking (Biblio. 3).

Resistance or induction welding, which includes flash welding, occupies a separate place. In this case, the tube end is left straight or suitably profiled, heated and then, pressed against the other symmetrically disposed tube, subjected to the same operation. Because of the peculiar penetration of this procedure, it is not generally accepted, but is quite often used for mechanical pipework.

Filling the joint

Having made the first pass and checked results by non-destructive methods in cases where exacting conditions apply, it remains to complete filling in the manner most suitable to the process adopted. Apart from the welding position referred to under "welding", page 617, the problems are similar to those applying to plate welding, or to large pressure vessels. In this connection, reference can be made to exhaustive and authoritative publications on the subject. It will be sufficient to say here that for certain conditions, jointing of ferritic steels should preferably be made by procedures leaving a basic slag deposit.

Automatic submerged arc welding process deserves special consideration for its ability to joint the heaviest materials used under the most exacting operating conditions. Thermo-electric power station plant is an example of operational severity which increases with generating capacity, thus requiring various types of tubing of exceptional thickness (see the table, p. 619). Application of the process to jointing such tubes differs from that related to plate or longitudinal work in that high currents of 1,000 amps., or more would not permit complete bead solidification on the pipe declivity, without running back on to that already deposited and causing serious defects. Progressive heat accumulation over a relatively small circumference is obviated by recourse to the multipass procedure. Current input is therefore reduced to 450-500 amps., thereby affecting substantial economies and also obtaining a constantly high level of quality. Figure 8, (p. 645), shows a weld bead section in a tube more than 80 mm. thick. Metallurgical problems arose here including ferritic band formation (Biblio. 4), decarburized discontinuities caused by successive weld deposits. Automatic welding can only be applied with a rotator and not to all cases which might be thought possible; complex fabrications are still welded manually.

To contribute to a counterbalance of stress and thermal conditions in the latter case, the employment of two welders is preferred (figure 9, p. 646).

Production quality

These notes cover a brief review of only some of many problems met and resolved by technologists in the practical applications of tubing for various purposes and the extent to which welding has contributed to their development will be evident. It must be stated however, that the technical successes described would not be possible without adequate inspection of weld quality in all phases of operations. Numerous methods of destructive and non-destructive testing are employed, X-ray and gamma ray methods of great efficiency having been developed. In properly equipped workshops, the results of radiographic examination can be known within about ten minutes. During welding of very thick material, X-ray examination can be introduced several times during the joining process while the material is still hot. In special cases, the use of ultrasonic testing is valuable, but this requires an adequate calibration system.

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Wilhelm RÄDEKER

Welding of Cladded and Plated Steel Sheet

(Translated from German)

From a metallurgical point of view, cladding is a very remarkable process, since thereby two metals, frequently very different in their physical and chemical properties, are welded together over a large surface area. The mutual adherence must be so firm that separation by mechanical and thermal stresses cannot occur. The latter requirement is a particularly serious one since on account of the different coefficients of expansion, significant shear stresses occur in both sides of the interface due to temperature variations; a reduction in strength occurs in at least one of the components with increasing temperature. In principle, the joining of two metals, i.e. cladding, may be achieved by differing applications of heat and pressure as follows:

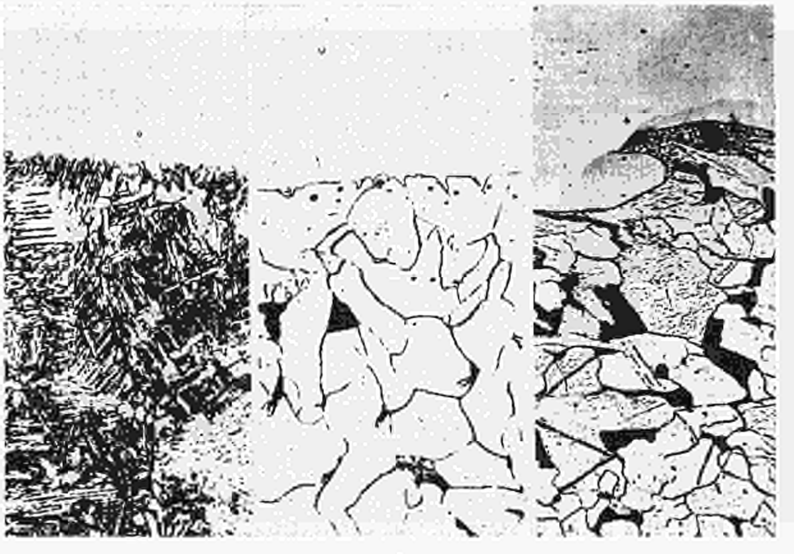
cladding by welding — corresponding to fusion welding — solely by heating of the pair of metals to the fusion point;

pressure or roll cladding — comparable to pressure welding — at reduced heat input, i.e. at rolling temperatures by means of the pressure arising during the rolling of the composite;

explosive or shock-wave cladding — similar to cold welding — solely by means of a controlled explosion, the resulting pressures ensuring complete welding, the applied energy no doubt also being to some extent transformed into heat.

Mutual adherence is effected through the adhesive and cohesive power which is influenced in the first place by the enlargement of the mating surfaces; in the second place, increased diffusion of the neighbouring alloying elements towards the interface influences the joint strength. Consequently, one can expect the highest attainable values from fusion-weld cladding and high values from explosive weld cladding if a very intense degree of interlocking is present. Roll-cladding gives average to high values according to the temperature and duration of the reaction at the interfacial surface. What has been said is particularly evident from a section through the interface and a table of adhesive strength values.

a — fusion-welding cladding
b — rolling-welding cladding
c — explosive cladding



a b c

Cross-section of metal-interface in three types of cladding:

Adhesive strength of steel-base claddings

Cladding metal	Process	Shear strength acc. to ASTM, A, 263-65 Kg./mm.²
Silver Copper Nickel X5 Cr Ni Mo 18 10	Rolling and welding cladding	13 — 18·4 12 — 27·5 24 — 28 20 — 42 (—32)
X5 Cr Ni Mo 18 10 —do— re-rolled Titanium	Explosive cladding	25 28 — 34 26
X15 Cr Ni 25 20 X12 Cr Ni 18 8	Melting and welding Cladding	44 — 52

In commercially-produced cladding such high adhesive strengths are normally attained that no detachment occurs in welding cold-formed parts, or during cyclical temperature variations during subsequent use. The type of cladding process selected is therefore dependent on the metallurgical data. Fusion weld cladding is predominantly undertaken on special formed parts which, owing to their large cross section, are better formed in the unclad state, from which the final form may be arrived at with great accuracy.

As hitherto, roll cladding remains the most economic and universally applicable procedure for chemical plant fabrication in surface layer thicknesses up to 10 mms. Thirty years practical experience has shown that this type of cladding is very resistant towards repeated and very sudden temperature changes; detachment or breakdown in heat transmission has never been known.

Explosive cladding should also be interesting for such cases since, on account of the specific properties of some surfacing metals combined rolling may not always be feasible e.g. titanium, molybdenum and some other metals utilised as well as for those metal combinations where the two components exhibit excessive differences in plasticity.

In welding cladded sheet and formed parts, the following requirements must be fulfilled:

(1) the strength and toughness of the unwelded sheet must be attained in the welded zone;

(2) on the side of the surfacing metal, the same chemical endurance must be attained in the welded zone as in the rest of the material;

(3) the deposit must be dense and crack-free;

(4) the zones adjacent to the weld must not be damaged as a result of the welding process.

There already exists a series of older and more recent researches concerned with the welding of clad sheet and tubes. Partly to discuss the findings of individual authors and partly also to consider again the continuous growth of our practical knowledge, it will be worth while to broach and to elucidate the whole complex question from this point of view. In this connection, again, the extent of our knowledge of good welding practice must be alluded to. A revolutionary renunciation of the earlier developments is not necessary however.

The excellent durability of numerous cladded plants shows that welding can be reliable in operation and that earlier procedures are right in principle. Through the development of reactor techniques, such extensive statements have however recently been made on the production and processing of clad materials that in retrospect, mention will be again made of the older classical processing methods and how they are being extended by new techniques. Thus the more recent knowledge will be considered in relation to the old and tried methods.

The great variety of present-day industrially fabricated cladding combinations (see the following table) makes it impossible to establish universally applicable rules. Some examples of methods will be given of the welding of steel sheets with silver surface deposits, which, on the one hand exhibit a relatively low melting point and, on the other hand, no significant solubility in iron; other measures are required in cladding with titanium on account of its high melting point (1660°C) and the formation of an iron-titanium eutectic of low melting point, which makes it especially difficult.

Normal practice is for the quality of the cladded steel sheet to be as laid down in the German Iron and Steel Institute Specification 075-54 and for the standard of the commercial welding to conform to the DIN standard 8553. The close relation between the two specifications referred to is firmly based owing to the extensive

Possible steel-based cladding combinations

Basic materials DIN Ref.	DIN Ref.	Cladding materials																														
		X7CrAl 13	X8Cr17	X12CrNi 18 8	X10CrNiNb 18 9	X5CrNiNb 18 9	X10CrNiTi 18 9	X10CrNiMoNb18 10	X10CrNiMoTi 18 10	X10CrNiMoNb18 12	X10CrNiMoTi 18 12	X5CrNiMoCuNb 1818	X5CrNiMoCuTi 18 18	X5CrNiMoTi 25 25	X4CrNiMoNb 25 7	X5CrNi 18 9	X5CrNiMo 18 10	X5CrNiMo 18 12	X2CrNi 18 9	X2CrNiMo 18 10	X2CrNiMo 18 12	X2CrNiMo 18 16	X10CrNiTi 18 9	X15CrNiSi 20 12	X15CrNiSi 25 20	X12CrNi 25 21	Ag	Cu	Ms 90	CuNi 10	Monel	Ni	NiMo
	Materials No.	4002	4016	4300	4550	4543	4541	4580	4571	4583	4573	4505	4506	4577	4582	4301	4401	4436	4306	4404	4435	4438	4878	4828	4841	4845							
H I	0345	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	Basic material for 18 8 CrNi steels only
H II	0425	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+					+	+	+	+	+	+	
H III	0435	+			+	+	+	+	+	+	+																+	+	+	+	+	+	
AST 35	0346	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
AST 41	0426	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+					+	+	+	+	+	+	
AST 45	0436	+			+	+	+	+	+	+	+																+	+	+	+	+	+	
17Mn 4	0916	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	
15Mo 3	5415	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+						+		+	+	+	
16Mo 5	5423	+			+	+	+	+	+	+	+	+	+						+	+	+	+						+		+	+	+	
13CrMo 44	7335	+			+	+	+	+	+			+	+						+	+	+	+						+		+	+	+	
(Mn47Mo)		+			+	+	+	+	+	+	+	+	+						+	+	+	+								+	+	+	
(Mn52Mo)		+			+	+	+	+	+			+	+						+	+	+	+						+		+	+	+	
10CrMo 9 10	7380	+			+	+	+	+	+			+	+						+	+	+	+										+	
(HSB50/505)	9853	+			+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+						+		+	+	+	
(HSB55C)	9877	+			+	+	+	+	+	+	+	+	+						+	+	+	+						+		+	+	+	

technical and economic advantages that the basic steel material offers. On these grounds, the predominant steel sheet clad in Germany corresponds to the DIN standard 17155. The adhesive strength can be tested on detached test material with torsion, quench- and shear specimens (latterly according to ASTM.A263-265).

At the surface itself, inspection of the joint is only possible ultrasonically, for which the German Iron and Steel Institute test specification 072-57 serves as a standard. The adhesive strength values attained are known, however, to fall within the test specification.

The DIN standard is concerned with steels having a cladding deposit of stainless Cr-steel, austenitic Cr-Ni-steel, nickel or nickel alloys as well as of copper or copper alloys. For the corrosion resistance of the welded seam at the clad locations to correspond to that of the surfacing material, at least two weld layers are necessary. In welding the basis metal with an equivalent filler alloy, no cladding metal must be melted since a hard and brittle intermediate layer would then be formed. In thin sheet clad with austenitic steel, the entire cross section can be safely welded with austenitic filler materials. There is no doubt that welding with unalloyed or low alloyed filler materials on high alloy surface metals or weld deposits must be avoided.

Large containers and plant occasion no difficulties in following these methods. Frequently and this is particularly the case with tubes and containers with narrow cross sections it is mandatory that the welding should be done from the base material side outwards. The specification considers two possibilities; either the entire cross section is welded, viz also the base metal, with an austenitic electrode or, after welding the cladded location, an intermediate layer is deposited with an alloy addition that ensures a crack-free weld deposit with the same strength and ductility-abroad, Armco iron has been proposed. There are no conclusive test results establishing that this procedure leads to high strength joints. We are of the opinion that, as with large wall thicknesses, the entire cross-section should be welded with austenitic electrodes. The small strength difference is of no importance compared to an unalloyed weld in circular seams on account of the smaller stresses. In longitudinal seams, a certain building-up of the weld bead can be made to compensate for this. These considerations are not however, valid for copper clad tubes. Here, it is proposed that at the joint, very narrow weld beads should be laid on the flanks in the base metal, strictly in the steel side in such a way as not to run over the copper and, moreover not to melt until a sealing bridge has been formed over the copper. It must be accepted that certain defects will occur in the steel side. In this case also the base metal should be overlaid with an austenitic weld deposit. A certain amount of transfer of copper into the weld deposit will not be injurious and it gives the austenite an intended copper addition.

In calculating the operating pressures that cladded plates can sustain, it can be concluded that the cladding metal lies definitely in the zone of plastic deformation and participates in the absorption of the stresses. Corresponding tensile tests and plasticity measurements have also established this. For precise comprehensive requirements, the instruction leaflet W.8. by "Arbeitsgemeinschaft Druckbehälter" (Pressure Vessel Study Group), gives the load-carrying wall thickness of the base metal corresponding to the known strength properties, with the following clarification:

> "With cladding metals for which the E-value and the yield point are about equal or higher than the corresponding value for the base metal, the total wall thickness can be inserted in the calculation as load bearing, the known strength values for the base metal being adopted for the wall thickness."

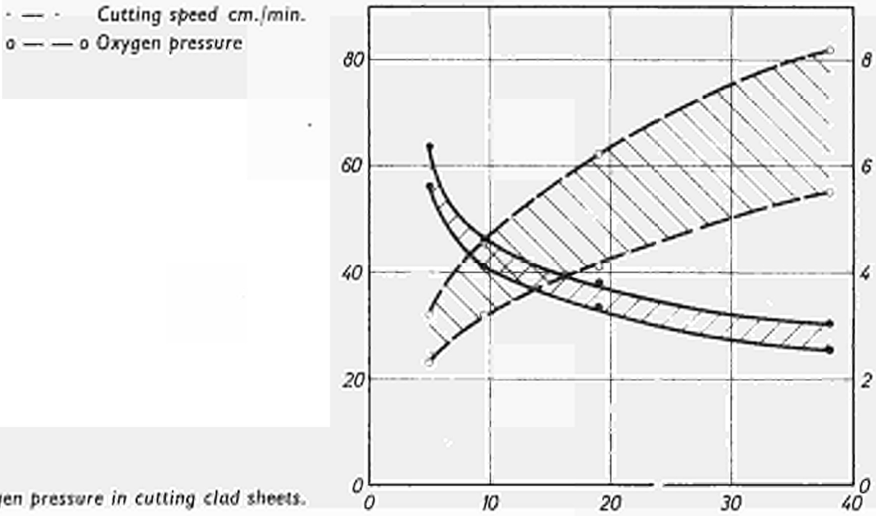
Since the base metal almost always exhibits the higher strength values, it is normal not to include the cladded deposit in the strength calculation and to consider its load bearing capacity as a reliable reserve, as it were.

Naturally, there goes with this the associated requirement that the welded joint in the steel should exhibit at least the same load-bearing cross-section and the same strength as the unimpaired base metal. Experience in practical applications which has been largely obtained in boiler and general steel construction, involving the welding of higher strength steels, has occasioned no further difficult problems.

Clearly, the basis metals may not be satisfactorily combined with every available type of surface material. It is inadvisable to clad very low-carbon austenite qualities on to hard base metals since a significant amount of carbon exchange takes place by diffusion; here, it is evident that a diffusion-inhibiting intermediate layer is preferable.

Hence the modern tendency is to obtain the strength of the base metal with the minimum carbon alloying content in order to satisfy the requirement for the minimum carburization of the austenitic cladding deposit (by diffusion).

With regard to joint edge preparation, no new proposed modifications have been published. Present practice is to cut plates up to 40 mms. thick with shears, the cladded coating being pressed towards the plate during this process. With blunt cutters and tough surface deposits, it can happen that the latter are to a greater or lesser extent drawn-up above the steel cross section, giving the appearance of an unequal surface deposit thickness. Larger plates are flame-cut with the greatest cutting speed (50-55 cms./min.) possible (see the following figure).



Cutting speed and oxygen pressure in cutting clad sheets.

Plasma cutting is being carried out experimentally, but owing to the great hardening of the edges it cannot as yet be considered practical.

After the crude shaping, the edges are given the normal machining. V- and U-joint preparations are possible on the steel side and this calls for the minimum of welding i.e. weld volume on the cladded side. The V- and U-type of butt-joints tend to distort and show high residual stresses after welding in the absence of heat-treatment. The X-type of joint preparation is advantageous in this respect; however, considerably larger amounts of weld metal must then be deposited on the cladded side.

Occasionally, examples are found of the use of corner and fillet joints in fabricating cladded plant. The postulate has thus been presented that a detached rim of cladding deposit occurs on the sheet edge and that, on this account, the selection of corner welds is preferable. Our own practical experience differs; only on tight bend radii does no blow occur. As this should be the case locally, a surface joint on the clad side of a corner seam constitues a slight disadvantage. Corner and fillet joints should therefore be avoided on account of their uncontrollability. Edge movement on the clad side would necessitate considerable amounts of filler materials. Certainly, on these grounds, they should be reduced to a minimum.

Since cladding is employed more with respect to its technical possibilities than with respect to economies on expensive surfacing materials, the indispensable minimum thickness of surface deposit for a reliable weld will not be discussed. The following summary may be considered as a rough guide.

Cladding thickness suitable for welding

Cladding Thickness	
< 1 mm.	Welding of the iron base cannot be avoided altogether
1 — 1·5 mm.	Thicker single-layer welding possible on the cladding side
1·5 — 2 mm.	Double-layer welding of the cladding with desirable properties of the second layer
2 — 3 mm. and over	Three layer welding of the cladding with optimum properties of the top-layer

The old established principle of welding the base metal first and then the cladding deposit, finds its metallurgical justification in that the surfacing metal generally tends to have the lower melting point, the lower heat of fusion and specific heat and the lower heat content in the molten weld so that a correspondingly lower degree of penetration can be adhered to. Edge preparation must be such that in welding the base metal, there will be little possibility of melting the coating material.

As a welding procedure for the base material, hand welding with covered electrodes has been employed or for larger cross sections, submerged arc welding. Basically however, most other efficient procedures are applicable. The established steel for atomic reactor construction ASTM-A-302, after undergoing a stress relieving heat treatment, gave the deposit properties reproduced in the following table in practical welding fabrications.

Strength of weld deposit

	0.2 Yield-point kg./mm.^{2}		Strength kg./mm.^{2}		σ_5 %	Notch impact strength mkg./cm.^{2}
	at 20°	at 310°	at 20°	at 310°	at 20°	at 20°
Manual welding with a lime-ferritic electrode	46-49	47·2	58·5	57·7	23-25	18-22
Submerged welding	48-54	45	62-65	59-63	22-26	11-12

The welding of surfacing metals

Silver

Apart from its low melting point, silver has the added advantage property that it is not soluble in iron nor does it possess a solubility for iron. The production of high adhesive strength in a silver-cladding on steel is therefore possible only by means of intermediate layers or by an enlargement of the adhering surfaces (through thermal roughening). In point of fact, this latter procedure has been succesfully carried out by us. When satisfactory adherence has been achieved by roughening the sub-surface to increase the interface, it is found however that only a limited interfacial weld joint is accomplished. With really satisfactory workshop equipment, good results are possible with gas-fusion welding since neither carburization nor oxidation of the weld deposit ensues.

With all the metals of which the thermal expansion and therefore also the shrinkage, is greater than that of steel, pre-heating before welding offers advantages. In welding the silver side by the TIG- (Tungsten Inert Gas) process, preheating temperatures of 300-400°C are recommended.

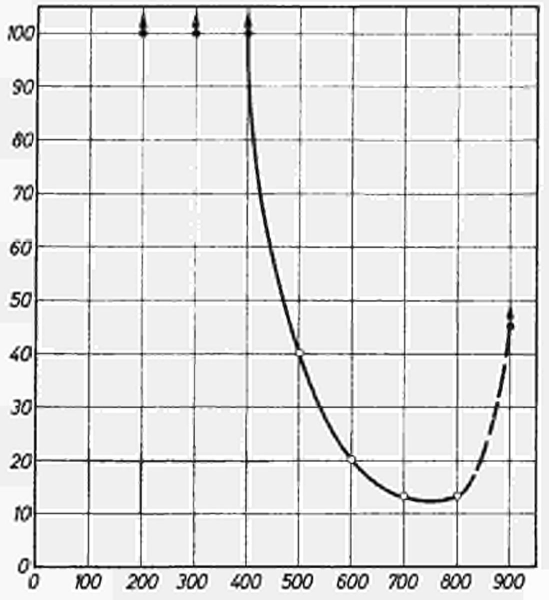
Copper

In metallurgical respects, copper resembles silver although it has a higher melting point (1083°C); it possesses a certain mutual solubility with iron and is also susceptible to oxidation. On this basis, autogeneous welding leads to somewhat unsatisfactory weld quality even when special welding wire, alloyed with 1% silver is used. The iron pick-up is certainly small. Furthermore, in the method developed by Lessel, a flexible electrode, alloyed with 5% zinc, is employed despite which the corrosion resistance does not approach that of copper.

Iron absorption of a copper built-up weld on a steel base under various welding conditions

Welding method	Preheating temp. °C	Amperage A	Electrode diam. mm.	Other details	Fe-content in %		
					1 weld-layer	2	3
Oxy-acetylene	20	—	—	relatively little welding heat	0·14	0·12	0·05
	20	—	—	relatively great welding heat	1·24	1·01	0·42
Arc welding with gas shielding	20	—	—	cracking of weld metal	1·24-2·61	—	—
				no cracking of weld metal	0·12-0·37	—	—
MIG with argon and forming gas	20	— 300	—	—	3·7	2·55	—
	200	—	—	—	10·0	—	—
	350	—	—	—	—	1·59	0·27
MIG		310	1·60	cracking of weld	9·6-7·8	—	—
	150	260	+ 2·4 currentless	metal	0·3	—	—

Copper is considered in the liquid state to produce the crack formation well known as hot-cracking. The basic hypothesis is namely that the steel must be in a state of tensile stress which will be the greater, the larger the temperature differences that are present on the steel side during welding. This can also be avoided by preheating. Nevertheless, this preheating again promotes the passage of iron into solution in the copper melt. The preceding table gives supporting results obtained in practice. At the present time, copper cladding is welded exclusively by the Inert Gas process. Some copper welds fabricated by a German plant construction firm gave cohesive strengths of 21,3 kg./mm.² (in plate 20,0 kg./mm.²) from which the quenching results illustrated in the figure below were obtained. Small additions of silver and phosphorus to the welding wire also have a good influence on the weld properties.



Number of chillings up to separation
o — seperated from base
↕ — not seperated

Number of chillings of welds on copper-clad sheet as a function of the chilling temperature.

Alloying by metals, which should improve the fluidity must be done with caution since even vestiges of residual melt can produce fine grain-boundary cracks in the weld deposit.

Nickel

The welding of nickel cladding has undoubtedly undergone a significant improvement in recent use. Nickel can be welded under Inert Gas (TIG: tungsten-inert-gas) process while for open arc welding, alloyed wires can be employed which, basically, contain titanium, silicon, manganese, copper and aluminium. Although a certain amount of alloying with the iron base beneath is unavoidable, this can be minimised by the use of low current densities and multiple-run welds. According to Denaro and Hinde, an iron content under 5% is not detrimental. Sulphur contamination would be bad and must under all circumstances be avoided.

Nickel alloys

Copper-nickel alloys well known under the name "Monel metal" are, at the present time, welded by electrodes with low-carbon coatings. Since melting of the steel base can lead to the presence of hard phases with hot-crack formation, it is expedient to lay down first a pure nickel layer.

For very high chemical stresses, especially in the presence of chlorides, nickel-molybdenum alloys have been proved satisfactory. These are so expensive that the cost is only compensated for by cladding with a chromium-nickel steel.underlayer. For the latter, an equivalent type of electrode is employed. The separation of the surface deposit by means of a pure nickel layer should also prove satisfactory here.

Stainless steel

For high alloy stainless as well as heat-resisting rolled and forged steels, much interesting data havé been assembled in the Stahleisen (German Iron and Steel) specifications for materials 400-60 and 470-60. Here again, data are found on welding the most advantageous addition materials and the heat treatment recommended after welding.

Build-up materials compared with the relevant welding additives

Build-up material						Welding additive					
Chemical composition					DIN-reference	DIN-reference	Chemical composition				
C	Cr	Mo	Ni	Others			C	Cr	Mo	Ni	Others
< 0·08	13·0	—	—	Al	X7CrAl 13	X8Cr14	< 0·10	14·5	—	—	—
< 0·07	18·0	—	11·0	Nb	X10CrNiNb18 9	X5CrNiNb19 9	0·05	19·0	—	9·0	Nb
< 0·07	17·5	2·3	12·0	Nb	X10CrNiMoNb18 10	X5CrNiMoNb19 12	0·07	19·5	2·8	11·5	Nb
< 0·07	17·5	2·8	13·5	Nb	X10CrNiMoNb18 12	X5CrNiMoNb19 12	0·07	19·5	2·8	11·5	Nb
< 0·07	17·5	2·2	20·0	Cu;Nb	X5CrNiMoCuNb18 20	X6CrNiMoCuNb20 18	< 0·07	18·0	2·2	21·0	Cu;Nb
0·06	25·0	2·2	25·0	Ti	X5CrNiMoTi25 25	X5CrNiMoNb25 25	< 0·07	26·0	2·2	25·0	Nb
						for all root layers : X3CrNi 25 20	0·05	25·0	—	20·0	—

For the accepted important cladding materials, the above table enables a comparison to be made between surfacing-and filler-welding addition materials. The latter have a somewhat higher alloy content as compared to the former, but only to the extent that this anticipates the higher losses of alloying elements in melting-down. Thinning of the iron base underneath due to melting is not taken into account. This must be dealt with by the welding technique, i.e. welding should be done with multiple runs in such a way that the lower layers are deposited as thinly as possible, at the lower range of current densities. Since these methods of working were established, the following specifications have been brought out:

In Germany in 1957, there existed an agreement between the technical Standards Associations and the cladding producers, according to which local limited defects in the cladding (surface damage such as porosity) due to welding must be made good after removal of the defective area. In this connection the following conditions must be adhered to:

The electrode diameter should be smaller than 2·5 mm., current density should be at the lower permissible limit, at least one weld run should be taken up per mm. of surface thickness; for over 3 mm. thickness, 4 runs. With this method of working, in which no very high alloy electrodes are used, no difficulties have arisen in practice in regard to the corrosion resistance of the repair welds.

At the present time, fabricated parts with thicker cladding surfaces are required for reactor construction and heat exchangers and these can only be produced by fusion weld-surfacing. The majority of these surface deposits can be welded under inert gas with the automatic oscillating-weave type of deposition. Exceptionally, in the centre of circular preparations, where only slow progress can be made, and in trimming-up the rough welding surface, hand welding is however, indispensable. The small penetration and the associated increase in the weld interface raises the adhesive strength. In previous experiments, it was found that the smaller the electrode diameter and the current density, the smoother the contiguous faces became. The largest bend angle was attained with electrode diameters of 3·25 mm. The lower layer was welded with electrodes of the 25/14 type, the upper one with the well-known stabilised 18/8 quality. These attained cohesive strengths of 47·3 to 58·8 kgs./mm.². Twenty chill specimens were quenched in water from 900°C without showing the slightest detachment. Carbon diffusion from the base metal, which can only occur during the welding process and to a lesser extent during stress relieving, was slight. Carbon contents of 0·13 to 0·06% were found in the first layer and below 0·04% in the second layer.

The welding of 13% chromium stainless steels which are much favoured in the petroleum industry, was briefly investigated. Their tendency towards grain growth and embrittlement is somewhat reduced by alloying with aluminium. Where the chemical process does not expressly preclude it, these steels are also welded as surface cladding with austenitic electrodes (18/8 or 25/20 or 25/14). In order to avoid grain growth and crack formation, particularly small diameter electrodes are employed at low current densities, with preheating at 150°-300°C. The 13% chromium steel may, with advantage, be cladded on to heat resisting high-strength steel containing about 1%Cr and 0·3%Mo (DIN Specification 13CrMo44) while, after welding, the combination requires heating at about 730°C, as an advantageous tempering treatment.

If these proposals for welding the high alloy stainless steel cladding are comprehensively considered, two basic trends are noticeable: one that aims at employing electrodes which give a weld deposit with a higher alloy content than the cladding, and another which aims at approximate equality of alloying content. It cannot be denied that the first conception offers a greater measure of reliability and is more independent of practical errors by the welder. Nevertheless, welding carried out according to the second method is essentially more economical and has been tried and tested for some thirty years.

Titanium

The cladding the first proper welding of titanium to steel encounters difficulties in so far as a low melting eutectic with about 68% by weight of titanium is formed at 1085°C which prevents hot forming above this temperature. In the second place, this temperature is not high enough for an adquate adhesive strength to be attainable through mutual diffusion.

Since brazing to typical cladding by means of a manganese-silver intermediate layer is incapable of producing joints with the highest stress-resisting capacity, it is out of the question. Perhaps better possibilities may be offered by explosive cladding, possibly with subsequent rolling. Since titanium has a high melting point, welding to a steel base is not practicable without significant melting. The titanium side should be covered first and then the steel side, using the minimum current density. With the range of welding processes available it is only possible to make the final weld a titanium to titanium joint by means of a type of local lining so that no alloying with iron can occur.

Heat Treatment

The question of the heat-treatment of welded pressure vessels made of fabricated steel plate has been of little practical importance for a long time because the majority of constructions had a wall-thickness of under thirty mm.; heat treatment therefore was not required under the German Pressure Vessel Regulations.

It may be considered that there is only one unique temperature at which two work materials with unequal thermal expansion coefficients may be joined together in a stress-free state. Above this temperature the material with the higher expansion is under compression-below this under tensile stress. Accordingly, in pressure vessels undergoing heating, the chemically stressed side will be eased to a certain extent; add to this that on this side, the casing has already undergone compressive forming, so that the subsequent internal tensile residual stresses have already been weakened previously. These two favourable factors substantiate the observation made in chemical processing that cladded pressure vessels are little more inclined to stress-corrosion cracking than solid ones.

It is different however with thick-walled or surface fusion-welded clad objects. For the latter, a small degree of penetration with high local stress concentrations must be expected. Even when these do not interfere with the capacity to resist mechanical and chemical stresses, stress relieving should be carried out in the region of 600°C in order to avoid uncontrolled distortion during operational use.

With the unstabilised austenitic qualities (with low carbon contents), at above 600°C chromium impoverishment occurs at the grainboundaries with the associated danger of grain disintegration. For these cases, titanium or tantalum-niobium stabilised qualities should be suitable.

When the heat-resisting high-strength steels with about 1%Cr and 0,3%Mo (13CrMo44) are clad with 13% Cr steel, a soft anneal at between 700 to 750°C is mandatory. In special cases, such annealing may be carried out locally by induction, the entire part subsequently being given a stress-relieving anneal at a lower temperature.

It should be mentioned that in individual countries, a series of test regulations have been published to guarantee consistent quality in cladded plate and the correct welding technique especially in pressure vessels. The most important ones are shown below:

U.S.A.:

ASME Boiler and Pressure-Vessel Code, Section 8, 1952.

ASTM and ASME Specifications.

ASTM A 263 (ASME-263) Corrosion-resistant chromium-steel clad plate.

ASTM A 264 (ASME-264) Corrosion-resistant Cr-Ni steel clad plate.

ASTM A 265 (ASME-265) Nickel and nickel-base alloy clad steel plate.

England:

BSS Fusion Pressure Vessels, 1959.

France:

Construction Code for pressure vessels, 1954.

Germany:

Iron and Steel Specification 075-54, AD-Instruction Leaflet W.8.

Thanks to the painstaking work in the welding workshops and to efficiently conducted standardisation, no serious mishap has been encountered up to now in plant made from cladded plate. These measures can therefore be instituted for future technical improvements.

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Automatic Welding Processes for Thick Material

(Translated from Italian)

Continuing developments in the chemical and petroleum industries in recent years have necessitated the employment of thicker materials for their processing installations and the advent of the nuclear era has contributed substantially to this trend. At the same time, progress in welding techniques has been of fundamental importance to such developments. It could indeed be said that present industrial development could not have been achieved without the high degree of confidence and safety offered by modern welding techniques.

A definition of thick material presents some difficulty since it depends on the type of material and its method of application, but in general, it can be applied where wall thickness exceeds 100 mm. The quality of joints depends upon metallurgical and executive factors, some of which are closely connected with the process adopted, whilst choice of process depends upon economic, technological, and technical considerations. It must be remembered that joining thick material involves a number of factors unfavourable to weld quality. There include more pronounced material segregation, greater liability to defects, more unfavourable analysis etc. There are also additional factors affecting weld quality concerned with more severe thermal gradients, lower structural ductility and greater rigidity which increase the possibility of contraction cracking, and internal stress increase which adds to the dangers of fracture. It is therefore necessary to adopt appropriate measures to reduce the incidence of unfavourable factors, to endeavour to achieve high resilience, low transition temperatures, to limit stresses by suitable choice of welding sequence, and by heat treatment either after or during fabrication.

Material composition for welding must be carefully designed for each application, bearing in mind that mechanical characteristics vary according to thermal treatment during the joining process. To achieve high quality results, it is essential to control the basic material of the weld metal and parent metal thermally affected, both as to mechanical and chemical characteristics associated with initiation of weld defects.

A wide range of non-destructive testing includes ultrasonic and magnetic methods, gamma rays, linear accelerators, betatrons etc. If correctly employed, the ultrasonic or magnetic methods can provide optimum results. An extensive field of welding processes can be applied for thick material, but for the purpose of this examination only two automatic processes will be considered; the submerged arc which is the basic process for joining thick material, and the Electroslag process employed for high productivity.

The Base Material

The final properties of steel plate depend upon the production process of fusion, refining, and the rolling method. On the first two of these points depend the quantity and distribution of non-metallic inclusions and the degree of chemical segregation, while the rolling process influences the dimensions and form of such inclusions. The lower degree of hot deformation in thick plates and the higher rolling temperature, coupled with a slower cooling rate give rise to an unfavourable metallic structure, and hence a higher transition temperature.

The highest degree of non-metallic and chemical segregation having a negative influence on weldability is usually contained in the middle third of thick steel plate. Steel producers must therefore exercise particular care to see that deoxidation products are easily eliminated by the slag; to limit sulphur content, and adopt adequate rolling temperatures with a high degree of reduction to ensure efficacious fragmentation of inclusions.

In special cases it is advisable to employ vacuum pouring for this substantially reduces inclusions and improves dispersion. Account must also be taken of degradation which may occur in thick plate after curvature at excessive temperature. Normalizing and stress relieving treatment is often necessary, a typical case being Mn-Mo steels. Another problem which may arise in the presence of impurities such as copper, tin, sulphur, arsenic etc., is the appearance of surface cracks running from the decarburized face inwards after forming. The re-heat temperature is directly proportional to the soaking time required. A further problem concerned with deeper flaws seems to be connected with unfavourable distribution of nitrides, especially A1.

It will be evident from the foregoing that careful production control is necessary both before and after forming thick plates to avoid defects which may contribute to subsequent welding problems. In addition to destructive testing, partial ultrasonic testing is desirable, and in special cases, complete magnetic examination may be necessary.

Submerged Arc Welding

This process has been continuously developed, and until a few years ago welding of thick plate was by the opposed two-pass method. The incidence of defects such as cracks and developments in steel quality however, stimulated employment of the multi-pass procedure, each pass covering the full gap width. Continuing difficulties with cracking along the middle line of the bead and slag removal problems have led to the present procedure of depositing a double run for each pass overlapping along the middle line. In this way each bead reheats previous deposits causing grain refinement and thus providing a high degree of resilience against brittle fracture.

Edge Preparation and Welding Technique

The form of edge preparation has a profound influence on welding procedure. The "U" joint is preferable with a root width of 7-8 mm., above which subsequent deposits may be made either vertically of with a slight inclination. The sides are inclined at an angle of 7°-30′ and the height is 80-85 mm. The choice of joint type may be single or double depending on material thickness, accessibility, degree of preheating, necessity to avoid deformation etc. In the case of a double "U" weld, it is advisable to locate the shoulder two thirds of the thickness dimension from the face and not half way. The root pass can be made by automatic process, but a manual support run is preferred. The multi-pass technique consists of a double pass superposed along the middle line for each layer with a welding rod of about 4 mm. diameter, each pass being carefully laid the correct distance from the wall of the "U". Carelessness in following this procedure may result in lack of penetration or side undercuts, with consequent slag inclusions and middle line bead cracks. Cracks of this nature occur when the bead section is geometrical in form and permits solidification at the sides before the middle. Welding voltage is also of great importance in this connection.

The thickness of each weld bead has the effect of reducing resilience with grain growth of the dendritic structure. This negative effect of grain growth is accentuated if the weld poll is contaminated by elements having a tendency to segregate during solidification. A high percentage of re-crystallized material is sometimes necessary to obtain determined characteristics. In addition to rod diameter, the welding current value is dependent on the base material. Special high tensile and hardened steels rarely permit a welding current of more than 500 Amp. For hardened steels particularly, rigid control of heat input and interpass temperature is necessary. While too rapid cooling may provoke cracking, an unduly long cooling period causes deterioration of mechanical characteristics in both filler metal and parent material in the heat affected zone.

Composition and Characteristics of Weld Metal

It has been previously stated that filler metal composition must be carefully studied and only in special cases is weld quality directly related to the parent material, otherwise weld quality depends on the welding rod and flux. The various elements in filler metal must be carefully balanced to obtain the desired mechanical characteristics, and in general, should approach those of the parent material. In practice, elevated loading values increase the tendency to cracking, often occurring transversely across the joint. The constituent elements in filler metal have varying effects on notch toughness and hence on transition temperature.

Carbon has a degrading effect, manganese exceeding 1·60-1·70% produces a rapid decrease of ductility, while silicon up to 0·30-0·40% causes no significant variation. It is therefore important to maintain a rather high $\frac{Mn}{Si}$ ratio. Molybdenum behaves similarly, up to 0·20% it increases transition temperature, decreases it up to 0·40%, and then increases it again beyond the latter limit. Chromium has no appreciable effect up to 0·80-0·90% nor does copper up to 0·40-0·50%. Nickel has a beneficial effect up to 2·6-2·8%, while even in small quantities, vanadium decesively increases transition temperature.

Regarding hardness effect on filler metal, the elements considered can be placed in the following descending order of effectiveness; vanadium, carbon, molybdenum, copper, chromium, silicon, manganese and nickel. To obtain high resilience characteristics, especially with high tensile steels, it is therefore necessary to reduce non-metallic inclusions and to have a fine structure. Sulphur and more praticularly phosphorus, must be substantially reduced. This also applies to oxygen and nitrogen. Sulphur is particularly harmful in regard to hot cracking, especially when high carbon weld metal is necessary as in the case of hardening after welding.

For welding high tensile and hardened steels, it is advisable to use highly basic fluxes. The sulphur and phosphorus content is thereby reduced, resistance to inter-crystalline fracture is increased, and the primary structure is improved. Prefused fluxes as compared with agglomerate require a lower arc voltage and this latter factor has an accelerating influence on slag reaction. With small diameter rods and low currents, increased arc voltage can cause a substantial phosphorus transfer from slag to weld metal.

An increase in binding elements can be obtained through the rod, the flux, or both. In many cases, only the rod carries the binding elements and in this connection, cored rods can resolve various problems.

Preheating and Stress Relieving

All multi-pass welds in steel require preheating to a varying degree according to base metal and filler metal composition, welding conditions etc. A reduction of temperature difference between the weld and the heat affected zone of the parent metal assists elimination of deformation, reduces contraction stresses, and hence cracking in the joint area. Reduction of the temperature gradient and thermal conductivity diminishes the cooling rate and thus facilitates diffusion of residual hydrogen and other gases, with beneficial effect against hair cracks beneath the weld bead, and against porosity and brittleness in the weld and adjacent area. Moreover, the lower cooling rate reduces hardness and improves ductility. Preheating is maintained while the weld is being made, and in certain cases until stress relieving treatment is applied.

Although preheating is beneficial, its effect must not be exaggerated. With high preheat temperatures as in the interpass procedure, slag removal becomes difficult and brittle problems may emerge beyond 300°C. In the case of hardened steels, preheating must be applied with great care in relation to the heat input selected.

Stress relieving is necessary for many reasons, including the reduction of internal stresses to diminish internal elastic energy which may cause brittle fracture, to improve metallurgical characteristics of the material, to eliminate local brittleness which may preduce defects due to contraction deformation on cooling to ambient temperature. It also eliminates the possibility of work hardening in the welding process and improves dimensional stability. The treatment temperature however has a limited effect and problems of ageing and hardening may arise which must be taken into account, especially in structures for service at low temperatures.

Development of the Process

With a single rod, welding deposit production is about 5-6 Kg.-h., but this can be increased by adoption of the tandem technique. Two rods can be fused in the same pool thus doubling welding speed with the same bead section. Another interesting method has been developed recently in Japan where a second cored electrode is fused by arc heat form a normal electrode and the parent metal. This method has notable advantages by way of higher production, lower penetration, a finer structure, and the possibility of introducing deoxidising agents, material producing basic slag, arc stabilization, and binding agents into the cored electrode.

Electroslag Welding

From the economic viewpoint, the Electroslag automatic process provides the highest productivity. Qualitative evaluation is more complicated since it is related to the principles of the process and particularly to metallurgical variations involved. The fused metal pool is large and permanently open at the top, thus providing very slow solidification and cooling, with corresponding effects on the weld metal structure and that in the heat affected zone which can be subjected to overheating and exaggerated grain growth. This heterogeneous joint structure can be balanced by appropriate heat treatment at a temperature above Ac 3 followed by a cooling rate which will produce a fine grain structure.

Description and Technique of the Process

The weld is made without edge preparation in the down-hand position, fusion taking place in the rectangular space between plate edges, normally 30-32 mm., and two water-cooled copper blocks moving along the seam at welding speed. The weld pool is covered by a layer of liquid slag in which the rod or rods are immersed. The slag becomes superheated through the Joule effect of the current passing through it and reaches a remperature which exceeds fusion point of the base metal thus causing fusion of the plate edges. The process is therefore based on heat exchange between slag and base metal with vigorous convection effect. The slag flows down the rod and rises up the walls of the base metal by electromagnetic effect. Energy developed in the weld pool is sufficient to bridge the joint transverse section by a vertical oscillating movement of the rod.

The process must be uninterrupted until the joint is complete, since a pause of only a few seconds permits rapid slag cooling with consequent danger of slag inclusion on restarting. It is therefore advisable to provide the weight of rod necessary to complete the joint without a stop, since restarting is a long and difficult procedure and does not always give the best results. With suitable mechanical arrangements, the process can be adapted for circumferential joints. For joints not easily accessible, or those of limited length, fusible guide rods are essential. To obtain the best results, a knowledge of the factors affecting penetration is of great importance, normal values varying between 25 and 35%.

An increase in plate edge gap increases penetration as does arc voltage increase, this latter being the major factor affecting penetration. The slag pool depth too has a strong influence on penetration due to temperature difference. If the energy applied is constant, the temperature is related to slag volume. In general, slag depth is 40-60 mm., as lower values would provoke unstable conditions, and higher values increas the risk of pasting up. Beside regularity and extent of penetration, rod oscillation affects metallurgical structure in that, as the rod moves towards one copper block, solidification occurs adjacent to the other. On the return movement, solidification is decelerated and accelerates again on the next backward movement. This solidifying modulation provides a measure of attenuating effect on the coarse grain structure. Welding current intensity is a direct function of electrode forward oscillating speed, and is generally maintained at 600-650 Amp., with a 3·2 mm. rod. Arc voltage is important from the metallurgical aspect in regard to weld profile, crystal growth being obliquely upwards almost perpendicular to the solidified face. This result is obtained with a weld pool of sufficient width and little depth. In the case of a narrow and deep weld pool, crystal growth is horizontal, meeting at the weld centre and creating a dangerous area subject to hot cracking, particularly if the content of segregated substances is high. Shrinkage cavities could also form in this central area.

Composition and Characteristics of the Weld Pool

The weld metal is composed of the fused rod and that of the parent material, while the flux forms the slag. The quantity of flux consumed for welding is small and the slag temperature relatively low so that the slag-weld pool reaction is reduced and the rod must provide the connecting element. If present in notable quantity, sulphur, phosphorus and carbon can segregate at the weld centre between the solidification crystals. One method of refining the primary structure is by the addition of modifiers such as titanium, aluminium, vanadium or molybdenum which act to form a greater number of crystal nuclei. Another method is the application of ultrasonics of appropriate frequency and power by means of transducers incorporated in the copper blocks.

The classic Electroslag process provides for employment of solid section rods, but we prefer cored electrode containing deoxidizer, refiner and binding elements in addition to the flux. In addition to having numerous metallurgical advantages, these rods permit easy changing of filler metal composition appropriate to the parent material. The heat affected zone structure depends upon the base material and in many cases is not weakened in deoxidized steels containing manganese and nickel.

Preheating and Heat Treatment

A special quality of this process is the auto-preheating of the base material in that the speed of heat propagation upwards in the parent metal is greater than welding speed. In general therefore, preheating is not necessary. The necessity for heat treatment depends on the characteristics it is desired to obtain in the weld and on resilience in particular. Due to a slow cooling rate, residual stresses generated by transverse contraction are very small, and because it is possible to complete the weld in one pass, deformation is practically eliminated. As already indicated, normalizing is the most suitable treatment. In addition to normalizing in a furnace, it seems that successful experiments have been made with local treatment of the weld and heat affected zone by induction heating.

Unfortunately, normalizing treatment in a furnace provokes substantial distortion, and while it is easy to correct a single component, it is almost impossible with a complex fabrication. An original method is to close the workpiece completely during heat treatment to create a controlled excess pressure which will maintain the circular form. Normalization treatment always follows stress relieving.

Conclusion

The Electroslag process is comparatively new and will certainly undergo further development. From the production viewpoint in regard to weld defects, its superiority is unquestionable. There is an almost total absence of such defects as hot cracking, hardening cracks, slag inclusions and porosity which are of importance in connection with brittle fracture. An unfavourable factor is resilience in the weld metal and heat affected zone requiring special heat treatment. This militates against its widespread use, especially for circumferential work.

While various methods have been suggested to improve resilience in the weld metal, both mechanical and metallurgical, the characteristics of the heat affected zone depend on quality of the parent metal. There are however, vast possibilities of employing steel types with the necessary qualities to conserve a satisfactory resilience in the heat affected zone.

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Henri GENY

Notes on the Fabrication of Thick-Walled Vessels in Clad Steel

(Translated from French)

Clad plates are primarily used for the fabrication of vessels and reactors for the petroleum and chemical industries, in which they are generally required to withstand high temperatures and pressures while subjected to extremely corrosive media. The principal reason for the use of such plates is economic: an important saving of costly materials is effected using steel plates clad with a few millimetres of stainless steel by comparison with using the same quantity of solid stainless steel plates. The choice of clad steel for these applications may however also result from technical considerations.

The *weldability of normal austenitic Cr-Ni stainless steels* is well known and generally very satisfactory. All the welding processes used for ordinary carbon steels are possible and those most often employed are:

(a) arc welding with covered electrodes;

(b) gas shielded arc welding (TIG or MIG process);

(c) submerged arc welding.

Difficulties are encountered however, when very thick plates in solid stainless steel are used and the welding engineer must not forget that this metal has certain peculiarities.

The *coefficient of expansion* is, on average, one and a half times that of unalloyed or low alloyed steel. This means that, in the course of cooling following each pass, when a thick weld is laid, the distorsion and strains are greater than in the welding of mild steel.

The *thermal conductivity* is below that of ordinary steels, so that the heat produced by the operation of welding is conducted away more slowly. This can be harmful with certain types of thick welds in stainless steel.

As regards *ferritic stainless steels (13% Cr for example)*, in spite of the addition of aluminium (AISI 405 type), the weldability can be so poor that it is generally considered dangerous to weld this alloy in thick sections for fabrications subjected to high pressures and temperatures. The precautions which must be taken to prevent cracking are then so considerable that it is uneconomic to undertake them; such precautions are: extensive use of pre-heating, post-heating, very low welding currents, special care in handling the electrodes, renunciation of the use of the welding processes with the highest productivity etc.

With *the employment of thick clad steel*, the welding engineer can without technical disadvantages, use processes with a high level of productivity and thus make welds more cheaply than in solid austenitic stainless steel. (In this connexion, it will be recalled that, in the case of heavy equipment for the petro-chemical industry, 60% of the cost is represented by the materials, 40% by labour.) The welding engineer can also fabricate, without risk of failure in service, reactors made of ferritic chrome stainless clad steels.

Thicknesses

The use of thick clad plates has thus become a necessity for the petroleum industry and we would like to mention the fabrication in the last two years of heavy tonnages in clad plates with a thickness of 132 mm. + 5 mm., the steel having the ASTM classification A 212 B and the 5 mm. stainless steel cladding being of the AISI 321 type. These clad plates were delivered to an Italian boiler-maker.

As an indication of average and absolutely normal dimensions and thicknesses, we may mention reactors with a diameter of 2,500 mm., a length of between 6 and 20 metres and a weight varying between 35 and 150 tons; the average thickness was about 60 mm. + 5 mm.

We give below an example:

It is a reactor delivered during 1963, working at about 400°C at a pressure of 43 kg.cm.^{2} Its internal diameter was 2,600 mm. and its length between lines of tangency 6,000 mm. It was intended to hold hydrocarbons and rested vertically on four supports.

The thickness of the plates was 51 mm. plus 4 mm. of cladding.

The ASTM classification of the base metal was A 204 A and the cladding was an 18/10 titanium stainless steel, type 321 (See figure 10, p. 646).

Acceptance of the plates

Acceptance tests on the plates are always performed by an official body. The following tests are carried out on a sample plate:

(i) one tensile test;

(ii) two bend tests;

(iii) two tear tests.

Before delivery such thick plates are normally straightened by cold rolling, sand-blasted with a fine siliceous sand on the stainless steel cladding and then cleaned, this being carried out in several operations:

(a) nitrofluoride pickling;

(b) washing in neutralizer;

(c) washing in water;

(d) drying using compressed air.

As delivered to the boiler-maker, the plates have normally undergone heat treatment. Depending on the type of stainless steel cladding, this predelivery heat treatment will be as follows:

(i) for 18/8 cladding: heating to a temperature of 1,050°C followed by cooling in air;

(ii) for 13 to 17% Cr cladding: heating at 900° and tempering at 700°;

(iii) for Monel cladding: tempering at 860°.

The alloys mentioned above are the most generally used in the petroleum industry.

Apart from the mechanical characteristics which are cheked in the official acceptance tests, the state of the cladding may be ultrasonically inspected.

Forming

In the case of the very thick materials for the reactor mentioned above, the shell-plates were cold-formed, a press with simple tooling (forming tool and die) being used. Two half-shells were made, the generator of the cylinder being moved under the forming tool by about 100 mm. for each operation of the press.

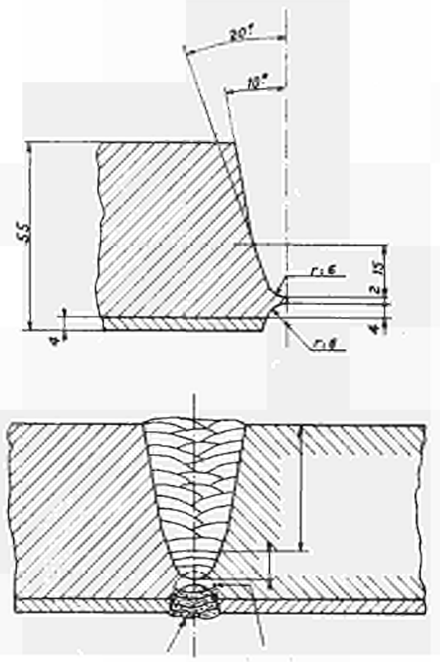
The ends are hot-formed and subsequent heat treatment is necessary to bring the plate back into the as-delivered state.

Edge preparation for welding

Two processes are commonly employed and are well known: oxygen cutting or machining.

Oxygen cutting should be carried out with the stainless steel cladding on the under side: the heating flame from the blowpipe thus attacks the base steel and the oxides thus produced facilitate the fusion of the layer of stainless steel cladding. Preparation by cutting is quite satisfactory but the cut surfaces must on no account be left as they are: they must be ground sufficiently to ensure that there are no oxides left which would prejudice to weld quality.

In our exerience, this method of preparation is little used and we prefer that the bevelled faces should be prepared by *planing*. In that case, with thick plates, the simple U preparation with faces sloping outwards towards the exterior is to be preferred, the angle of the faces being about 10 degrees to a line normal to the plate surface. The depth of the U preparation is determined by the thickness of the cladding: it starts 5 or 6 mm. above the line of the bonding of the cladding and the base plate, thus leaving sufficient space for the sealing run to be made on the stainless steel surface by a manual welding process. If tapering of the cladding material is laid down by the specifications, this can only be carried out by planning, but we are now firmly convinced that it is not indispensable in a works accustomed to the welding of plates of this kind. The tapering of the stainless steel appreciably increases the cost of welding clad plates because the quantity of costly materials added during welding is increased in the ratio of 1 to 2 (see following figure).



Type of joints and distribution of weld passes.

Welding

Before any large piece of plant in thick materials is welded, a series of precautions should be taken which are listed below:

(a) qualification of the welding engineers;

(b) qualification of the welding process: a testpiece about 500 mm. long is welded and from it are taken samples for testing the mechanical characteristics and for chemical analysis to check the filler metal. The testpiece is generally X-rayed. If it has been automatically welded it also serves to check the performance of the welding machine and its operator.

(c) during fabrication, one or two sample testpieces are welded at the same time as the longitudinal welds to ensure that the quality of welding remains constant.

Welding procedure

The longitudinal and circumferential joints of a reactor in thick plate can have the same profile and the same welding methods can be used. The U preparation on the outside with provision for a large interior sealing run, as described above, can be used for all vessels to the inside of which the welding engineer has access (generally the case with reactors). This has the advantage that, particularly in the case of circumferential joints, if the internal edges are not entirely level, the risk of inadequate fusion of the stainless steel cladding on either of the two plates is avoided.

An economic and technically efficient welding procedure for the vessel described above might be as follows:

1. (a) Maintenance of a pre-heating temperature of from 120 to 180°C during the whole time that the parent ASTM A 204 A steel is being manually and automatically welded;

   (b) a manual pass using a 4 mm. diameter electrode at a high current at the root of the main (exterior) U-groove;

   (c) two further manual passes using 4 and 5 mm. diameter electrodes;

   (d) multipass automatic submergend arc welding with a current of about 600 to 650 A until the exterior U-groove is completely welded;

   (e) grinding (using a grinding wheel) with pre-heating maintained at about 80°C of the root of the interior side of the joint;

   (f) slow cooling using an insulating protection;

   (g) dye-penetrant inspection of the internal ground surface.

2. (a) For the welding of the 321 type cladding steel, the minimum currents compatible with each diameter of electrode should be used;

   (b) one pass with a 3·2 mm. diameter electrode
one pass with a 4 mm. diameter electrode } in the centre of the groove;

   (c) passes using 4 mm. diameter electrodes with minimum current for the whole surface between the two lips of the cladding. It is mandatory to do this in two layers;

   (d) no pre-heating during welding of the clad side.

One hundred per cent inspection of the welds is carried out by radiography.

Choice of the electrodes

(i) For the parent A 204 A steel which is a manganese molybdenum steel with 0·5% Mo, electrodes having a basic covering with 0·5% Mo are used. For the automatic welding of this steel a wire having a small Mo content is used with a neutral flux.

(ii) For the 321 type (18/10 titanium) stainless steel of the cladding, a choice may be made between several types of electrode:

The 20·10·3 Mo electrode may be suitable and will provide a guarantee against the risk of cracking but it is not recommended if, when the vessel is in service, the weld will be in contact with nitric compounds or if occasionally the service temperatures may exceed 550°C. In that case a basic 19·10 electrode is used depositing a metal whose carbon content must be below 0·03%; this will prevent any risk that the stress relieving after welding may lead to weld decay (intergranular corrosion).

Stress relieving by heat treatment

Stress relieving was carried out on the reactor described above using the following procedure:

rise in temperature	100°C per hour
maintained at	625°C for 2½ hours
cooling at	150°C per hour down to 300°C
release of the air.	

The advantage of this final treatment lies in the reduction of the stresses set up by forming and welding. It must not be forgotten however that, the coefficient of expansion of the two metals being different, new stresses are set up in the plates during cooling. With austenitic clad steels, great prudence must be exercised in respect of any final stress relieving.

In the case of vessels clad in 13% chrome stainless steel, the problem in this connexion is different: on the one hand, the coefficients of expansion of the base steel and the 13% chrome are very similar and therefore the effects of the stresses set up during cooling are less important; on the other hand tempering at 700°C after welding seems to restore the ductility of the welded assembly, since, with steel of this composition (405 AISI), it makes bending to 180° possible on the assembly without cracking, while such bending is sometimes difficult to achieve before stress relieving on a welded assembly.

As stated elsewhere, many national codes have laid down various rules on heat treatment. We believe that, in preference to fixed rules, it is essential that the special case of every piece of plant being constructed should be the subject of joint study between the user, his engineering staff and the constructor.

Mechanical results

In the case of the reactor in heavy plate which we have discussed, with *tensile tests* across the weld, their cross-section covering the full thickness of the material (the base metal and the cladding), fracture outside the weld occurred in all cases at between 50·2 and 51·6 kg.²/mm.2.

The only *bend tests* laid down by the specification were those which put the clad side in tension and required elongation above 20% on the surface of the weld metal before the appearance of the first crack. The first cracks occurred when the elongation amounted to 40% and bending was carried out without giving rise to cracks with parallel branches.

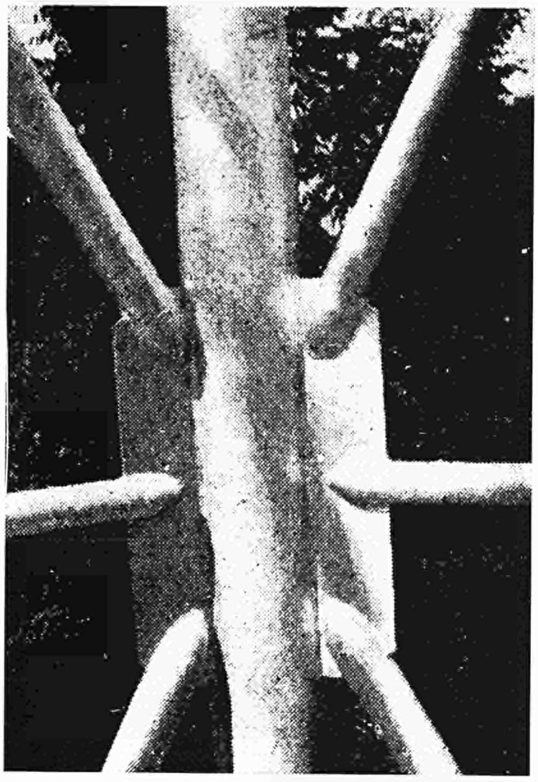
Conclusion

Boiler-makers and welding engineers are anxious to use these thick composite plates which they have come to know quite well. In very many cases both cost studies and technical considerations continue to favour the use of this material in preference to solid stainless steel.

We would like to mention here, together with the user, the maker of the plates and the constructor of the plant that we really believe this material to be the only one which provides an elegant solution to the majority of the problems raised by the risk of serious corrosion in plant working at high temperatures and pressures.

One suggestion in conclusion — would it not be worth devoting one day at some future E.C.S.C. Congress specially to the subject of the relations between the steel industry and the chemical industry?

List of illustrations



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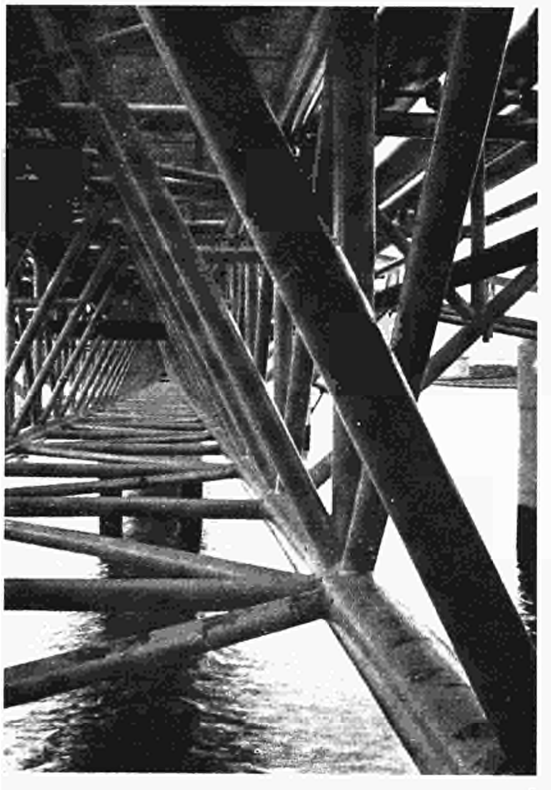

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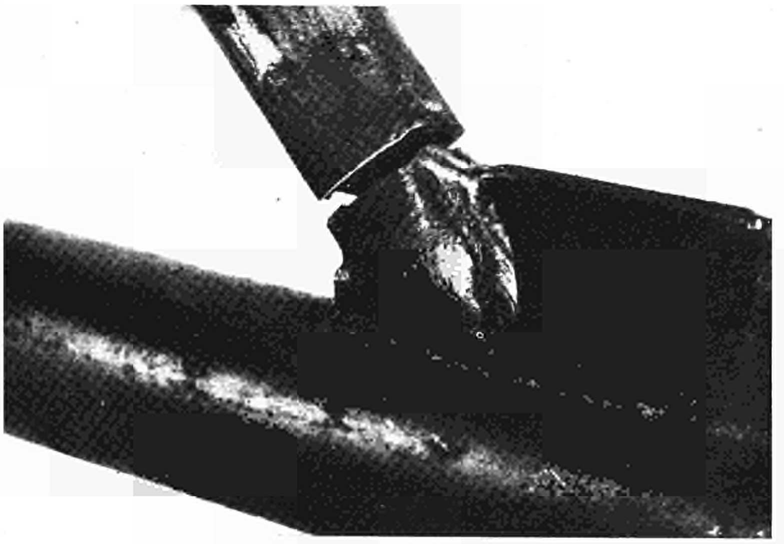

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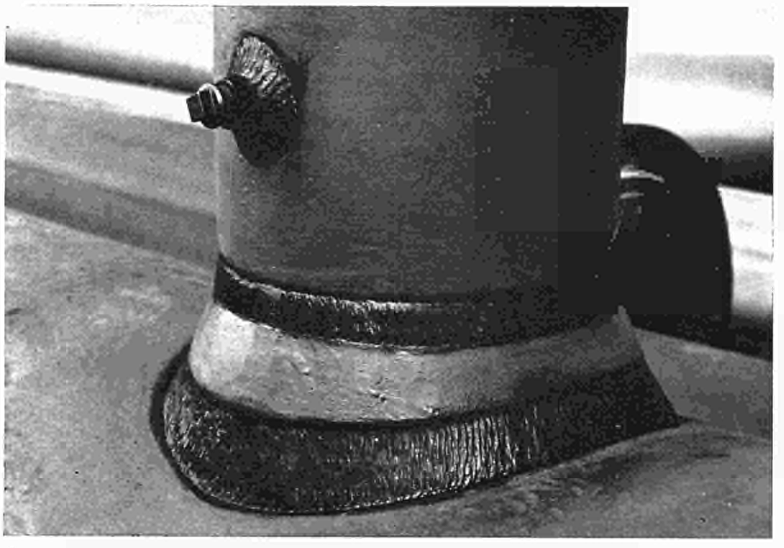

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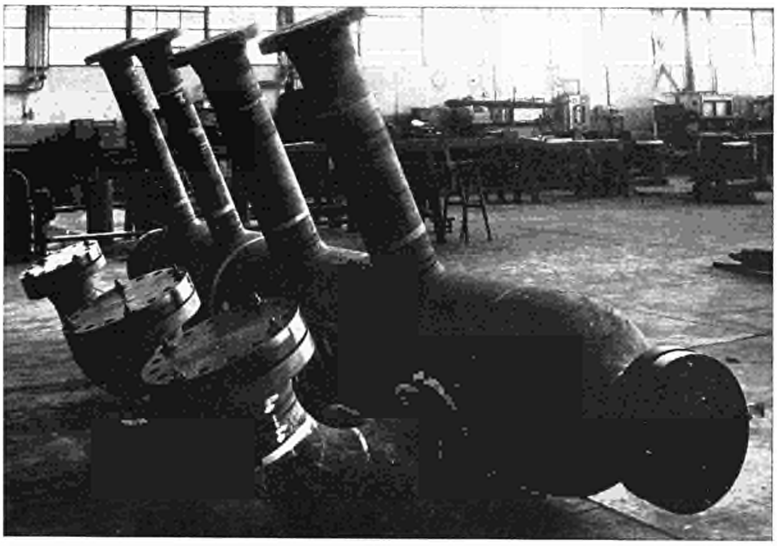

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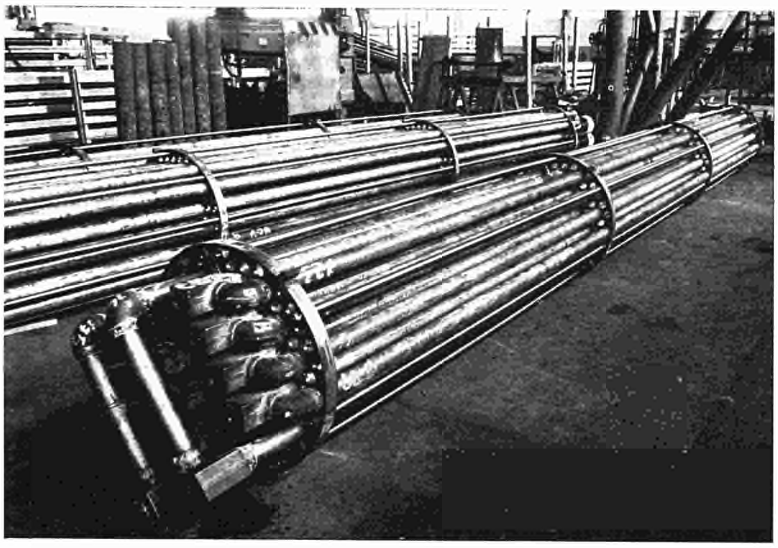

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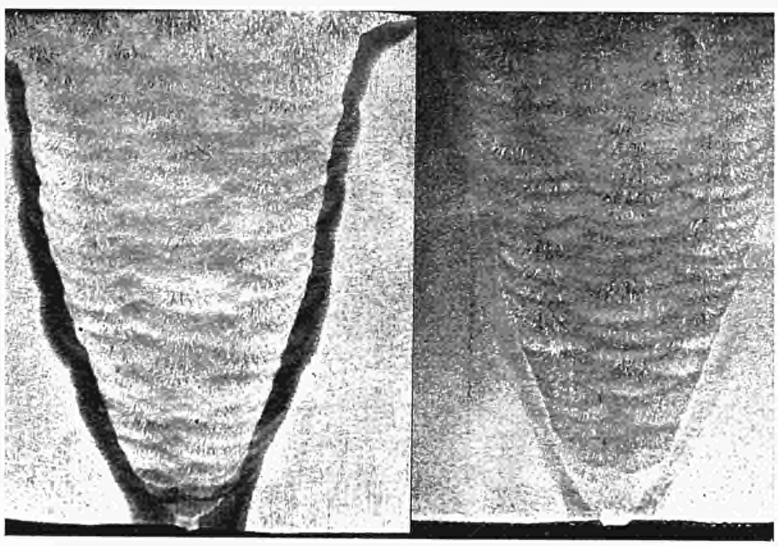

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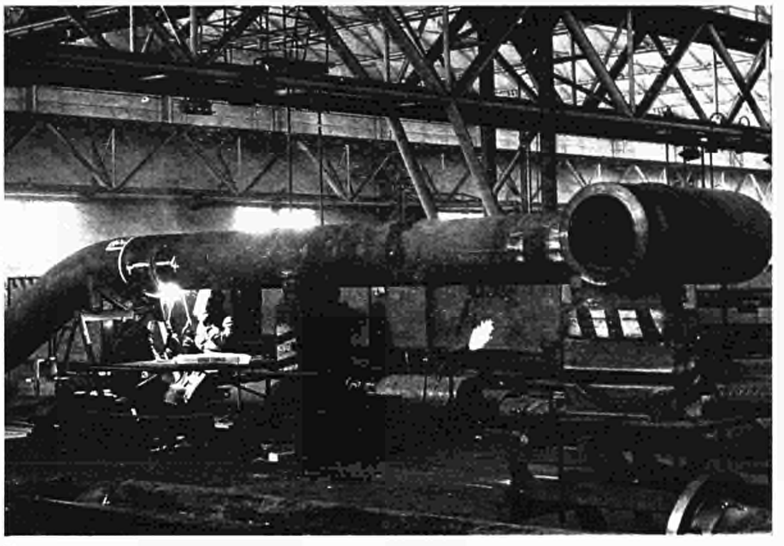

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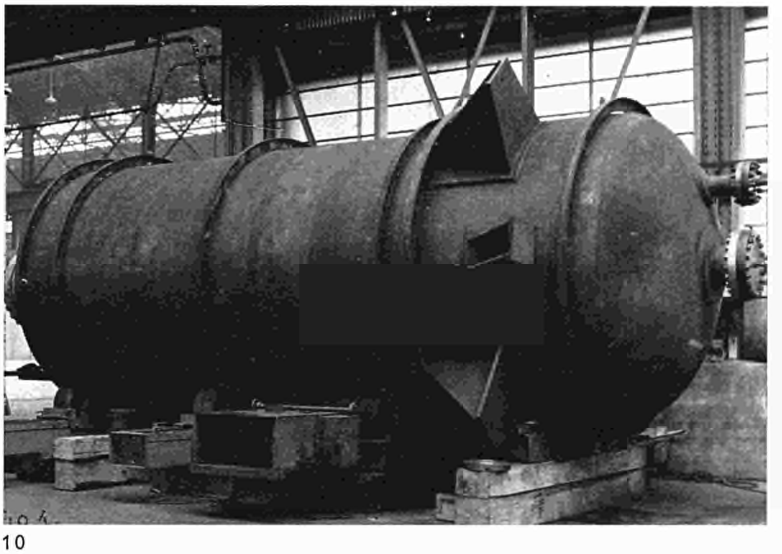

10

SPECIAL COMMITTEE

Problems of Steel Utilization in Emergent Countries

Chairman:

Gaston Thorn

Rapporteurs:

Kouakou Paul Yao

Carlos Quintana

André-Gustave Anguilé

Introduction

The subject of steel utilization in emergent countries was considered by the Committee from many angles.

— On the technological side, emphasis was laid on the particularly powerful action of corrosion in the tropics, and also on the special requirements to be fulfilled by metal structures there, if these are to withstand earthquake and hurricane hazards.

— On the economic side, the Committee discussed the special features of the range of iron and steel products used in the developing areas, the difficulties arising from inadequate existing material and human infrastructure, and certain possibilities for developing steel-processing industries.

Kouakou Paul YAO

Utilizatition of Steel in Tropical Countries

(Translated from French)

Until recent years the tropical countries of Africa were only small consumers of steel. Only lately most of these countries are becoming industrialised at an increasing pace, the spheres of utilization becoming more diversified and demand increasing. Problems hitherto not tackled in view of the very small tonnages consumed now require to be studied closely.

In this account I propose to examine in turn

— the purposes for which steel is used in tropical countries, i.e. the different steel consuming sectors in these countries,

— the problems arising in connection with its utilization.

In view of the lack of adequate documentation facilities in our various countries I am referring, in the following, to the situation in Ivory Coast. This will give an idea of the utilization of steel in tropical African countries, for their industrial development commenced at the same time, and the problems in Ivory Coast are the same as those in Guinea or in the Congo.

Uses for steel in Ivory Coast

Most of the steel consumed in African countries is used in civil engineering and building (in Ivory Coast more than 80%), the remainder in mechanical engineering and various manufactures.

Building and civil engineering

At present the building of new factories, the construction of dams and the development of port facilites account for a substantial quantity of sections and concrete-reinforcing bars. In 1964, the port of Abidjan registered imports of over 70,000 tons of these two products. Only 10% of this was re-exported from Ivory Coast to Mali and Upper Volta.

All the industrial buildings in Ivory Coast today consist of a steel framework and, in most instances, a roof of galvanized-steel or aluminium "Canadian tiles". The structural steelwork companies use about 3,000 tons of steel per annum. Some of the latest buildings are the workshops of the African Renault Car Company (SAFAR), the Société des Ciments et Matériaux (SOCIMAT), the Nescafé factory, the Treichville market, the grandstands and pylons of the Houphouet Boigny Stadium, etc.

In residential buildings, steel, in the form of concrete-reinforcing bars, is used less, most of these dwellings being of the "economy" type. It is used largely for roofing, although in close competition with other materials such as aluminium sheet, asbestos-cement sheet, tiles and water-proof slabs.

However, apart from aluminium, which is used in about the same proportions as steel, the other products are eliminated on grounds of cost and labour.

Although asbestos-cement sheet costs Ffr. 700 per sq.m. (6/10 steel roof tiles Ffr. 800 and 7/10 aluminium tiles Ffr. 900), asbestos cement soon becomes discoloured, requires a heavier and more expensive framework and more highly skilled labour. However, we must expect keener competition in the near future from this material, the price of which will probably drop when it is manufactured locally.

A local company, which builds cheap dwellings, uses annually about 30,000 sq.m. of galvanized-steel Canedian tiles, about the same quantity of aluminium tiles and 700 tons of reinforcing bars.

This consumption should increase apprecialby over the next few years with the modernisation of villages in the interior.

Among bridges and similar works in which concrete-reinforcing bars were used we would mention the Moussou bridge, the Ayame dams I and II, and the second Abidjan bridge now under construction.

Other uses

In developed countries, the mechanical-engineering works (motor vehicles, aircraft, railway equipment, machine tools, etc.) account for a large proportion of the steel consumed. In the African countries the market for this type of equipment has not yet made it necessary to set up such factories. Only some services, such as the State Railways and the large public-works companies, have general work shops for the maintenace of their rolling-stock.

I would furthermore mention

— the metal-furniture industry, which is expanding despite the tendency of African countries to use their own resources in local industries (wood, most of which was hitherto-exported);

— ship-building: small shipyards in the port areas are concerned in repairing the hulls and bottoms of small vessels. One of these yards at Abidjan uses about 1,000 tons of steel per annum;

— boilermaking, which is connected with one or another of the above-mentioned sectors.

Origin of the steel used in Ivory Coast

The African countries are not steel producers, the steel they consume coming from foreign producer countries. Ivory Coast imports its steel from all the producer countries in the world.

Problems of steel utilization in tropical countries

The uses which we have just listed inevitably give rise to mapy problems; the most important is corrosion, followed by the problems connected with labour requirements supplies, etc.

Origin of goods imported in Abidjan in 1964

Country of origin	Millions of tons	Country of origin	Millions of tons
Algeria	0·015	Israel	0·028
Germany (F.R.)	0·300	Italy	2·100
Belgium	11·000	Marocco	0·500
Cambodia	0·021	Niger	0·006
China	0·015	Norway	0·005
Congo (B.)	0·018	Netherlands	0·500
Dahomey	0·012	Senegal	9·200
France	52·000	Togo	0·006
Ghana	0·029	U.S.S.R.	19·000
Great Britain	0·050	U.S.A.	0·100

Estimated steel consumption in 1970 ('000 metric tons)

	Merchant bars and rods	Wire-rod	Wire products	Hoop and strip	Sections	Universals	Tin-plate	Sheet	Galvanized sheet	Tubes	Rails	Total
Nigeria	68·6	22·9	16·2	6·1	25·3	18·3	13·3	31·2	78·2	33·0	48·1	351·2
Ghana	56·0	12·0	4·0	4·0	11·5	5·0	2·8	11·3	16·5	21·8	35·7	180·2
Senegal	18·2	4·4	1·5	1·5	18·0	3·0	2·1	2·7	11·5	9·0	11·4	83·3
Ivory Coast	15·5	3·6	1·5	1·5	15·3	3·3	2·4	3·2	12·9	8·1	9·6	76·9
Guinea	13·6	3·6	1·3	1·3	13·0	1·8	1·3	1·6	7·0	5·5	8·9	58·9
Liberia	16·2	4·3	1·6	1·6	9·2	1·0	0·7	0·8	3·9	8·6	10·5	58·4
Sierra Leone & Gambia	7·2	1·4	0·7	0·7	1·6	1·9	1·6	6·2	14·4	2·8	4·5	43·0
Dahomey	3·05	0·7	0·3	0·3	2·5	1·3	0·9	1·1	4·8	1·3	2·0	18·7
Mauritania	3·7	0·9	0·4	0·4	3·7	0·2	0·1	0·1	0·7	2·5	2·2	14·9
Upper Volta	3·0	0·7	0·3	0·3	2·9	0·7	0·4	0·6	2·9	1·2	1·8	14·8
Mali	2·8	0·7	0·3	0·3	2·6	0·7	0·4	0·6	2·9	1·1	1·8	14·2
Togo	2·6	0·3	0·3	0·3	0·9	0·9	0·4	0·7	3·1	1·0	1·5	12·0
Niger	1·4	0·3	0·1	0·1	1·4	0·2	0·2	0·1	0·7	0·8	0·9	6·1
Total	212·3	55·8	18·5	18·4	107·9	38·3	26·5	60·2	159·5	96·7	138·9	933·0

Corrosion problems

In Africa, the majority of the large and therefore most industrial towns lie in the coastal areas where the atmosphere is most corrosive. At Abidjan the temperature varies between 22° and 30°C., with an average annual humidity of 92%. This humidity and the atmospheric salinity, decrease as one travels inland. Test pieces of steel sheet (3 × 125 × 250 cm.) left in a saline atmosphere (close to the sea) were completely corroded after two years.

Most local builders have experimented with paints which are giving very satisfactory results.

For structures exposed to the atmosphere the following protective coats are applied

— one of red lead,

— two or three of linseed-oil paint.

For materials immersed in sea-water the following procedure is adopted

— sand-blasting,

— application of a passivator,

— application of one coat of red lead,

— two or three coats of linseed-oil paint.

The other corrosion-proofing method is the *Schoop metal spraying process* which, although only recently introduced, is steadly gaining ground. However, to be effective its use in tropical countries calls for special precautions. Because of the humidity of the air it is necessary to cary out metallisation immediately after sand-blasting and the distance between the spray gun and the workpiece must be carefully adjusted, so that the workpiece is not overheated (gun held too close) or the sprayed metal oxidized during its passage from the spray gun to the workpiece (gun held too far away).

Galvanized sheet is highly resistant to corrosion and does not at the moment present any particular problem.

Labour

One still very acute problem is the lack of skilled labour. Most of the steel frameworks are therefore prefabricated and then simply erected on the site. Moreover, the work is rather slow.

Supplies

Generally the dealers carry fairly large stocks, which again raises corrosion problems. Stocks may be held for several years being constantly exposed to the elements.

It is often impossible to find replacements for worn machine parts on the spot and ordering from the capital involves waiting two to three months for delivery. Work can be brought to a complete standstill. To overcome this drawback most of the people concerned carry out repairs by metallisation, which saves time and costs less than a new part.

These few examples provide some idea of our problems given the present African scale of consumption. They will undoubted increase as our consumption rises. Everyone is aware of these difficulties which are now being considered even at international level, with the object of finding ways and means for dealing with them. For instance, a colloquium on the behaviour and life of building materials in hot climates was held in Ivory Coast in November 1963, at which the effects of micro-climates were discussed in relation to the corrosion of steel.

The construction of the Ayame dams in the corrosive waters of the Bia has given rise to a number of problems which the contractors are now studying.

Thus only the utilisation of steel will enable these problems tó be pinpointed and dealt with effectively.

Takeo NAKA

Export of Steel from Japan to the Tropical Zone

The Tropical Zone which is geographically defined as the region between latitudes 23°27' of north and south where the average temperature is higher than 20°C, is, I suppose, commonly understood by the nations where the temperature is very high all the year round, and in this sense I shall often have to use it here. Yet I would not like you to think of its industrial state merely as a suitable and highly potential market-place for the export of steel from the advanced nations.

Export of Steel from Japan to Tropical Countries (x 1000 ton)

Countries	1962	1963	1964
Thailand	223	247	275
Hong Kong	183	278	274
Philippines	167	330	383
India	153	232	333
Formosa	128	150	210
Singapore	123	127	165
Brazil	120	124	
Malaya	103	99	148
Venezuela			137
Total	1200	1587	1925

The above table shows the total tonnage of steel exported from Japan to various nations in or near the tropical zone. Standards used for the steel and for the production and uses of steel in several nations in South-Eastern Asia are shown in the following tables.

Some Problems of Steel Structures in the Tropical Zone

Steel structures built in the tropical zone may reasonably be subjected to peculiar problems encountered in geological, climatical, social, economical, financial and labour conditions. In an effort to overcome these difficulties many newly rising nations in such zones are making efforts to erect various kinds of steel structures for the urgent requirements of industrial, commercial, educational, urban, sanitary and traffic uses.

Generally speaking, specifications, site conditions, temperature and humidity, earthquake and typhoon or wind pressure, are the fundamental considerations for the designing and fabrication of steel structures. Some brief explanations for them are given below.

Standards (¹) used for Exported Steel from Japan to Tropical Countries

Countries	Cold-rolled Sheets	Bars	Heavy Plates
Thailand	JIS 95%	—	JIS 100%
Hong Kong	JIS 95%	JIS 10%, ASTM 40%, BS 50%	JIS 60%, BS 40%
Philippines	JIS 85%	ASTM 100%	JIS 30%, ASTM 70%
India	ISS 60%, JIS 25%	BS 90%, JIS 10%	ISS 43%, IRS 42%, JIS 5%
Formosa	JIS 95%	JIS 90%, ASTM 10%	JIS 80%, ASTM 20%
Singapore	JIS 95%, ASTM 2%	ASTM 100%	JIS 30%, BS 70%
Brazil	JIS 60%, ASTM 40%		
Malaya	JIS 95%, ASTM 2%	ASTM 100%	JIS 30%, BS 70%
Venezuela	JIS 50%, ASTM 30%		

Countries	Shapes	Secondary Steel Products	Galvanized Iron Sheets
Thailand	JIS 70%, ASTM 30%	JIS 100%	—
Hong Kong	JIS 70%, ASTM 30%	JIS 98%, BS 2%	JIS 100%
Philippines	JIS 70%, ASTM 30%	JIS 100%	—
India	—	JIS 98%, BS 2%	JIS 100%
Formosa	—	JIS 100%	JIS 100%
Singapore	—	JIS 98%, BS 2%	JIS 100%
Brazil	—	JIS 100%	—
Malaya	—	JIS 98%, BS 2%	JIS 100%
Venezuela	—	JIS 100%	JIS 80%, ASTM 20%

Countries	Tinplates	Wire Rods	Pipes for general use	Pipes for Structure	Light Gage Sheets
Thailand	—	—	BS 90%, JIS 10%	JIS 100%	JIS 90%
Hong Kong	—	AISI 100%	BS 90%, JIS 10%	JIS 100%	JIS 90%
Philippines	JIS 100%	AISI 100%	ASTM 100%	ASTM 100%	—
India	—	—	BS 90%, JIS 10%	JIS 100%	ISS 70%, IRS 20%
Formosa	JIS 100%	AISI 100%	—	—	JIS 90%
Singapore	JIS 100%	—	BS 90%, JIS 10%	JIS 100%	JIS 90%
Brazil	JIS 100%	—	API 90%, ASTM 10%	JIS 100%	JIS 90%
Malaya	—	—	BS 90%, ASTM 10%	JIS 100%	JIS 90%
Venezuela	JIS 100%	—	API 90%, ASTM 10%	—	—

(¹) JIS Japanese Industrial Standards
ASTM Standards of Amer. Society for Testing Materials
API Standards of Amer. Petroleum Institute
AISI Standards of Amer. Iron & Steel Institute
BS British Standards
IRS Indian Rail Standards
ISS Indian Steel Standards

Production and Uses of Steel in Several Nations in South-Eastern Asia (crude Steel × 1000 ton)

Countries	Production		Uses		Balance
	1960	1970 Estimated	1960	1970 Estimated	1970 Estimated
Burma	0	80	96	210-290	130-210
Ceylon	0	80	100	170-230	90-150
India	4093	11400	4789	10900	500
Indonesia	0	80	318	700-780	620-700
Korea	58	140	113	1050	910
Malaya, Singapore	65	200	292	470-560	270-360
Pakistan	11	770	507	2410-2630	1640-1860
Philippines	67	660	417	600-640	20-60
Formosa	193	340	283	640-650	300-310
Thailand	20	80	300	630-660	550-580
Hong Kong	53	160	249	330-590	170-430

Specifications

Steel structures should be built in accordance with appropriate specifications approved by the national authorities. In some cases when satisfactory specifications are not obtainable for the design particular of structure, the designer and the fabricator will be required to follow established practices with sound engineering judgment.

Site Conditions

A particular climate is the distinctive wet and dry season which occurs annually in South-Eastern Asia. Numerous deltas cultivated for agriculture in such districts are now changing their circumstances due to industrial development. Steel structures are often built on soft and loose soils in such places, and consideration must be given to the sub-soil structures and foundaticns or uneven setting of the structure will result.

Workmanship and Labour Conditions

It must not be supposed that in general the workmanship and labour conditions for steel structures are the same in the tropical zone as in the more advanced nations. Sometimes structural engineers and workmen for steel construction are very few in number and for this reason designers of steel structures may have to use reinforced concrete construction. The steel structures described in the following examples are designed and shop-fabricated by Japanese engineers and are mostly erected on site by local engineers and workmen under the direction and management of Japanese engineers.

Temperature and Humidity

Except on very high land or in mountainons districts, for example, the Himalayas, the average temperature in the tropical zone is rather higher than 20 degrees C. by reason of geological conditions. From the northern coast of Libya along the Mediterranean Sea, the Sahara deserts begin to the east, west, and southward inland of Africa. In such deserts where modern industrial activities have recently developed (see figures 1 to 3 on p. 695) the highest temperature recorded exceeds 45°C.

In the coastal region along the Ocean, steel structures are subject to rapid corrosion. Corrosion rates for the structures are strikingly greater in coastal regions than in inland regions. The report of the investigation into corrosion in steel structures in India is summarized by Mr. M. Tagaya (See Tagaya, Masayoshi: Report on the corrosion state and anti-corrosion plan of steel products in India. *Corrosion Engineering* (Boshoku-Gijutsu) Vol. 9, No. 12, p. 38. Dec. 1960.) in which many references written by Indian scientists are introduced.

It may be of interest to observe here that Mr. Hajime Nakamura, as the chairman of the Study Group for the Prevention of Atmospheric Corrosion of Steel Structures founded in Japan in 1960, is conducting the laborious investigations of the corrosion state of metal products throughout Japan, and some of these reports are published in *Corrosion Engineering* (Boshoku Gijutsu, Feb. 1963, Jan., Dec. 1964, Jan., March 1965).

Average Corrosion Degree for Various Kinds of Steels per Annum (mm./Year)

	Industrial District (Kawasaki and Tokyo)	Pacific Coast (Onmaezaki and Makurazaki)	Japan Sea Coast (Wajima)	Inland District (Takayama and Obihiro)
Ni-Cr St. No. 2	0·074	0·027	0·025	0·015
Cr-Mo St. No. 4	0·107	0·036	0·028	0·021
Ni-Cr-Mo St. No. 8	0·084	0·029	0·022	0·016
Killed St.	0·125	0·038	0·029	0·020
Bessemer St. (Cu-Contain)	0·101	0·039	0·029	0·019
Weather proof, High Strength St.	0·082	0·031	0·026	0·016

Data from Report by the Group for PACSS, Jr. Corrosion Engng. Vol. 13, No. 12, Dec. p. 11.

Except for strikingly rapid corrosion in industrial districts, the rate of corrosion in the coastal regions is remarkably higher than for inland districts (see above table). The table below shows corrosion rates of steel plate test pieces under atmospheric conditions in an industrial district of Tokyo.

Earthquake

Earthquakes should be considered and the necessary action taken to combat its effect on steel structures in certain districts of the tropical zone. For structural design, ISO-TC98 "The Fundamental Bases of Calculation of Structures" is now actively forming an international conception for the safety of structure and load and forces for the structure in which earthquake action is included. The Japanese delegation for the committee is expressing a proposal of structural calculation to the earthquake actions on the building structure which was prepared by the Structural Standards Committee, Architectural Institute of Japan.

Recent experience gained when the severe earthquake occurred at Niigata in June 1964, shows that buildings with foundations in the soft sub-soil, or sand with high water level, are prone to uneven setting due to quick-sands, encouraged by earthquake motion.

Typhoon or Wind Pressure

A typhoon is a powerful storm with high velocity of wind. It occurs every summer in the tropical zone of the Pacific Ocean and moves northward, crossing many oceanic islands before moving inland to Asia or the Pacific Ocean.

Many structures suffer damage by typhoons annually and we must therefore estimate the powers of the typhoon in order that the structures will not be destroyed.

Corrosion Rates of Steel Plate (¹) Test Pieces exposed under Atmospheric Conditions in the Industrial District of Tokyo

Month/Year	Temp. °C	Humidity RH %	Precip. mm.	SO_2 mg./day/100 cm.²	Sea Salt Particle mg./100 cm.²
April '62	13·9	55·9	115·7	3·22	0·3
May	18·9	65·4	212·7	3·12	0·3
June	20·8	73·1	227·9	2·10	0·2
July	24·9	81·3	108·1	3·15	0·1
Aug.	28·1	69·5	31·8	2·80	0·7
Sept.	25·0	67·9	6·8	1·90	0·5
Oct.	16·8	67·4	126·0	1·35	0·2
Nov.	11·9	64·8	139·5	1·44	0·3
Dec.	7·8	56·8	69·9	2·03	0·2
Jan. '63	3·9	50·0	0·3	2·28	0·3
Feb.	5·4	51·0	16·6	2·00	0·4
March	7·8	59·0	73·9	2·88	0·7

Month/Year	Wind/Direction m./sec.	Soluble Substance g.	Insoluble Substance g.	Sulfate g.	Tar. Sub. g.	Corrosion Rates mdd = mg./dm.² day
April '62	2·3 S	0·0739	1·3937	0·0628	0·0038	42·4
May	2·3 S	0·3172	1·0515	2·1663	0·0049	75·1
June	2·4 SW	0·1613	0·7562	0·2414	0·0022	96·8
July	1·9 S	0·4902	0·5269	0·1839	0·0023	95·1
Aug.	3·5 SW	0·2862	0·7412	0·1106	0·0027	50·0
Sep.	2·1 S	0·4950	0·7520	0·0994	0·0001	41·2
Oct.	3·6 W	0·3712	0·5123	2·5227	0·0108	52·3
Nov.	3·4 W	0·4132	0·7583	0·1496	0·0076	44·3
Dec.	3·7 N	0·5783	0·6533	2·9891	0·0124	25·8
Jan. '63	2·1 NW	0·1238	0·5330	0·2445	0	2·1
Feb.	5·4 N	0·1598	0·3393	0·0837	0·0019	6·3
March	5·1 N	0·4143	0·5527	0·0563	0·0017	25·8

(¹) Composition of Steel Plate : 0.04% C, 0.015% Si, 0.25% Mn, 0.009% P, 0.014% S.

Sources: Date from Report by the Group for PACSS. Jr. Corrosion Engng. Vol. 14, No. 1, Jan. 1965, p. 16

The Architectural Institute of Japan has a code for the calculation method of wind pressure to the buildings and steel towers (excepting power transmission towers), expressed by the following formula,

$P = cq\,A$

where

P = wind pressure, kg.,

c = wind coefficient,

q = velocity pressure, kg./m.²,

A = subjected area of the structure, m.².

The basic conception of the velocity pressure is assuming the maximum velocity of the wind at typhoon as 63 m./sec. at 15 m. high at ground level of the site of the structure.

Velocity of the wind is increased by the height along the structure, in the case of buildings not higher than 45 m., velocity pressure

$q = 120$ h. 1/4 kg./m.²,

where

h = height measured along the structure from ground level, m.

and in the case of towers and tall buildings higher than 35 m., velocity pressure

q = 120 h. 1/4 kg./m.^{2},

where

h = height measured along the structure from ground level, m.

Carlos QUINTANA

Some Development Possibilities and Problems of the Iron and Steel Transforming Industries in Latin America

Due to the close relationship between the problems of growth of the iron and steel transforming industry in Latin America and those of overall economic development of the Region, I will consider the former in the context and will account briefly for the latter even at the risk of over-simplifying.

The economic development of the Latin American countries in the past has not been sufficient to assure a steady and satisfactory growth of *per capita* income. Thus, although gross regional product grew at an average rate of 4·4 per cent per year between 1955 and 1964, the *per capita* increase was only 1·5, on account of a growth of population of about 2·8 per cent, which is one of the highest of the world. A similar rate is of about 1 per cent for the countries of Southern Europe, and close to 2 per cent for Africa and Asia. Furthermore, it is expected that in the future the rate for Latin America will be higher, since a decrease in mortality rates has been forecast, and no significant changes in birth rates are envisaged.

Partly as a result of this, the industrialization has not been sufficient to significantly reduce unemployment, real or disguised. On the one hand, the demographic explosion has given rise to considerable increases in the labor force, whilst on the other, industrial development has tended to concentrate on high productivity tasks which do not absorb labor in large amounts.

Linked in a complex manner with these problems, are the difficulties in the balance of payments of most of the countries of the Region. Their import capacity has either been relatively stable or deteriorating, and this has forced them to curtail their imports of industrial raw materials and capital goods. The result has been a decrease in the rate of capital formation and in the growth of the economies as a whole.

Even assuming that the problems of capital formation could be solved, there still remains — as a resultant force of the growth problems — the urgent need for increasing industrial production at a much higher rate than in the past. Domestic demand cannot be accelerated at will, because it depends on a better distribution of income and on the growth of income *per capita*. An improvement in both is a process which is too slow when compared with the urgency of increasing production at a fast pace. The only two solutions envisaged are:

(a) export of those industrial goods in which Latin America could have a relative manufacturing advantage *vis a vis* industrialized countries; and

(b) more substitution of imports, mostly in durable consumer goods and capital goods, since in non-durable consumer goods the Region is practically self-sufficient.

There still remains the question of defining in which manner the development of the iron and steel transforming industries can contribute to attaining these two ends. The only way to rapidly increase exports of manufactures to industrialized countries is through schemes of industrial co-operation with those nations which have complementary resources in relation to the exporting country. This can be explained more easily with an example drawn from experience. In a recent study that I was asked to undertake on the complementarity of the economies of Holland and Mexico, I showed that the rate at which the economy of the Netherlands is presently growing is higher than the rate at which the country can provide herself with the resources needed for industry, particularly manpower. The annual increases in real wages are progressively greater than the growth in gross product per employed person, in spite of the great effort which the Government is vesting in technological research. The solution to this problem is either to slow down industrial development — something which is not easy to do, even with strict regulations, due to the dynamic character of private enterprise — or to change the industrial structure, abandoning manufacturing activities characterized by low labor productivity, and stressing those with a high ratio of value of production per man-hour. If this is not done, the country would be losing competitive power in relation to other countries with less acute conditions regarding the availability of manpower, and would be harming her most important relative advantage, which is the possesion of wide markets all over the world.

It was easy to show that the best solution would lie in some form of industrial co-operation with countries which are of a complementary nature, in matters of resources, such as those of Latin America. Specifically, it was suggested to transpose certain manufacturing activities to a complementary territory — in this case it was Mexico — and to produce not only for the local market, but for the world market as well, as if the premises in the new territory were an extension of the Dutch factory.

What has been said about Holland can be repeated in relation to many other highly industrialized countries of Europe. The creation of this new type of Latin American companies with capital from Europe and Latin America would be highly advantageous for both regions and would provide a means for increasing the regional production at the desired faster rate.

Many of the steel transforming industries would make good candidates. We could put first on the list the heavy machinery and equipment industry, which requires mostly foundry and welded heavy plate. As it will be seen later, investments are not very large in relation to the value of production, and recent experiences in Brazil and Mexico show that, with adequate direction and engineering designs, Latin America can produce this equipment with better quality, less cost and even higher labor productivity, inasmuch as their construction involves a great deal of hand operations, for which Latin Americans can be trained easily.

The other type of manufacture to be listed is that of precision instruments. It might sound paradoxical to select this kind of production which is the opposite to heavy machinery in so many aspects, but the fact is that the European precision instrument industry is no longer able to cope with the fast growing markets of the world, and most of its factories have a continuously increasing backlog of orders, because of the lack of highly specialized and semi-specialized labor. This type of labor intensive industry can be more appropriate for Latin America, as long as the Region can count on markets larger than her own territory. The industrial co-operation between Europe and the Region would therefore be profitable for everybody. The problem in this case is the lack of people to train workers, but this could be solved, within a reasonable period of time, by having qualified Latin Americans trained in Europe.

The other way of increasing production in Latin America at a faster rate is by import substitution of certain products from the iron and steel transforming industry, which many Latin American countries have not dared to manufacture up to now. The main obstacles have been the smallness of their markets and the fact that the processes used by the industrialized countries have been designed for larger scales of production and for the availability of an ample assortment of iron and steel raw materials. One way towards this solution is, of course, to continue pressing for a Latin American common market, which would allow for larger production series, but another is demonstrating that even the smaller countries can produce some of their machinery and equipment in relatively good economic conditions if they work with a smaller assortment of steel materials and employ less specialized machine-tools, jigs and fixtures.

Before going into more details about these possibilities of increasing production, let us take a look at the potential market for machinery and equipment in Latin America.

The demand projections for machinery and equipment given in this paper must be considered only as a very rough estimate, inasmuch as there is no statistical material which might be taken as a basis for a more accurate work. The first obstacle was the lack of information on the structure of the regional gross industrial product and the possible growth of each branch. By taking existing meager statistics, borrowing coefficients from other regions, and adopting for the economic development of the Region the rate set as a minimum goal in the Punta del Este Charter, it was possible, nevertheless, to project the growth of gross product for twelve industrial branches (see table 1, p. 665); to determine investment required in each branch (see table 2, p. 665); and, on the basis of these figures, to ascertain the specific needs for machinery in the manufacturing industry, as well as in agriculture, mining and the construction industry (see table 4 on p. 667). By the year 1975, Latin America would be needing machinery at the rate of 5,390 millions of dollars per year. The demand would be mostly concentrated, in order of importance:

— in machinery for the construction industry, machine-tools, specialized industrial machinery, agricultural machinery, pumps and compressors, conveyors and cranes, and motors and generators;

Within the specialized industrial machinery, the most interesting lines, in order of importance:

— machinery and equipment for chemicals and petroleum derivatives; paper and paper products;

— non-metallic mineral products; food, beverages and tobacco; textiles, shoes and apparel; and basic metal industries (see table 3, p. 666).

Measured with any scale, this machinery market will be a very important one, not only from the point of view of the industrialized countries who want to export their manufactures but from that of the developing countries themselves who wish to have a large enough market to justify economically the expansion of their mechanical industries. However, considering independently each of the smaller and medium sized countries of the Region, their markets in 1975 would still be too small for most of the machine manufacturing, if the industries are considered as separate entities each trying to be responsible for the whole process of making one type of machinery.

The solution here is to combine activities of several industries and to centralize some of the operations which would be uneconomical for one particular establishment, such as foundry, forging, stamping, bending with large brake presses, heavy plate rolling; and turning, drilling, planing, boring or milling, with machine-tools of large capacity. All the other operations, mainly plate cutting, welding, general machining, assembling, finishing and testing, could be done by decentralized small factories. This type of industrial structure is already in operation in Brazil and in Querétaro, Mexico, and is being programmed for the industrial complex of Guayana, in Venezuela.

If the smaller developing countries want to be succesful in machinery manufacturing, they need not only a horizontal industrial structure but an intelligent industrial strategy in the selection of the products they wish to manufacture, and the degree of integration, both in specific establishments and in the country as a whole. In the absence of sufficient information on industry in the underdeveloped countries, it is useful to employ data from the United States, as a general guide in the industrial strategy, with the understanding that, contrary to the common belief, the representative industry of that country consists of small and medium establishments, although the large ones are responsible for most of the national output and value added. I have used such data in this paper in order to show the possibilities of machine manufacturing in the smaller countries of the developing regions, and to relate them afterwards to the role the industrialized countries can play in such a development.

The table 5 (p. 668) shows the cost structures of a number of industries, including some highly mechanized ones. They are based on data taken from the United States Census of Manufactures of 1958. Complete cost structures, including depreciation and other details, can be computed only as averages for all of the establishments of each classification. Less detailed data has been taken from the size brackets where the average size establishment and the median size establishment fall.

Speaking in very general terms, it is possible to say that the iron and steel transforming industries which are appropriate for the smaller developing countries are those which have a high ratio of labor to depreciation, and at the same time can work efficiently in small productive capacities. In the absence of other data, it was decided to take as the minimum establishment which can work efficiently, the representative establishment in the United States. It is very difficult to define what is "representative," but for the purpose of this study a "representative size" meant the median size of the establishments, but only when it approaches the average size. If there is a great difference between the median and the average sizes, the representative establishment lies somewhere between both.

Table 6 (p. 671) shows that a great many of the steel transforming industries considered in this paper have very high labor-depreciation ratios and very small representative sizes, the latter measured both in number of workers and in output per establishment.

The fact that the item of cost called "other materials" is high (see table 5, p. 668) means that the normal structure in an industrialized country like the United States is not very highly integrated. Actually, one mechanical industry buys considerably from other mechanical industries, something which is very appropriate for the developing countries, because it favors the centralization in the manufacture of certain components which the finished products industry cannot undertake, because of market and quality considerations.

Taking into account the importance of the market, the labor-depreciation ratio, the representative size of the establishments, and the time it takes to form personnel that can work in complex operations, in a first stage the smaller developing countries could manufacture some agricultural, construction, and mining machinery, plus some process equipment requiring boiler shop work, mainly for the chemical industries. In a second stage, they could undertake more complex boiler shop work, such as that required for the petrochemical, cement and iron ore reducing industries, and they could go into pumps, compressors, blowers, fans, conveyors, hoists, cranes, and electric transformers and motors. In a third stage, they could manufacture some specialized machinery, mostly for the food industry; and in the last stage, the smaller developing countries could undertake the making of some machine-tools and a large proportion of the specialized machinery.

As it was said before, the industry would have to be disintegrated, in the sense of having some operations being performed in centralized establishments, but it will have to be disintegrated also in the sense of having to import many parts, such as motors, ball bearings, wheels, control mechanism, instruments, axles, and some forgings and casting which cannot be produced in the country.

Although the figures relating to most of the machine manufacturing industries indicate that there are no handicaps concerning scale of production and excessive investment in relation to the labor employed, for the size of establishments that would fit the market of the developing countries, there are some problems which have to be mentioned in a meeting like this, since the co-operation of the High Authority of the Coal and Steel Community, and the steel and machinery producers of the industrialized countries will be extremely useful to solve them.

The most important problems are:

(a) the economic difficulty in having the great assortment of steel materials which the factories find very easily in the industrialized countries;

(b) the expensiveness of some of those materials when they are manufactured internally, or when they are imported in small amounts;

(c) the use of jigs and fixtures called for by the design of the machines, which for the smaller production series would be expensive and uneconomical; and

(d) lack of technical assistance and external services, such as engineering, die making and laboratory testing.

The first two problems arise from the fact that the machines have been designed so as to be manufactured in countries with a great assortment and ready availability of materials, such as rolled products of all sizes and shapes, special or non-common steels of different kinds; nuts, bolts, automatic lathe products, cables, and ball and roller bearings. These problems and the problem of the expensive jigs and fixtures call for a redesign of the machinery to be produced, in order to adapt its manufacturing to the conditions of the developing countries; i.e., to a limited variety of materials and to simplified machining and assembling processes, even if this means slightly better steels in some applications which do not require that quality, and the use of more labor, mostly in the positioning and transport operations.

As will be seen later, the type and kind of some of the materials themselves could also be changed in order to adapt them more easily to small scale production, and to the flexibility required in establishments that have to be changing continuously their manufacturing from one product to another, and even adapting one product to different applications or situations.

The absence of technical assistance and services reflects the lack of development of an industrial environment. The pooling of resources of several factories and the centralization of some operations and services, as stated before, will tend to solve the problem, but the most effective means would be the close co-operation between the industrialized countries and the developing ones.

In relation to rolled products as materials, it is proposed to shift as much as possible from rolled sections to weldments and to cold-formed sections, made with flats. Besides the advantages of flexibility and economy of steel, the proposal fits the ideal structure for the future steel industry in the developing regions which will probably be characterized by

(a) the centralization of the production of flats in one or a few countries, in order to be able to work in large production series and to obtain the best quality of material;

(b) the avoidance as much as possible of the manufacture of rolled medium and large sections, either in each country or in centralized plants;

(c) the manufacture of welded medium and large sections in relatively small scale, practically in any country of the Region, by using good quality plate, either imported or produced in the centralized plants of the Region;

(d) the manufacture of concrete bars and similar small sections, in every country, mostly using billets produced by large centralized plants. If the steel industry progresses towards this structure, the non-flat structural elements will have to be weldments manufactured at the machinery factory, or cold-rolled sections produced locally by specialists. Both would be based on steel plates either imported or produced at the centralized plants.

Besides taking into account these changes of materials in the design of the machinery, the machinery itself will have to be redesigned so as to replace heavy and medium forgings with castings or welded parts, and to replace some former castings with weldments. The reason to avoid forgings is that the market for them in most of the developing countries is too small to take full advantage of modern press forging. The market might be enough for hammer forging but in most cases it is worth waiting until the work with presses results more economical. The reason to replace castings, in some cases, is that heavy plate weldments are more economical, and can be made even in the smaller plants, with a relatively low investment — because no models are required — and a reasonable amount of labor.

Before finishing with the subject of re-designing, I would like to point out that there is one more field for doing it, in the modification of production machine-tools in order to adapt them to the work in small series, at the factories of the developing countries. To give one example only, the production turret lathes should have two heads which can be replaced one by the other so the setting-up of tools, when changing from one job to another, can be done while the machine is working. This is one way to avoid setting-up time losses, which are very important in small scale production, and relatively unimportant in large production series.

On the basis of all the foregoing, and in order to have a rough idea of how important the machinery industry for internal consumption would be in Latin America by 1975, I projected some ratios of production to demand which range between 40 per cent for commercial machinery and 90 per cent for pumps, compressors, fans and blowers (see table 4, p. 667). The weighted average for 21 industry classifications was 70 per cent, which is not a very high figure, considering that the proportion set for the most important classification, i.e., construction machinery, is 80 per cent. Under these assumptions, the Region would be producing annualy around 3,770 millions of dollars of machinery and equipment.

For the steel makers it might be interesting to know that the steel needed for this production would be around 1,150,000 metric tons per year, with a total weighted average price about 18 per cent higher than the lowest average price (see table 4, p. 667). This steel use would represent around 4·2 per cent of the total steel consumption in Latin America by that year. Similar figures for selected countries are: 17 per cent for Austria, 22 for Great Britain, 18 for Japan, 19 for Poland, 14 for the United States and 20 for West Germany. All of these countries are important machinery exporters.

The plans for increasing machinery production in Latin America, or in other developing regions, rest on the assumption that the countries will be able to finance the sale of machinery in similar terms as those generally used by the industrialized countries. This is a problem that will have to be solved by the industrial development institutions of the particular countries, but in many cases the development institutions themselves, or the manufacturers, will have to be assisted in this respect by the industrialized countries.

I know that one of the responsibilities of the High Authority of the Community is "to ensure the steady expansion and modernization of the iron and steel industry with due regard for the legitimate interests of the producers, consumers and workers concerned." To achieve this, the High Authority is authorized to make the fullest use of all the means at its disposal. For this reason, a deeper exploration into the subject of the re-design of the products of the iron and steel transforming industry, including machinery, as well as of the processes for their manufacture, is something that falls neatly within the scope of the activities of the High Authority. By doing this, it will be assisting the developing countries and contributing to a better co-operation between the European machinery manufacturers and those of the developing countries. It should be well understood that the progress of the developing countries in matters of the mechanical industry does not mean a reduction in the exporting possibilities of the industrialized countries. On the contrary, as the industry develops in Latin America, Africa or Asia, their needs for machinery are larger. Besides, as shown at the beginning of this paper in table 5, p. 668, the amount of semi-products, parts and components produced outside of the machine factory is important, even in the industrialized countries. Very probably, most of these materials will have to be imported from Europe or the United States, until the mechanical industry of the developing regions gets to a point of maturity.

The industrial co-operation for extending manufacturing to the developing countries will create also the export of a better sort of merchandise from the part of the industrialized nations, I mean, industrial designing, engineering and technical services. Europe will always be able to produce and to export this type of merchandise, while, as it was stated before, she will not always be capable of producing economically those goods requiring a large amount of labor.

Table 1 — Latin America : estimates of industrial gross product by sectors, in 1975 (Millions of U.S. dollars)

	Structure of the value of production in 1960 (1) (%)	Ratio of the gross product to the value of production (R) (2) (%)	Theoretical structure of the gross product in 1960, with „R" corresponding to 1975 (3) (%)	Estimated rate of growth of the gross product (4) (%)	Structure of the gross product in 1975 (%)	Estimated gross product		
						1975	1965	Increment 1975/1965
Total industry	100·0	40·0	100·0	7·1	100·0	44,000	22,160	21,840
Food, beverages and tobacco	29·0	32·0 (5)	24·2	3·0	13·5	5,940	4,504	1,436
Textiles, shoes and apparel	16·1	30·2 (5)	12·7	3·0	7·1	3,124	2,369	755
Wood and wood furniture	3·4	28·4	2·5	3·0	1·4	616	467	149
Paper and paper products	2·5	46·2	3·0	9·9	4·4	1,936	767	1,169
Printing and allied industries	2·2	46·8	2·7	3·0	1·5	660	500	160
Leather and leather products	1·5	41·6	1·6	3·0	0·9	396	300	96
Rubber and rubber products	1·9	45·2	2·2	8·8	2·8	1,232	540	692
Chemicals and petroleum derivatives	14·3	38·1	14·2	9·3	19·2	8,448	3,540	4,908
Non-metallic mineral products	3·7	51·3	4·9	8·8	6·2	2,728	1,196	1,532
Basic metal industries (6)	8·3	30·0	6·5	9·3	8·8	3,872	1,622	2,250
Mechanical industries (6)	13·6	55·0	19·6	9·3	26·6	11,704	4,902	6,802
Other industries	3·5	65·0 (7)	5·9	8·9	7·6	3,344	1,453	1,891

(1) Economic Commission for Latin America, El Proceso de **Industrializaciôn en América Latina**, Vol. I, 1965 (Table 12).
(2) Figures based on rations of interindustry use given for Italy in Chenery and Clark, **Interindustry Economic** , John Wiley and Sons, New York, 1959 (Table 8.13).
(3) In the absence of data on gross product by sectors, the structure for 1960 was computed on the basis of the actual structure for the value of production in Latin America but with an interindustry use similar to that of Italy. This interindustry use was held constant in the projections towards 1975, which reflects the hypothesis that by that year Latin America might resemble Italy in that respect. The gross product structure for 1960 is, of course, only a theoretical tool, not intended to have statistical value.
(4) Based on information from the Economic Commission for Latin America, **Economic Survey of Latin America**, 1964 (in press). The rates were modified assuming a 5·5 per cent rate of growth for the total gross product, and 7·1 per cent for the industrial product. The growth of the traditional industries was deliberately set at 3 per cent per year.
(5) Averages to reflect combinations of industry denominations.
(6) These two industries appear grouped together in the publication from ECLA. They were separated assuming that 75 per cent of the gross product of the group comes from the mechanical industries.
(7) Estimate based on figures from the U.S. **Census of Manufacturers** : 1958.

Table 2 — Latin America : estimates of investments in machinery and equipment required to increase industrial capacity during 1966-1975 (Millions of U.S. dollars)

	Gross industrial product increment 1966-1975 (1)	Ratio between investment in machinery, and productive capacity expressed in terms of value added (2)	Investment in machinery and equipment
Total industry	21,840	0·69 (3)	15,160
Food, beverages and tobacco	1,436	0·49	704
Textiles, shoes and apparel	755	0·46 (3)	348
Wood and wood furniture	149	0·47	70
Paper and paper products	1,169	0·78	912
Printing and allied industries	160	0·50	80
Leather and leather products	96	0·23	22
Rubber and rubber products	692	0·53	367
Chemicals and petroleum derivatives	4,908	0·80 (3)	3,926
Non-metallic mineral products	1,532	0·61	935
Basic metal industries	2,250	1·10	2,475
Mechanical industries	6,802	0·61	4,149
Other industries	1,891	0·62	1,172

Sources and remarks:
(1) See Table 1.
(2) Result of multiplying by 1.20 the figures from United Nations, Industrial Development Division, **Projection of Demand for Industrial Equipment**, New York, 1962.
(3) Weighted averages.

Table 3 — Latin America : estimate of specific needs of machinery and equipment to increase industrial capacity during 1966-1975 (Millions of U.S. dollars)

	Total industry	Food beverage tobacco	Textiles shoes, apparel	Wood, wood furniture	Paper, paper products	Printing and allied industries	Rubber, rubber products	Chemicals petroleum derivatives	Non-metallic mineral	Basic metal industry	Mechanical industries
Machinery, except electrical											
Engines, steam turbines	129·7	8·6		0·5	2·0			99·3		19·3	
Machine-tools	4,244·9		3·4	13·3	4·0			55·4	27·5	1,018·8	3,122·5
Cutting tools, jigs, fixtures	268·0			0·1						2·8	265·1
Specialized industrial mchy.	3,840·6	325·7	318·9	20·8	663·1	72·0		1,845·6	453·8	135·3	5·4
Pumps, compressors	640·2	4·0	0·4	1·7	15·0		101·0	454·4	16·5	40·1	7·1
Hoists, conveyors	1,010·8	74·4	1·9	5·8	33·8	5·3	64·2	208·2	107·2	373·5	136·5
Fans, blowers	331·0	16·8	0·4	0·5	8·1		30·4	137·9	10·9	66·3	59·7
Power transmission equipment	127·7		1·1		36·4		73·4	5·9	5·5	5·4	
Refrigeration equipment	233·7	63·0	2·3		2·0			158·3	2·7	5·4	
Ind. mchy. not specified	579·1	67·6	1·9	2·9	10·0		82·5	307·9	30·3	76·0	
Ind. trucks, tractors	150·5		1·1	3·5	28·3			11·8	8·2	9·7	87·9
Construction mchy.	290·3			1·7	4·0			46·7	112·7	99·4	25·8
Commercial mchy.	195·0	22·7	2·3	0·5	15·0	2·7	8·1	46·7	8·2	12·4	76·4
Electrical machinery											
Motors, generators	529·6	18·1	2·3		30·3			181·9	27·5	252·9	16·6
Transformers	167·5		1·6		20·2			55·7	5·5	34·7	49·8
Switchgears, switchboards	413·2		0·4	1·2	26·3			105·7	66·0	125·7	87·9
Welding eqmt., appliances	373·6	0·9		0·5	4·0			113·9		84·2	170·1
Transport equipment	440·6	102·2	10·0	17·0	9·5		7·4	90·7	52·5	113·1	38·2
Total	13,966·0	704·0	348·0	70·0	912·0	80·0	367·0	3,926·0	935·0	2,475·0	4,149·0

Source: The totals are the same as in Table 2. The percentages used to distribute the totals according to the type of machinery were taken from United Nations, Industrial Development Division, **Projections of Demand for Industrial Equipment,** *New York, 1962.*

Table 4 — Latin America : estimates of demand and production of machinery and equipment, and of steel required for the manufacture of machinery and equipment (Millions of U.S. dollars)

	Requirements for capacity expansion		Estimate for replacing in 1975 machinery of 1965 (3)	Total yearly demand in 1975	Estimated Latin American production in 1975		Steel requirements per dollar of production (e)		Steel requirements		
	1966-1975 (1)	1975 (2)			% of demand (4)	Value	Metric tons	Dollars	Metric 1000 t/year	U.S. per year	Relative price of steel
For the manufacturing industry	13,966·0	2,541·8	1,085·0	3,626·9	65	2,340·7	0·28	0·06	527·5	123·3	115
Engines, steam turbines	129·7	23·6	8·3	31·9	60	19·1	0·11	0·03	2·1	0·6	140
Machine-tools	4,244·9	772·6	312·3	1,084·9	60	650·9	0·12	0·03	78·1	19·5	125
Cutting tools, jigs, fixtures	268·0	48·8	19·5	68·3	70	47·8	0·10	0·04	4·8	1·9	200
Specialized industrial mchy.	3,840·6	699·0	344·4	1,043·4	60	626·0	0·17	0·05	106·4	31·3	145
Pumps, compressors	640·2	116·5	31·6	148·1	90	133·3	0·11	0·03	14·7	4·0	135
Hoists, conveyors	1,010·8	184·0	79·9	263·9	80	211·1	0·42	0·08	88·7	16·9	95
Fans, blowers	331·0	60·2	21·6	81·8	90	73·6	0·34	0·07	25·0	5·2	105
Power transmission equipment	127·7	23·2	4·5	27·7	75	20·8	0·24	- 0·07	5·0	1·5	150
Refrigeration equipment	233·7	42·5	24·5	67·0	80	53·6	0·26	0·06	13·9	3·2	115
Industrial machinery not spec.	579·1	105·4	41·2	146·6	30	44·0	0·15	0·04	6·6	1·8	135
Industrial trucks, tractors	150·5	27·4	10·7	38·1	80	30·5	0·30	0·06	9·2	1·8	100
Construction machinery	290·3	52·8	17·8	70·6	75	53·0	0·40	0·07	21·2	3·7	85
Commercial machinery	195·0	35·5	16·8	52·3	40	20·9	0·06	0·02	1·3	0·4	155
Motors, generators	529·6	96·4	39·1	135·5	80	108·4	0·30	0·07	32·5	7·6	115
Transformers	167·5	30·5	10·7	41·2	80	33·0	0·34	0·11	11·2	3·6	160
Switchgears, switchboards	413·2	75·2	26·4	101·6	70	71·1	0·15	0·03	10·7	2·1	100
Welding eqmt., appliances	373·6	68·0	23·4	91·4	70	64·0	0·78	0·16	49·9	10·2	100
Transport equipment	440·6	80·2	52·4	132·6	60	79·6	0·58	0·10	46·2	8·0	85
For the construction industry	—	—	—	1,310·0	80	1,048·0	0·40	0·07	419·2	73·4	90
For agriculture (only agricultural machinery and equipment)	—	263·8	166·1	429·9	85	365·4	0·53	0·10	193·7	36·5	120
For mining (only mining mchy)	—	14·1	10·1	24·2	80	19·4	0·34	0·08	6·6	1·6	120
Total	—	—	—	5,391·0	70	3,773·5	0·30	0·08	1,147·0	234·8	100

(1) Figures from Table 3.
(2) Total for 1966-1975 multiplied by 0.182.
(3) It was assumed that machinery bought in 1965 would be replaced in 1975.
(4) Estimates. The estimates for Construction, Agriculture and Mining were based on assumed relationships of their gross product to the total regional gross product in 1975, and on ratios of machinery input to product, based on Mexican experience.

Table 5 — Price structure of selected metal transforming industries in the United States (Per cent of factory price)

	Farm machinery			Construction machinery			Mining machinery		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.
Materials:	55·1	58·2	55·6	51·5	55·8	48·9	51·6	45·4	53·7
Steel	9·8	9·8	9·8	7·2	7·2	7·2	8·4	8·4	8·4
Electricity, fuel and other materials	45·3	48·4	45·8	44·3	48·6	41·7	43·2	37·0	45·3
Electricity and fuel	0·9			0·9			0·9		
Other materials	44·4			43·4			42·3		
Value added:	44·9	41·8	44·4	48·5	44·2	51·1	48·4	54·6	46·3
Labour	22·7	21·7	24·0	23·5	24·8	25·1	28·3	27·8	23·0
Depreciation and other value added :	22·2	20·1	20·4	25·0	19·4	26·0	20·1	26·8	23·3
Depreciation machinery and equipment	2·8			2·7			2·7		
Depreciation buildings	1·2			0·9			0·9		
Other value added	18·2			21·4			16·5		

	Oilfield machinery and equipment			Industrial trucks and tractors			Metal cutting machine-tools		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.
Materials:	42·5	46·8	41·4	56·4	55·2	52·2	38·1	37·8	40·3
Steel	9·4	9·4	9·4	5·5	5·5	5·5	2·1	2·1	2·1
Electricity, fuel and other materials:	33·1	37·4	32·0	50·9	49·7	46·7	36·0	35·7	38·2
Electricity and fuel	0·9			0·7			1·2		
Other materials	32·2			50·2			34·8		
Value added:	57·5	53·2	58·6	43·6	44·8	47·8	61·9	62·2	59·7
Labour	29·8	25·1	29·5	28·3	28·0	25·8	44·1	38·6	38·9
Depreciation and other value added:	27·7	28·1	29·1	15·3	16·8	22·0	17·8	23·6	20·8
Depreciation machinery and equipment	2·1			2·8			1·8		
Depreciation buildings	—			1·2			0·7		
Other value added	25·6			11·3			15·3		

	Metal forming machine-tools			Food products machinery			Textile machinery		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median setabl.
Materials:	44·6	41·3	36·5	41·4	43·0	43·8	43·1	41·0	48·6
Steel	4·9	4·9	4·9	5·8	5·8	5·8	5·6	5·6	5·6
Electricity, fuel and other materials	39·7	36·4	31·6	35·3	37·2	38·0	37·5	20·0	43·0
Electricity and fuel	1·0			0·7			1·3		
Other materials	38·7			34·6			36·2		
Value added:	55·4	58·7	63·5	58·9	57·0	56·2	56·9	59·0	51·4
Labour	41·6	42·1	36·7	33·4	31·7	33·3	41·0	38·0	36·1
Depreciation and other value added	13·8	16·6	26·8	25·5	25·3	22·9	15·9	21·0	15·3
Depreciation machinery and equipment	1·8			5·6			5·6		
Depreciation buildings	0·7			1·1			1·1		
Other value added	11·3			24·4			9·2		

	Wood working machinery			Paper industries machinery			Boiler shop products		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.
Materials:	47·3	48·0	46·5	60·1	43·1	39·6	54·8	53·5	53·8
Steel	3·9	3·9	3·9	5·9	5·9	5·9	21·8	21·8	21·8
Electricity, fuel and other materials	43·4	44·1	42·6	54·2	37·2	33·7	33·0	31·7	32·0
Electricity and fuel	0·9			0·8			1·1		
Other materials	42·5			53·4			31·9		
Value added:	52·7	52·0	53·5	39·9	56·9	60·4	45·2	41·9	46·2
Labour	29·6	34·0	31·4	28·9	33·6	38·9	29·7	29·0	27·7
Depreciation and other value added	23·1	18·0	22·1	11·0	23·3	21·5	15·5	12·9	18·5
Depreciation machinery and equipment	5·6			5·6			1·9		
Depreciation buildings	1·1			1·1			0·3		
Other value added	16·4			4·3			13·3		

	Pumps and compressors			Conveyors, hoists, cranes, monorails			Blowers and fans		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.
Materials:	51·4	49·9	45·6	49·9	50·0	54·6	46·6	45·2	43·1
Steel	3·2	3·2	3·2	7·9	7·9	7·9	6·7	6·7	6·7
Electricity, fuel and other materials	48·2	46·7	42·4	42·0	42·1	46·7	39·9	38·5	36·4
Electricity and fuel	0·8			0·7			0·7		
Other materials	47·4			41·3			39·2		
Value added:	48·6	50·1	54·4	50·1	50·0	45·4	53·4	54·8	56·9
Labour	28·8	27·0	25·8	30·3	29·4	27·2	30·3	31·7	35·3
Depreciation and other value added	19·8	23·1	28·6	19·8	20·6	18·2	23·1	23·1	21·6
Depreciation machinery and equipment	0·8			3·8			0·8		
Depreciation buildings	3·9			0·8			3·8		
Other value added	15·1			15·2			18·5		

	Transformers			Electric motors and generators			Steam engines and turbines		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.
Materials:	43·3	43·8	46·2	41·6	47·2	47·3	41·0	53·7	43·6
Steel	10·7	10·7	10·7	7·1	7·1	7·1	3·9	3·9	3·9
Electricity, fuel and other materials	32·6	33·1	35·5	34·5	40·1	40·2	37·1	49·8	39·7
Electricity and fuel	1·0			1·0			0·8		
Other materials	31·6			33·5			36·1		
Value added:	56·7	56·2	53·8	58·4	52·8	52·7	59·0	46·3	56·4
Labour	29·0	24·0	32·8	35·1	29·2	29·4	28·5	32·1	27·1
Depreciation and other value added	27·7	32·2	21·0	23·3	23·6	23·3	30·5	14·2	29·3
Depreciation machinery and equipment	1·1			0·6			2·9		
Depreciation buildings	0·4			0·7			0·2		
Other value added	26·2			22·0			27·6		

	Internal combustion engines			Ball and roller bearings			Computing and related machines		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.
Materials:	52·7	48·9	9·9	37·2	39·2	43·1	47·6	44·8	35·4
Steel	1·7	1·7	1·7	15·4	15·4	15·4	1·2	1·2	1·2
Electricity, fuel and other materials	51·0	47·2	8·2	21·8	23·8	27·7	46·4	43·6	34·2
Electricity and fuel	0·8			1·5			0·7		
Other materials	50·2			20·3			45·7		
Value added:	47·3	51·1	90·1	62·8	60·8	56·9	52·4	55·2	64·6
Labour	26·3	37·1	18·7	37·1	35·6	29·7	42·9	51·5	38·8
Depreciation and other value added	21·0	14·0	71·4	25·7	25·2	27·2	9·5	3·7	25·8
Depreciation machinery and equipment	2·2			2·2			4·0		
Depreciation buildings	0·4			0·6			0·5		
Other value added	18·4			22·9			5·0		

	Typewriters			Electric measuring instruments		
	Industry average	Average establ.	Median establ.	Industry average	Average establ.	Median establ.
Materials:	29·1	28·9	28·9	37·7	33·1	34·2
Steel	3·1	3·1	3·1	0·7	0·7	0·7
Electricity, fuel and other materials	26·0	25·8	25·8	37·0	32·4	33·5
Electricity and fuel	0·9			0·6		
Other materials	25·1			36·4		
Value added:	70·9	71·1	71·1	62·3	66·9	65·8
Labour	35·5	27·9	27·9	37·8	37·4	37·8
Depreciation and other value added	35·4	43·2	43·2	24·5	29·5	28·0
Depreciation machinery and equipment	4·0			2·2		
Depreciation buildings	0·5			0·7		
Other value added	30·9			21·6		

Sources: Percentages based on data from U.S. Bureau of the Census, U.S. Census of Manufactures, 1958.
The depreciation of machinery and equipment and buildings was based on capital coefficients from Robert N. Grosse, Capital Requirements for the Expansion of Industrial Capacity, *Bureau of the Budget, Office of Statistical Standards, Washington, 1953. The depreciation periods assumed were 20 years for buildings and 10 years for machinery and equipment.*

Table 6 — Average and median sizes of establishments in selected industries of the United States (workers and yearly output per establishment)

	Average size		Median size		Labour depreciation ratio (average for all industry)
	workers	output (US $ 000)	workers	output (US $ 000)	
Farm machinery	73	14,750	14	237	5·7
Construction machinery	165	3,375	14	283	6·5
Mining machinery	99	1,414	16	332	7·9
Oilfield machines equipment	82	1,510	14	230	14·2
Industrial trucks, tractors	58	1,195	13	222	7·0
Metal-cutting machine-tools	84	1,055	13	179	17·7
Metal forming machine-tools	77	960	14	209	16·7
Food products machinery	41	642	14	201	5·0
Textil machinery	62	859	14	164	6·1
Wood-working machinery	47	479	14	201	4·4
Paper industries machinery	78	1,215	15	199	4·3
Boiler shop products	72	1,220	17	244	14·7
Pumps and compressors	103	3,650	14	253	6·2
Conveyors, hoists, cranes	14	14,800	14	2,170	
Blower and fans	77	1,125	14	194	6·6
Transformers	198	2,762	14	168	19·3
Electric motors and generators	248	2,660	33	540	27·0
Steam engines and turbines	1,600	33,280	787	17,150	9·2
Internal combustion engines	450	5,200	690	1,885	10·1
Ball and roller bearings	433	5,100	71	1,175	13·2
Computing and related machines	594	7,670	34	518	9·6
Typewriters	1,100	24,600	1,831	24,700	7·9
Electric measuring instruments	95	978	14	179	13·0

Source: Based on data from the U.S. Census of Manufactures : 1958.

André-Gustave ANGUILÉ

The Creation of an Infrastructure of Men and Material for Developing the Production and Use of Steel

(Translated from French)

In discussions on economic and political problems, it has for some years been the custom to speak of industrialized countries and emergent countries. This division into two groups is intended to differentiate between those countries in which the process of industrialization and the building up of a labour force have been developed to the point where the most important industrial products can be manufactured, and those countries with an economy which is essentially agricultural or mineral together with those just beginning to become industrialized. Taking the world as a whole, this rough classification shows that the industrialized countries represent 22% of the world population and the emergent countries 78%. Thus the greater part of the human race lives in these latter countries; Their share in world commerce in 1964 however was only about 21% as compared with about 79% for the industrialized countries. This lack of proportion is more or less the same in the field of crude-steel consumption, the figures being 31% for the emergent and 69% for the industrialized countries. Many other such comparisons could be made. The backwardness of the emergent countries, and the size of the problems to be solved, are amply demonstrated by these figures.

In the setting up of their industries, the emergent countries encounter serious difficulties. These are mainly due to lack of investment resources, insufficiently trained labour, climatic and geographical problems, and transport systems which are still only rudimentary. Furthermore, some of these countries did not become independent until a few years ago.

The extent of the problem having now been indicated, what follows will relate mainly to the African countries.

Apart from the regions in the north and south which are already partly industrialized, Africa is still a young continent the vast majority of the population of which is engaged in stock farming, agriculture, hunting and fishing. The first steps in industrial development have been taken, but there is a very long road ahead.

A significant indication of the still relatively low level of development in the African countries is their steel consumption. This, in 1964, was about 2 million tonnes of crude steel (this does not include consumption in the Union of South Africa). For each inhabitant, this gives an average consumption of only 8 kg, against 350 kg per head in the European Community countries. Africa's steel consumption has, essentially, been covered by importing. Thus, in 1964, 80% of her needs were met by imports and only 20% by indigenous production.

A large part of the steel consumption, in most African countries, is accounted for by the building and structural industries. A far from negligible amount also is used in maintenance and repair work. The amount used in the manufacture of machinery and various means of transport has on the other hand remained very small. This pattern of steel consumption is in striking contrast to that of the industrialized countries, where the largest consumption is in the mechanical engineering and transport manufacturing industries and the associated sub-contract work.

The African countries which are already producing steel utilize, in the main, indigenous ferrous scrap. Although this scrap is of importance in providing Africa with steel, it would not remain so, if steel consumption increased, unless the scrap reserves in Africa could continue to constitute a sufficient foundation for production. In this connection, it must not be forgotten that steel consumption is conditioned by the current level of industrial production, whereas a large part of the scrap resources derives from steel-containing articles made some 20 years ago. The Africans should therefore construct integrated plants, suitable for their needs, in which the process of manufacture begins with the production of pig iron. Integrated plants of this type are already being established in South Africa, Egypt and Rhodesia, and are under construction in Algeria and Tunisia.

The conditions governing utilization account for the pattern of consumption and its analysis into categories of products. Thus, commercial rolled products and sections represent a large part of the consumption, as do galvanized sheets which are used, in particular, for roofing and containers. Rail track material and, in certain countries, steel tubes also make up a large part of the steel consumption.

What developments will there be in the future?

To start with, it can be assumed that steel consumption can be further increased in all those sectors where it is large at present, that is, the two large sectors of building and metal structures, and that of maintenance and repair. Then, in a first phase of industrialization, it would be possible to start the manufacture of tools, particularly those needed for agriculture, and also to introduce the first stage of transformation, i.e. the production of cast steel, forgings, and drawn wire. The manufacture of ironmongery and containers also seems to be indicated for this first phase of industrialization, while the production of machinery, electro-technical equipment and vehicles of all types will, as they are not of simple construction, in general appear in the second stage of industrialization.

Increase in steel consumption however is conditioned by several factors represented, primarily, by the available capital and investment resources necessary for the industrialization of the production centres, by the formation of a labour force, by the creation of a suitable transport system, and by the availability of sources of energy. This brings us to the very core of the problem of development. Optimum results can only be achieved when progress in all fields is simultaneous. However well organized and equipped it may be, no enterprise can be successful unless it has a labour force which is sufficiently qualified and unless the distribution of the goods it produces can be properly assured. The simultaneous occurrence of these problems explains the great difficulties which the African states encounter in organizing their e;onomy.

The Economic Commission for Africa recently tried to establish forecasts for steel consumption in the West African countries. It concluded that consumption in these countries may increase from about 600,000 tonnes in 1962 to between 1·1 and 1·3 million tonnes in 1970. Although this increase in consumption corresponds to a growth rate of 8 to 10%, the amount forecast for 1970 is very small when compared with the consumption in the industrial countries. How can these needs be met?

The Economic Commission for Africa, or committees appointed by it, have already made a thorough study of the problem.

The markets in the various West African countries are still too small to justify the establishment of iron and steel plants the production of which would serve only the national requirements of the countries in which they were located. The creation of an iron and steel industry is largely dependent on the formation of a common market for steel.

Let us consider now the problems imposed upon industrialization by the formation of a labour force, the construction of an appropriate transport system, and the necessity for a dependable source of energy.

In forming a suitable nucleus of the necessary workers and employees, a part of it can no doubt be taken from the industrial enterprises already in existence; this possibility will, however, be somewhat limited. Consequently, it will be necessary for the most part to train the personnel essential for industrialization. This task is a very difficult one for the emergent countries.

The population of the greater part of these countries has not yet reached a high enough level of education. Although, in most of these countries, there are groups of people who have received a sound education up to university level, most of the population have received little or no education. For the great majority of the population, the only contact with modern technology has generally been through means of transport. On the other hand, this part of the population includes enough people available for employment with an aptitude for skilled work and, in general, the ability to adapt themselves rapidly.

How should the education of these people be planned? It seems appropriate to start their education simultaneously at all grades. Thus, the construction of schools should not only be promoted so as to extend elementary education, but also to set in motion a programme of further education. This further education, the real aim of which is to adapt the human being to technology, cannot be undertaken merely by training a small number of specialists at plants in the industrial countries. On the contrary; in the interest of rapid industrialization the emergent countries must themselves train a large number of people for the technical professions. The setting up of apprentice schools is essential for this purpose; in these establishments, the general knowledge which all mechanics in the machinery and automobile trades must possess will be taught. The industrial countries can make a substantial contribution in starting the process of industrialization in the emergent countries by building technical schools for apprentices and by making available, temporarily, the first instructors.

In connection with the labour problem, another factor relating to production must be mentioned, namely energy. As you know, the use of energy in its many forms is playing an increasingly important role, in particular in saving man-power. Although it may be true that the emergent countries have a sufficient supply of men, these countries will not be able to dispense with an energy supply, because in numerous production processes, particularly in primary and transformation metallurgy, the employment of energy is essential for physical or chemical reasons. The setting in motion of the process of industrialization in the emergent countries is therefore dependent on the exploitation of the sources of energy which exist in these countries. The size of the problem for the African countries becomes apparent when it is considered that the European Community's energy consumption, expressed as an equivalent amount of coal, rose to 2,970 kg per head of population in 1963, as against 290 kg in the African countries. Energy consumption per head in the Community is thus ten times as great as that in Africa.

Turning to the transport problem, it should be noted that the creation of a suitable transport system assumes great importance because the African countries cover a very extensive area and the places to be linked together are thus very far apart. The present communications system is still far from being adequate for present needs. In the past, the commerce of Africa was orientated by trade with the industrial countries of West Europe and North America, and the lines of communication between the different countries of Africa have been little developed. It will be seen that the organizing of a transport system embracing all the countries of Africa is one of the principal tasks within the framework of the industrialization process itself.

The following examples illustrate the differences between the European Community and Africa in respect of the amount of goods transported and the available means of communication.

Taking rail transport first, in 1963 the amount transported in Africa was 65·2 thousand million tonnes-kilometres, whilst the figure for the Community was 150 thousand million tonnes-kilometres. Remembering that the area of Africa is 26 times that of the Community countries and that Africa's population is higher by some 100 million, the figures quoted show that the amount of goods transported in Africa is comparatively small.

A similar conclusion is drawn from the numbers of commercial vehicles. In 1963, Africa had 840·000 commercial vehicles available, whereas in the same year the Community had 3·83 million. The size of the merchant shipping fleet is similarly very limited, only Liberia, the Union of South Africa and the United Arab Republic having fleets of any size. Air transport of course can play an important part in Africa because of the long distances involved, but this can hardly be taken into account for transporting heavy products.

The problems described show that if industrialization is to be encouraged in the countries of Africa, it is necessary for simultaneous efforts to be made in the most diverse sectors, otherwise the evolution as a whole will encounter a bottleneck. With the multiplicity of difficult problems which arise, the emergent countries see themselves confronted by complicated tasks such as were unknown in the past. Consequently, it is unlikely that the goal of industrialization will be attained without the support of the already industrialized countries.

As far as ores are concerned, Africa has large rich deposits of iron ore which are considered to be among the best in the world. She also possesses deposits of copper, uranium, cobalt, tin, and other minerals. Prospecting has been systematically undertaken in only a few regions, and it can be assumed that further deposits exist.

The energy sources found up to now are primarily, the petroleum and natural gas of the Sahara and the coal deposits which are concentrated, except for some of minor importance, in the Union of South Africa. The great rivers of Africa constitute another important source of energy; these hydraulic forces have only been exploited to a small extent.

The underground riches of Africa have not yet been adequately explored. It is therefore important that the necessary efforts in this field should be energetically pursued; this will enable sites, suitable for the industries which are to be created, to be chosen on the basis of information as complete as possible on the location of the resources, and allow an appropriate system of communications to be established.

André GUILLABERT

Problems of Steel Utilization in Africa

(Translated from French)

The consumption of crude steel is much lower in the developing countries than in industrialised countries. It is actually in the proportion of one to three, whereas the industrialised countries account for less than one quarter of the population of the world. These percentages, although only rough estimates, demonstrate yet again the backwardness of those other countries compared with industrialised populations.

In Africa, however, steel is being used more and more in preference to other materials, such as wood, concrete or aluminium, for many reasons connected with the climatic, economic and political conditions, which are specifically African.

For all that, preference for steel does not eliminate the many problems connected with its use.

First of all let us examine these problems and the way they have been tackled to date, to enable us to see what they are for the future.

From the climatic viewpoint

The chief difficulties are corrosion, heat and wind resistance.

An international colloquium was held in Abidjan in 1963, from which it emerged that the conventional anti-rust coatings applied to metal surfaces are as effective as they are in our climate; the purity of the atmosphere offsets the harmful effect of the humid climate. Observations have shown that this applies to both the inside and the outside of dwellings.

This humidity is also responsible for the very low quality of certain hydrophilous soils, very much given to swelling, which make the construction of foundations a difficult matter.

Where the use of concrete is impracticable, the usual solution is a foundation block at medium depth with a frame of fairly light steel.

The wind also presents problems at times. An appropriate choice of the shape to be given to buildings should make it possible to reduce the wind-drag coefficient as far as possible and facilitate control of pressure variations.

To combat heat, galvanized-steel roofing is being more and more widely used, dwellings being covered with great lengths of Canadian tiles and industrial buildings both covered and clad entirely with galvanized steel, a method which has proved its worth even close to the sea.

From the economic and political viewpoint

The main concern is cheapness, but steel is able to compete with the other traditional materials.

An investigation carried out in West Africa in 1964 showed that it is more economical to build with a steel frame, even if the requisite steels are imported from Europe, than with cement which generally has to be imported also.

Moreover, steel usually makes for savings on foundation work and useful area, with the additional advantages of flexibility, durability and ease of processing.

As Africa is dependent for its supplies on the industrialised countries and the transport of materials often involves long delays, certain priority constructions, for example public works, call for the stocking of large quantities of steel, which raises serious problems in respect of financing.

Moreover, since the granting of independence the different African countries have been setting up their own separate legal and tariff systems, which make it very difficult to carry out inter-state projects.

Finally, for the same reason, private investment has paradoxically declined considerably, and, in general, operating credits have appreciably increased over investment credits. It has however, been possible to check this tendency by a policy of strict budgetary control, which must be specially stressed here. In Senegal for instance "for the third year in succession operating expenditure has stayed at the same level (34 million FAC francs)," while investment credits provided out of the State's own funds are constantly increasing.

All these problems which are being encountered at the present time and which slow down the steel market are, fortunately, due only to temporary difficulties which always occur during a transition period. The Governments are already responding to this situation and agreements have been concluded between different states for lifting export duties. This trend is bound to become more pronounced and more general in the years ahead.

These difficulties, stemming from the economic and political situation, are aggravated by the labour problem.

Africa lacks skilled workers. Preference is therefore given to the "boltable" type of framework, to avoid welding. Although some native skilled workers do exist, there are too few and very often foreign specialists have to be called in, whose services are very expensive.

This lack of skilled labour increases the difficulties not only in regard to the utilisation of steel products but also as regards maintenance, repair and replacement. These difficulties also explain why steel is preferred to any other material, because of its high-strength properties. They also impose certain essential requirements as regards ease of assembling and dismantling of the material and keeping repairs as simple as possible.

Great efforts have been and still must be made to ease this labour problem. Already there are several technical centres of mechanical engineering which are trying to meet labour requirements in co-operation with company representatives, but there are still not enough students and the enterprises' budgets are in many cases too heavily burdened by the cost of European labour.

Having thus enumerated some of the problems raised by the utilisation of steel in Africa, I now propose to define the exact position and its future.

Of all the traditional materials steel is the most suitable material for the specific climatic and economic conditions in Africa, as it is the only one capable of withstanding the hazards of climate, transport, handling by non-skilled labour, and its versability enables private initiative to use it for a great variety of different purposes.

However, greater efforts must be made to overcome these difficulties in order to enable steel to be used in a great number of new fields.

In private and industrial *building* steel is already being used in Africa at all stages, from the foundations to the galvanized-steel "Canadian roof tiles," frames and sun-breaker windows.

In *public works*, its use is also increasing from year to year, as, for instance, for the construction of ports (Cotonou) or rail or road bridges, and soon perhaps for the construction of pipelines, wharves and fuelling jetties.

In *agriculture* likewise, steel will be increasingly used for the manufacture of mobile equipment.

It remains to be seen in what other sectors, such as mission houses or bush dwellings, there are also good openings for steel on account of its ease of pre-fabrication and cheapness.

The use of steel is thus bound to increase considerably in Africa, when adapted to specific African problems and not beld back by them.

Henri LEJAY

Problems of Steel Utilisation in Tropical Countries

(Translated from French)

Certain steels of traditional use in the building of boiler plant or auto-welded equipment in temperate climates may be of heightened interest in tropical countries.

While heat favours the shaping of steel by substantially reducing risks of cracking during bending — a very important consideration in countries having very severe winters — moist heat, on the other hand, is extremely harmful from the point of view of atmospheric corrosion.

Since protective coatings such as paint, are not always possible and often present imperfections, the use of unalloyed lined steels, apart from the practical impossibility of welding them, would also run the risk of corrosion. The constructional engineer has therefore an even greater incentive to turn to low-alloy steels which, in addition to their high mechanical and good welding properties, possess excellent resistance to atmospheric corrosion.

On this subject we would point to the interest of the mining and quarrying industries in impact and abrasion resistant steels; the mineral wealth of Africa, in particular, is such that there should be a considerable market for these products in that part of the world.

All mining installations must have a number of machines for handling ore which is often hard and abrasive. In tropical countries handling equipment in mines and quarries is therefore subject to impact, abrasion and greater atmospheric corrosion than in dry countries.

As already mentioned, high-carbon unalloyed steels, whilst having good abrasion resistance and reasonable impact resistance, perform poorly in a moist atmosphere, and since both impact and abrasion are present any paint or coating protection is pointless.

The best solution is thus offered by low alloy steels such as Cr Mn or Ni Cr Mo steels supplied as treated plate or sheet ready for use.

I would add that the simplicity of using and welding such steels compared with other hard carbon or manganese steels brings the construction and, above all, the maintenance of plant made of them within the reach of the maintenance divisions of many firms. Of the many examples of the employment of these steels we will quote three in the field of mining equipment which clearly show the value of these steels.

(1) A bucket-wheel ore elevator with buckets and sides made from very hard Cr Mn Mo welding steel. A machine of this type is used in a mine in South Africa (figure 4, p. 696).

(2) A dumper the bulk of which is made entirely of Ni Cr Mo high-elastic-limit steel. It stands up to abrasion, violent impact and atmospheric corrosion in a remarkable manner. Large numbers of these dumper bodies, made from steel of this class, are in use, particularly in Katanga (figure 5, p. 696).

(3) A spiral chute made from very hard Cr Mn Mo welding steel, which, together with troughs, hoppers and spouts also made from the same steel, is used in many mines in the Gaboon, Mauretania and Morocco (figure 6, p. 696).

Jacques ASTIER

Expension of Steel Consumption in Developing Countries

(Translated from French)

The discussion papers submitted by MM. Anguilé and Yao raise the very interesting problem of growth and variety in the consumption of steel in a developing country.

It is a well-known fact that when the steel consumption increases in a given country, i.e. when that country is "developing", the distribution of this consumption among the various types of steel product is bound to change. To illustrate this point, though without being able to give precise figures, we have studied the situation in a number of developing countries, and give some average data below.

If we take, as an example, a developing area whose population grows from 10 to 12 million inhabitants, while the consumption increases from 20 to 100 kg. of crude steel per head of population and per annum, we arrive at the following figures (see second table below).

Approximate distribution of steel consumption of developing areas. (All the data are in kg. per head of population per annum.)

Consumer area concerned in terms of crude steel	20	100	500
Flat products			
Total	7	35	250
Sheet and heavy and medium plate	5	25	200
tinplate	1·5	5	20
Long products	10	40	140

Growth of steel consumption in a hypothetical area

Population, millions of inhabitants	10	12
Steel consumption, kg. of crude steel per annum and per head of population	20	100
Total consumption, tons per annum	200,000	1,200,000
Distribution of consumption, tons per annum		
Long products	100,000	480,000
Flat products of which:		
sheet and heavy and medium plate	50,000	300,000
tinplate	15,000	60,000

Some conclusions can readily be drawn from a study of this table:

(a) in the entire area under consideration, a large, modern, integrated steelworks is difficult to conceive, because these plants are designed for much higher production capacities, of something like 2-4 million tons of steel per annum;

(b) this proves even more difficult if the distribution of the types of steel product is examined; a continuous strip-mill and even a semi-continuous one is practically out of the question;

(c) the best solution would be to set up a medium-sized plant for 300,000 to 500,000 tons of crude steel, concentrating on long products (rounds, small sections, etc.) and to bring it into operation in, say, two stages, each fo 150,000 to 250,000 tons per annum.

This again poses the problem of deciding which would be the most appropriate type of plant to set up, a question which IRSID has been studying for a number of years. (Biblio. 1 and 2).

Mr. Anguilé has stressed the fact that, in such a case, the choice of the production-cycle pattern is far from obvious. IRSID has on several occasions had to make comparisons of this kind, and, taking into account the location of energy supplies and the nature of the available iron ores, widely differing answers can be given to this question.

We would here merely recall that two main types of production cycles must be distinguished:

(a) those based on the conversion, generally with oxygen, of pig iron produced, according to circumstances, in a coke or charcoal blast-furnace, in an electric melting furnace, or even by means of a rotary furnace of the Dored, Imphy or similar type;

(b) and those based on the melting of sponge iron or ore reduced at low or medium temperatures.

In Africa, as in other parts of the world, the nature of the ore will tend to decide the choice, the richest and purest ores being as a general rule essential for the latter type of production-cycle.

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G. P. CHATTERJEE

Some Aspects of the Problem of Corrosion in a Tropical Country

I am grateful for the invitation and opportunity to present before this august and international Congress some aspects of the problem of corrosion in a tropical country like India.

With the icy cold of Kashmir and other hilly regions, with the torrid blistering heat of Rajasthan and other parts in the interior, with atmospheres, dry and dreary (of quite low humidity), of the tropical plateau and with near saturation humidity existing for months during the year in many regions and particularly at Cherrapunji, recording highest rainfall in the world, with the salt and moisture-laden atmospheres of an extended sea-cost, with the impacts of Monsoon and the dust-laden summer storms, with comparatively clean atmospheres of rural regions and the obnoxious gases, fumes and smokes of industrial belts, India presents a fairly representative sample of a tropical country with regard to a variety of aspects of the problem of corrosion.

The term "Corrosion" usually refers to the destruction of materials by chemical and/or electrochemical reactions. Fundamentally all reactions leading to corrosion are electrochemical in nature. In fact all reactions — physical, chemical and even biological — involve ultimately in some way or other (by donation and/or sharing) redistribution of electrical charges through the agencies of the so-called valence electrons of atoms of matter undergoing those reactions. Fundamentally, therefore, all matter — be it in Metal or in Man, in polymer or in plastics, in ceramets or in ceramics — undergo deterioration and eventual destruction. Not only inorganic and lifeless matter but living organisms undergo corrosion deterioration and eventual destruction or death.

Thus all matter — living or non-living — undergo "corrosion". Corrosion in some form or other is omnipresent and, like "Entropy" when left to itself, it is unidirectional and is continuously increasing, leading eventually to the destruction and disappearance of the material.

Corrosion cannot be stopped. What the Scientist, the Technologist and the Engineer can do is to combine to fight this menace and halt its forward march, decrease the rate or the kinetics of onslought created by "corrosion" and thereby save much of the materials that mankind makes with so much energy and effort.

To be able to minimize the rate of corrosion and thereby prolong the life of a material under a given set of environments, scientists and engineers all over the world have set their minds to find out the fundamental cause that initiates corrosion and the fundamental factors that accelerate or decelerate corrosion.

An attempt has been made in this paper to present briefly the magnitude of the problem in a tropical country like India and to indicate briefly the basic and fundamental scientific aspects of the problem and so help to understand the behaviour of metals and alloys under different sets of corrosive environments and to present briefly an outline of some aspects — both fundamental and applied — of the work done and the measures adopted in India.

Then and now — The magnitude of the problem

Prior to India's independence in 1947, the production of indigenous metals and alloys was very limited and except for routine measures adopted:

(a) by the Public Works Department and Railways and other essential services under the Government; and

(b) by a few private industries like the Steel and the Textiles

not much attention was given to the problem of corrosion.

After independence the picture changes rapidly. With the setting up of a chain of industries and the progressively increasing production and consumption of metals and alloys, with a railway system (the largest in Asia and second in world), having to maintain nearly 100,000 bridges and 300,000 wagons, coaching vehicles and freight cars, more than 6,000 stations and 11,000 locomotives; and last, but not least, with the rapidly advancing frontiers of the production and consumption of a variety of materials, the problem of corrosion assumed new dimensions in kind and in complexity.

An approximate estimate of the loss

An approximate estimate indicates that the total expenditure involved in minimising corrosion in the Railways, in industry and other institutions amounts to more than 1,500 million Rupees as can be seen from table 4, p. 687. The Railways alone account for more than 200 million rupees.

Actual total loss

Considering the indirect losses due to idle hours of plant and equipment, losses due to leakage of products, losses due to unnecessary uses of metals and alloys, both in quality and quantity, due to over-design and undue safety factors for lack of information on corrosion rates, the total cost of corrosion is certainly very much more than 1,500 millions rupees.

From a survey of the measures used for the prevention of corrosion in the Railways and various industries, like Machine Tool, Electrical, Cycle, Automobile, Coach building, and Ship building and other industries in India, it has been estimated that on an average about 5 to 15% of the finished products go towards preservation, replacement, plating, painting and so on. These are in effect anti-corrosive measures. The steel consumed by the Second Five Year Plan is approximately 4·3 million tons and the cost of the finished products is more than 20 billion rupees. It is estimated that about 10% of the cost of finished materials is involved in corrosion. Assuming that on an average of 8% of the cost of the finished product is due to corrosion prevention, the amount in rupees spent on corrosion protection comes to nearly 1·6 million rupees — a figure which agrees with that indicated in table 4, p. 687.

After the end of the Third Plan period the steel production and consumption in India is expected to increase by at least threefold, with a commensurate increase in the cost of corrosion.

Field test — Atmospheric, underground and marine corrosion at different places in India — Corrosion map

Atmospheric corrosion

(a) The corrosion rates of structural steel in some of the major cities in India are summarised in table 2, p. 686.

(b) The corrosion rates of structural steel measured in mg./sq.dm./yr. against the month in which the exposure is started are indicated in table 6, p. 688. It has been found that corrosion rates of structural steel depend to some extent on the time of initial exposure. If the samples are exposed for some time, possibly some protective films form which subsequently reduce the corrosion rates. Sometimes the marine effect is washed off by monsoons if the exposure starts in August, September or October.

(c) The corrosion rates of non-ferrous metals under outdoor exposure conditions at some typical places in India are indicated in table 7, p. 688.

Effects of distance from sea

The sharp decrease of corrosion rates due to the effects of distance from the sea may be noted from the data in the tables 5 and 7, pp. 687 and 688. Theory indicates that the corrosion rate is expected to be an exponentially decreasing function of distance (in the absence of wind and other disturbing effects). How far this is true will be evident from the figure below.

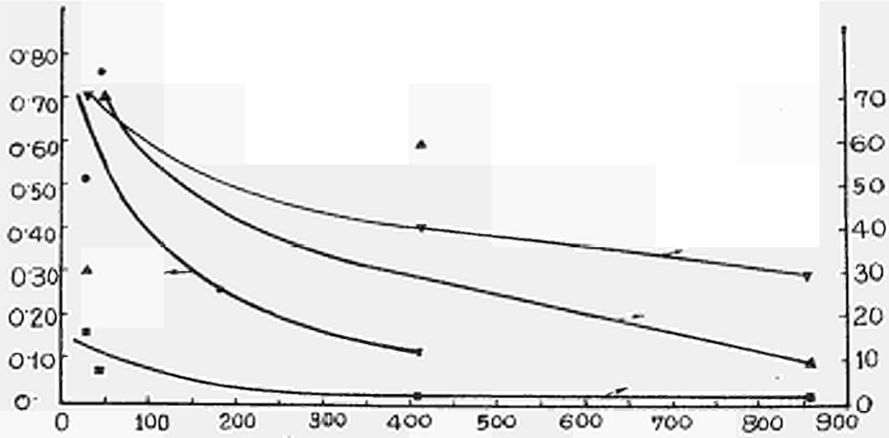
Corrosion map

Based on the rates of corrosion of ferrous and non-ferrous metals, India may be broadly divided into eight zones as indicated in table 1, p. 686 (see also map below). Details in this connection are indicated in the appendix (pp. 684 685).

(i) As can be expected, corrosion rates are heavy in marine coastal zones particularly those in the industrial belt.

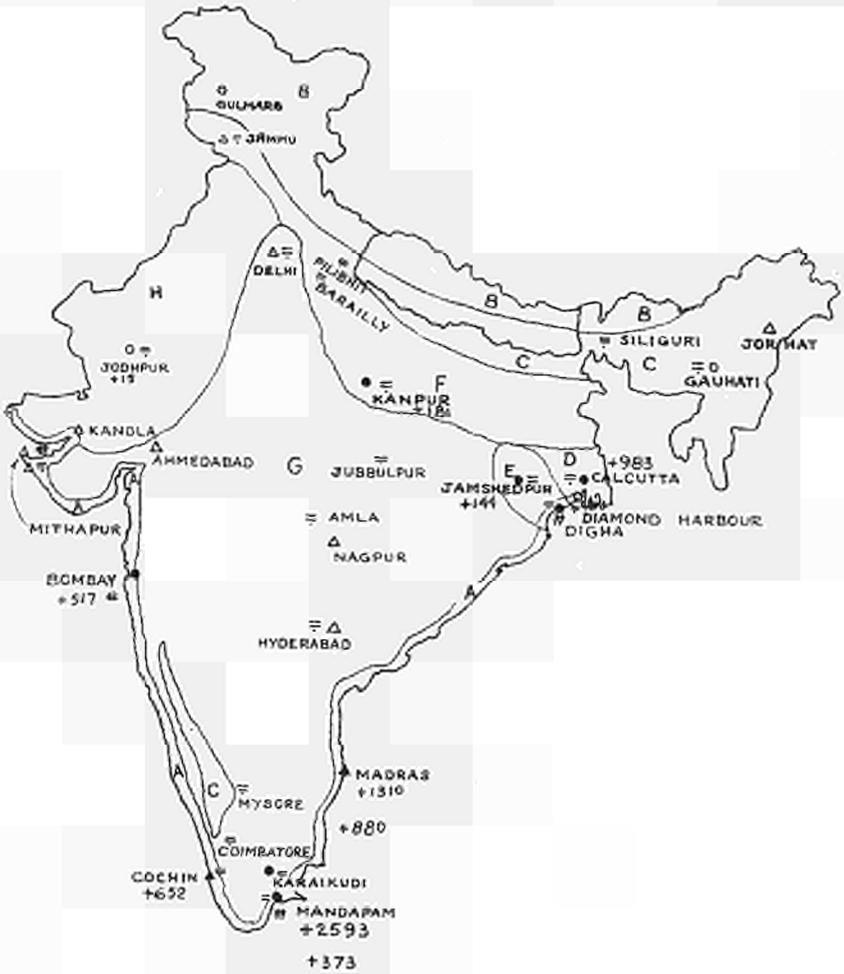
(ii) Initial exposures have a marked effect on retarding corrosion.

(iii) In inland tropical and sub-tropical places the corrosion rates are uniformly very low (5×10^{-3} mm./yr. for copper, steel and $0{\cdot}1 \times 10^{-4}$ mm./yr. for Zn). The low corrosivity of the famous Delhi pillar is partly due to the non-corrosive atmosphere of the inland tropical zone.



Different zones

A. Coastal strip having both industrial and non-industrial station
B. Undifferentiated high lands
C. Monsoon rain forest
D. Hot and moist industrial areas
E. Hot and dry industrial areas
F. Humid sub-tropical indo-gangetic plain
G. Central indian dry zone
H. Tropical desert



Atmospheric corrosion

- ○ Existing "A" stations
- ⊙ Proposed "A" stations
- ▲ Existing "B" stations
- △ Proposed "B" stations
- = Underground corrosion sites
- ≠ Immersed (sea water) corrosion sites

Comparative data of some tropical experimental stations in Asia and Africa

The relative rates of corrosion of the atmosphere of the Indian sub-continent may be compared with those of some other experimental stations in Asia and Africa as indicated in the table 8 on page 688.

The table indicates that corrosion rates at surf beaches in the tropics are exceptionally severe and the rate of corrosion at Lagos is five times more than that of the most corrosive industrial atmosphere in Great Britain. In India, Mandapam represents the corrosive atmosphere at Lagos, while Singapore, Basrah, Nigeria are less corrosive than Calcutta, Bombay or Cochin. This is because these great cities in India, besides being nearer to the sea, have also corrosive industrial atmospheres. Dry tropical places like Khartum can be favourably compared with Delhi in respect to its low-corrosive character of the atmosphere.

From the existing data it may reasonably be concluded that contrary to general belief, corrosion in tropical countries is not generally very much higher than in the temperate climates. Air-borne salt is the principal factor contributing to the corrosivity of atmospheres in tropical climates. Atmospheric pollutions by industry also affect the rates of corrosion to some extent. But where these two factors and the effects of micro-organisms are absent, hot humid tropical climates do not appear to contribute appreciably towards increasing the rates of corrosion in tropical countries.

Underwater marine corrosion

Work carried out on "underwater marine corrosion" in the coastal regions of India is not exhaustive. An idea of the corrosion rates of different metals in sea water at Bombay and Cochin are given in table 2 on p. 686. It may be noted that while naval brass and zinc have higher rates of corrosion in Cochin sea water compared to Bombay, it is just the opposite in the case of copper.

Soil corrosion

There are four major groups of Indian soil, viz., Bangalore red soil, Amraoti black cotton soil, Bankura laterite soil and Berhampore alluvial soil. The corrosivity data of these four groups of soils under laboratory conditions with modified Denison cell are summarised in table 3 on p. 686.

Besides the laboratory test with four major groups of soil, field trial experiments at selected spots at the Durgapur-Calcutta route were carried out. The results are summarised in table 9 on p. 689 and some details are indicated on page 685 (3 first paragraphs — right hand column).

It may be mentioned here that the flow or exchange of electrons causing corrosion may be initiated and sustained not only by non-living inorganic and organic agents but by living micro-organisms. Work is in hand to find out the effects of such micro-organisms.

Corrosion — The fundamental cause and the fundamental mechanism

A considerable volume of work has been done on the causes and mechanism of corrosion and the means to minimize corrosion. Published literature throughout the world provides valuable data and information in abounding measure, and I shall not make any attempt to reiterate these in this paper. However, a few fundamental facts, emerging through the efforts of many great minds, working not only in the field of corrosion but in other fields of discipline are of considerable interest and help.

The fundamental cause of corrosion is due to the universal tendency of particles of matter (electrons, atoms, ions, molecules and so on) to flow from one site to another along the gradient of some potential function in a suitable field (electro-magnetic and/or gravitational).

Since particles of matter possess mass (which is affected by gravitational field) and since all corrosion phenomena involve interactions of charges (affected by electrical, magnetic or electromagnetic field), both these fields, viz., gravitational and electromagnetic, affect corrosion phenomena in some way or other.

Field has three essential features:

(a) A potential V which determines whether or not the tendency exists for the flow of matter and of charge (both of which take part in corrosion).

(b) A potential gradient $\partial V/\partial x$ or in general ∇V which determines the direction and speed of flow of that matter and/or of that charge. This potential gradient profoundly affects the kinetics of corrosion and therefore all factors tending to accelerate or inhibit corrosion are directly or indirectly affected by this gradient.

(c) A field capacitance $C = V/\sigma$ where σ is either mass m. or charge γ, as the case may be. Field capacitance determines the magnitude of flow and therefore the magnitude of corrosion. (both in breadth and in depth) under a given set of conditions.

Corrosion is first initiated at some surface or interface. The figure on p. 683 depicts the fundamental features of different potentials in relation to the surfaces of metals and alloys. The following fundamental facts will be helpful in understanding the behaviour of metals and alloys under different environments.

(i) Solid metallic surfaces, unlike liquids, are not equipotential.

(ii) Solid surfaces are not homogeneous due to (a) lack of enough mobility of surface atoms, (b) different types of linkages, (c) different orientations of small crystals and (d) pseudo-lattices.

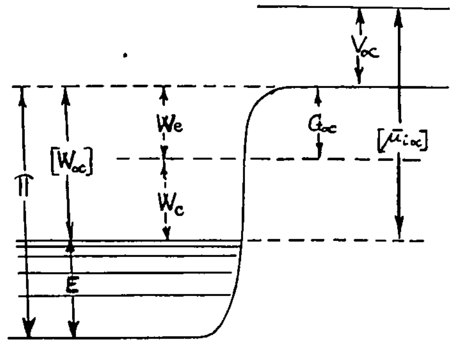
(iii) A phase boundary potential in the region of interfaces between two phases exists due to (a) differences in the rates of escape of positively and negatively charged particles, (b) preferential adsorption and (c) presence of dipoles.

(iv) Three distinct and different potentials profoundly affect corrosion and other phenomena

- (a) The Fermi potential E;
- (b) The work function $W = W_e + W_c$ where W_e = work against long range electrostatic forces, the so-called internal electrostatic potential and W_c = work done against short range dipole electrical force = chemical potential; and
- (c) the external electrostatic or volta-potential V.

Other potentials like the mean inner potential $\pi = E + W$. The electrochemical potential $\mu_{i\alpha}$ of a charged particle i in phase *a*, $\mu_{i\alpha} = (W + V) + \mu_{io}$, where μ_{io} is the electrochemical potential of i in standard phase o. The Galvani potential $G = W_c + V$.

Once initiated at some surface or interface, corrosion continues by movement of particles (electrons, atoms or ions) through the process of diffusion expressed by the following



chematic diagram representing different potentials in metals and alloys. The diagram attempts to show the relations between the different potentials which affect the behaviour of metals and alloys under different environment

fundamental relation:

$$\frac{\partial \varphi}{dt} = K \nabla V(\varphi)$$

Where φ is the flux of matter or of charge per unit cross section and $V(\varphi)$ is the potential associated with φ and is some function of φ and K is some suitable constant related to the flow of φ.

A host of data in the field of corrosion of metals and alloys (and also of materials in general) can be explained in terms of the above few basic concepts.

Research and investigation work in India on problems of corrosion

Different aspects — both fundamental and applied — of the problem of corrosion are being studied by the Indian Railways, by the Council of Scientific and Industrial Research, by the National Test House, by the Atomic Energy Establishment, by the Defence Science and Research Organization, by the Research and Control Laboratories of the Iron and Steel and other Heavy Industries, by the Universities and a number of higher Institutes of learning and research centres.

A brief outline of different fields of study

Many significant contributions have been made in one or more of the following different fields:

(a) factors affecting corrosion, including effects of temperature, moisture and other constituents in different environments;

(b) corrosion inhibitors, including inhibition efficiency of various compounds;

(c) surface film — passivity, rates of growth and allied phenomena;

(d) cathodic potential of inhibitors, including cathodic protection;

(e) protective coatings of various different types, inorganic and organic;

(f) corrosion tests and studies by different techniques — accelerated corrosion tests, immersed corrosion test, electron diffraction, radio active tracer work and so on;

(g) corrosion resistant alloys.

Details in this connection have been indicated on page 685 "Brief outline..."

Measures adopted to combat corrosion

Metal Research Committee — the Corrosion Bureau

To be able to correlate the corrosion data from different institutions at different places in India, with more or less similar specifications of materials under known conditions, the Metal Research Committee of the Council of Scientific and Industrial Research, India, have taken an active interest and have initiated a number steps in the various aspects of corrosion problems with the help of ten corrosion subcommittees (formed in 1960) and the Corrosion Advisory Bureau (formed in 1962).

(a) For collecting atmospheric corrosion and pollution data, different field centres have been created all over India covering a variety of environments.

(b) Mild steel panels of uniform composition and requisite specifications have been sent to most of these stations by the Corrosion Advisory Bureau.

(c) Exposure of standard metal panels supplied by the Corrosion Advisory Bureau were started in the middle of 1964 and systematic data are being collected at present.

Corrosion research by the Defence Laboratory, the Railways, the National Laboratories and the Test House

Besides the above mentioned stations, researches on different aspects of corrosion are being carried out at the National Laboratories, at the Defence Research Laboratory, at the National Test House, by the Railways, by different Universities and Institutions and other scientific organizations. Some of the researches that are bieng carried out at different centres in India are listed below:

1. Atmospheric corrosion of metals and alloys with particular reference to iron and steel and some common nonferrous alloys.

2. Corrosion studies in saline atmospheres and investigations on incrustation in corrosion pipes.

3. Studies on corrosion of metals and alloys under other different environments.

4. Studies on corrosion inhibition.

5. Studies on the mechanism of corrosion of metals and alloys with particular reference to iron, nickel and chromium.

6. Investigations into the quality of indigenously produced materials required for heavy duty corrosion protection in marine and industrial atmospheres.

7. Underground and subsoil corrosion of metals and alloys.

Conferences and Symposia — National and International

To be able to exchange information, symposia and conferences — on national and international levels — have been held within the last few years and valuable information has been collected and incorporated in reports and papers (indicated in the Bibliographic references).

Concluding remarks

Following independence in 1947 India is on the threshold of industrialisation on a massive scale. For a high rate of growth one needs the help of Men, Money and Material. But Matter — whether it is in men or whether it is in money or material — undergoes continuous corrosion.

Industries consume raw materials and produce finished and semi-finished products through different processes to be used under different environments. But all types of matter in all types of process and under all sorts of environments undergo corrosion at different rates.

Men, Money and Material form the Capital to start with. For the sucessful utilisation of that Capital, in this age of science, one needs another "C", viz, the Capacity, the technological Capacity to effectively utilise that Capital. These two "C's", the Capital and the Capacity, form therefore the Core for the creation and cumulative creation of more Capital and more Capacity to contain that Capital.

Both these two "C's" — the Capital and the Capacity — are however under the continuous influence of a third "C" — the "Corrosion".

Corrosion, as I have already indicated is omnipresent and everlasting. Creation and corrosion, like life and death, happen to be the two complementary phases in Nature. Creation continues and so will Corrosion. Corrosion cannot be stopped.

Corrosion can however be appreciably minimized by suitable treatment and suitable environments.

Considering all these facts, India has launched on the great task of combating corrosion. The Railway Research Centres, the Defence Research Laboratory, the National Research Laboratories, the National Test House, the Research and Control Laboratories in Iron and Steel and other Heavy Industries, the Metal Research Committee, the Council of Scientific and Industrial Research, the Universities, the higher Institutes of learning and various other organizations have commenced activities with a view to pooling their resources to mitigate some of the losses due to the complex character of corrosion and thereby save some of the materials for the service of man.

Appendix

A. *Tropical marine zone*

Though the effect of the saline atmosphere is quite marked, the patterns of corrosion in Bombay, Madras or Mandapam are not exactly the same. At Mandapam camp and Cochin, high corrosion rates are obtained during April to September, namely during those months in which high mean temperature is accompanied by high humidity and salinity, which are typical for marine corrosion. In Madras however the corrosion rate is more or less uniform throughout the year, and higher corrosion values are obtained during the half-year October-March, i.e. the period when the mean temperature is low, which is a particular feature of corrosion in industrial atmospheres. The SO_2 content of Madras atmospheres varies between 10-65 mg. SO_2/Sq.dm. PbO_2/month, and that of Cochin atmosphere is about 3·5 mg. SO_2/Sq.dm. PbO_2/month, while the Mandapam site is almost free of SO_2. The effect of SO_2 combined with the salinity of marine atmosphere is therefore particularly marked in Madras, while at Mandapam camp and Cochin the causes of corrosion mainly correspond to marine atmosphere.

At Bombay the rates of corrosion of mild steel are very high during the rainy season (about 925 mg./Sq.dm./month) and are lower and nearly uniform during the other months (about 330 mg./Sq.dm./month). The SO_2 content of the atmosphere is about 14·1 mg. SO_2/Sq.dm./month. A good correlation was obtained between the corrosion rate and humidity. So though the place is industrial, the contribution of marine climate to corrosion is more marked in Bombay.

B. *Undifferentiated high lands*

The Himalayan region, Kashmere, north of U.P. and Gangtok etc. comes under this zone. The climate is cold and represent sub-tropical and there are no big industries in this belt. A corrosion study field station has been set up at Gulmarg to collect atmospheric corrosion rates throughout the year. Results are awaited.

C. *Monsoon rain forest*

Two different places in India come within these climatic conditions, one in the western part of Mysore and the other at Assam. They are marked by heavy rainfall exceeding

2540 mm. year. A minor corrosion laboratory for the collection of corrosion data at Coimbatore has been proposed.

D. *Hot and moist industrial area*

Calcutta and its surrounding areas is typical of this zone. The maximum humidity values are higher than the critical humidity values for the entire year, and the concentration of SO_2 is also fairly high, and varies between 3-10 mg./sq.dm./month. The rates of corrosion exposed outdoors vary between 426 to 1298 mg./sq.dm./month in this region. High rates of corrosion are marked in December. Rainfall during the year is above 1500 mm. and occurs between June and September. In cities like Calcutta, Bombay, etc. the maximum humidity values are higher than the critical values for 12 months and there is heavy rainfall. The concentration of SO_2 is also fairly high in these cities and varies between 2-10 mg./sq.dm./months. The corrosion rates are generally higher in those places during the rainy season, and have been found to depend on the time of initial exposure. The yearly rate at Calcutta and Bombay varies between 1399 and 3170 mg./sq.dm. and 2100 to 4355 mg. sq.dm. respectively. Amongst the non-ferrous metals the corrosion rates of aluminium and stainless steel are found to be the minimum.

E. *Hot and dry industrial areas*

This zone covers Jamshedpur and surrounding places in Bihar. The corrosion rates are comparatively low due to the dry climate and at Jamshedpur the average corrosion rate is 144 mg./sq.dm./month.

F. *Humud sub-tropical Indo Gangetic plain*

The zone covers most of U.P., part of Bihar and W. Bengal. The average indoor and outdoor corrosion at Kanpur in this region is 45 mgs./sq.dm. and 169 mg.sq.dm./ respectively.

G. *Central India dry zone*

This zone covers the dry plateau of Central India, representing Tropical Inland climate. The corrosion rate is low and at Karaikudi the corrosion rate is ·013 mm./face/yr. while at Delhi the corrosion rate of steel is as low as ·005 mm./year, and zinc 0·0001 mm./yr. The resistance to corrosion of the famous iron pillar is attributed by some investigators to this particularly low corrosive atmosphere.

H. *Tropical desert*

This zone includes the Thar desert in Rajasthan and also part of Punjab, and is marked by extremely low humidity and high temperature. The corrosion rate is extremely low reaching only 15 mg./sq.dm. at Jodhpur.

The weight losses of mild steel and cast iron electrodes with respect to Amraoti black soils and Berhampore alluvial soil is in close range. The relative corrosivity of these two soils are almost identical though they differ widely in composition and physical and chemical characteristics. Mild Steel, however, seems to be more resistant to corrosion in Amraoti and Berhampore soils compared with cast iron. The Bangalore red soil and Bankura laterite soil are more corrosive to mild steel and cast iron than Amraoti and Berhampore soil. The corrosion rate of mild steel in the case of the first two soils is almost three times as great as the last mentioned soils.

From actual field trials the corrosivity of soils with respect to cast iron are in the following order: Burdwan, Chinsurah, Saktigarh, Durgapur, Shibpore, while with respect to mild steel the order is: Chinsurah, Saktigarh, Burdwan, Durgapur, Shibpore.

There is very little correlation between weight losses of the electrodes and maximum pitting. It is also evident that the corrosivity of soils differs with respect to different materials. The existing data do not show any correlation with any single valued soil characteristic and the weight loss of the electrodes. A mild relationship however appears to exist between the combined weight losses of the electrodes and the ratio of the total anions to the water-holding capacity of the respective soils. Extensive fields trials and collection of data will be necessary before any comprehensive map of corrosivity of Indian soils could be formulated.

A brief outline of the fields of study on the problem of corrosion

Factors affecting corrosion: The influence of humidity, SO_2, period of exposure, temperature, presence of dissimilar metals, atmospheric dusts, nuclei, electrolytes and aerosols on corrosion has been studied. Comparative rates of corrosion of metals plotted against relative humidity showed decreasing corrosion in the order: mild steel, copper, zinc, aluminium.

In the case of mild steel it has been noticed that there is increasing corrosion with increasing SO_2 concentration up to about 0·9%, after which there is a fall to about 3·8% followed by a slight rise up to 9·9%, chlorides have been found to be more corrosive than sulphates, and the corrosion of mild steel increases with the quantity of sodium chloride deposited on the metal surface. The role of aerosols on metal corrosion has been studied in a laboratory salt fog chamber in which marine atmospheric conditions have been simulated. The influence of atmospheric sea salt governing the intensity of corrosion was estimated.

The inhibition efficiencies of various compounds such as acridine, thiourca, nicotinic acid, and colloids such as dextrin, agar agar, gum acacia, gelatine and glue have been studied. The inhibition efficiencies of the colloids have been attributed to the absorption of colloids on metal surfaces. The mechanism of corrosion inhibition by the tracer technique have also been studied. The effect of the addition of the pickling inhibitor dibenzyl sulphoxide studied by this

Table 1 — An outline of the eight corrosion zones with essential characterictics

Zone	Area	Characteristics
A. Tropical Marine	All southern coastal strip including industrial and non-industrial area.	(i) Most corrosive (ii) Humidity about (90%) (iii) Heavy rainfall (5537 mm/yr. at Cochin) (iv) Temp. 30-32°C. (v) High wind velocity (vi) Typical corrosion rate in Table-8, page 688.
B. Undifferentiated High lands.	Northern Himalayan region, Kashmir, U.P. Belt (Non-industrial area).	Cold and dry climate, low corrosivity. A corrosion station has been set up — results awaited.
C. Monsoon Rain Forest.	Western coast of Mysore, Assam.	Heavy rainfall (about 2540 mm./yr.) A corrosion laboratory has been proposed at Coimbatore.
D. Hot and Moist Industrial area.	Calcutta and its surroundings area.	(i) Maximum humidity above critical humidity. (ii) High SO_2 concentration. (iii) Heavy rainfall in June-September. (iv) High corrosion rate in December.
E. Hot and Dry Industrial area.	Jamshedpur and its surrounding, part of Bihar.	(i) Dry climate. (ii) Corrosion rate comparatively low.
F. Humid Sub-tropical Indo-Gangetic Plain.	U.P., Part of Bihar and West Bengal.	(i) Maximum humidity value is above 70% throughout the year. (ii) Good rainfall. (iii) Temp. 25 to 40°C.
G. Central India Dry Zone.	Central India Plateau.	(i) Tropical inland climate. (ii) Low corrosion rate.
H. Tropical desert.	Deserts of Rajasthan and Punjab.	(i) Extremely low humidity. (ii) High temperature. (iii) Very low corrosion rate.

Table 2 — Corrosivity of sea water at Bombay and Cochin

Metal	Corrosion rate mm./yr.	
	Bombay	Cochin
Mild Steel	0·187	0·170
Copper	0·028	0·026
Naval Brass	0·019	0·027
Zinc	0·042	0·045

Table 3 — Corrosivity of four major groups of Indian soil mgm./sq. cm./yr.

Soils	Materials tested	Total wt. loss of the electrode	Max. pitting in mm.
Amraoti (Black)	Cast Iron (C.I.)	41·0	0·229
	Mild Steel (M.S.)	19·0	0·025
Bangalore (Red)	C.I.	52·0	0·127
	M.S.	60·0	0·279
Bankura (Laterite)	C.I.	53·0	0·127
	M.S.	50·0	0·203
Berhampore (Alluvial)	C.I.	44·0	0·127
	M.S.	19·0	0·013

Table 4 — Cost of corrosion in India (Totals have been rounded)

Cost involved in	Total million rupees
1. Paints, varnishes, lacquers and other materials	440
2. Copper and copper alloys	550
3. Alloy steel	250
4. Tin and tin alloys	120
5. Electroplating industry	110
6. Aluminium and Al-alloys	90
7. Zinc and zinc alloys	65
8. Lead and lead alloys	35
9. (a) Nickel and nickel alloys (b) Internal combustion engine corrosion (c) Miscellaneous	30
Grand Total :	1,690

Table 5 — Corrosion rate of steel at different places in India measured in mm./year.

Sl. No.	Group	Station	Type of climate	Local pollution	Penetration mm./year
1	α	Madras	Tropical Savana	Marine	
		(i) 27·3 m. from sea	Tropical Savana	Marine	0·254
	α	(ii) 183 m. from sea	Tropical Savana	Marine	0·127
2		Mandapam Camp	Coastal, Tropical	Marine	
	α	(i) 45·75 m. from sea	Coastal, Tropical	Marine	0·381
	β	(ii) 411·75 m. from sea	Coastal, Tropical	Marine	0·064
3	β	Cochin	Coastal, hot humid monsoon, rain, forest	Marine	0·069
4	γ	Calcutta	Hot, humid, Tropical Savana	Industrial	0·030
5	γ	Bombay	Coastal, hot, humid tropical savana	Industrial cum marine	0·046
6	γ	Kanpur	Humid sub-tropical	Semi-industrial	0·023
7	γ	Jamshedpur	Sub-tropical	Industrial	0·018
8	δ	Karaikudi	Inland, Tropical	Rural	0·013
9	δ	Delhi	Sub-tropical	Urban	0·006

N.B : — α — Most Corrosive group — above 0 127 mm./year.
β — Medium Corrosive — 0.06 to 0.127 mm./year.
γ — Low Corrosive — 0.018 to 0.06 mm./year.
δ — Very low corrosive — below 0.018 mm./year.

Table 6 — Loss of metal in one year's exposure mg./sq. dm./yr.

Month on which exposed	Calcutta	Bombay	
June	3,170	4,385	Marine effect
July	2,876	3,253	
August	3,397	2,978	Marine effect
September	1,399	2,310	washed off
October	1,830	2,108	by monsoon
November	1,948	3,902	
December	1,877	3,981	
January	1,541	3,604	
February	2,414	3,124	Marine effect
March	1,821	3,824	
April	1,749	3,235	
May	2,408	3,171	

Table 7 — Corrosion loss mg./sq./yr. at stations

Metal	Bombay	Calcutta	Jamshedpur	Mandapam Camp.		Madras Post		Kanpur	Cochin	Delhi
				45.75 m. from sea	411.75 m. from sea	30.5 m. from sea	854 m. from sea			
Copper	87		10·2	70	60	30	10		12·7	
Brass	69		87						2·8	
Lead	30								—23	
Galvanized iron on clating.	293									
Zinc	240	50	140	440	40	70	30	2	40	25·2
Aluminium			5	7	2	16	2		12	
Stainless steel			—3·7						— 6	
Tin Plate									160	

Table 8 — Comparative data of some tropical experimental stations

Station	Atmosphere	Rates of corrosion in mm./yr.	
		Ingot iron	Zinc
Khartoum	Dry Tropical	0·00254 mm.	0·000508 mm.
NKPOKU	Jungle Tropical	0·00508 mm.	0·000508 mm.
Aro (Nigeria)	Inland Tropical	0·01270 mm.	0·001524 mm.
Basrah	Dry Sub-Tropical	0·01524 mm.	0·001016 mm.
Singapore	Marine Tropical	0·01524 mm.	0·001016 mm.
Apapa (Nigeria)	Marine Tropical	0·02794 mm.	0·001270 mm.
Congella (Durban)	Marine Industrial	0·11430 mm.	0·004826 mm.
Lighthouse beach (Lagos)	Surf beach Tropical	0·61976 mm.	0·014224 mm.

Table 9 — Corrosivity of some Bengal soil mgm./sq. cm./year

Soils	Depth of soil	Materials tested	Total Wt. loss of the electrodes	Maximum pitting in anode (mm.)
Burdwan	0·610 m.	C.I	77·0	0·152
		M.S	57·0	0·178
		C.S	46·0	0·025
		N.S	59·0	0·025
	0·915 m.	C.I	57·0	0·178
		M.S	59·0	0·076
		C.S	66·0	0·076
Saktigarh	0·610 m.	C.I	56·0	0·051
		M.S	66·0	0·152
		C.S	46·0	0·076
		N.S	41·0	0·038
	0·915 m.	C.I	45·0	0·178
		M.S	53·0	0·203
		C.S	39·0	0·178
		N.S	34·0	0·178
Chinsurah	0·610 m.	C.I	74·0	0·076
		M.S	77·0	0·406
		C.S	52·0	0·127
		N.S	59·0	0·051
	0·915 m.	C.I	64·0	0·127
		M.S	76·0	0·152
		C.S	52·0	0·025
		N.S	45·0	0·127
Durgapur	0·610 m.	C.I	43·0	0·025
		M.S	39·0	0·279
	0·915 m.	C.I	68·0	0·279
		M.S	54·0	0·635
Shibpur	2·440 m.	C.I.	37·0	0·025
		M.S	24·0	nil

method suggests the following mechanism of inhibition:

(1) The anions first displace the chemisorbed oxygen layer from the surface; and

(2) the chemisorbed anions are then displaced from the metallic surface by the inhibitor.

Corrosion inhibitors: Extensive studies have been carried out on corrosion inhibition at different laboratories in India. It has been proved that corrosion inhibition properties of urea and di-o-toluyl thiourea are excellent. Nicotinic acid and dextrin have been found to inhibit the corrosion of aluminium in hydrochloric acid. The inhibiting effects of colloids on the corrosion of brass have been investigated in detail. The inhibiting efficiencies of some of the colloids studied in decreasing order are:
Pulvi acacia, egg albumen, gelatin, agaragar, dextrin, potato starch.

The mechanism of inhibition was observed by polarisation studies.

Corrosion inhibitors incorporated in bentonite dispersions have been found to act as protective coatings against atmospheric corrosion.

Various vapour phase inhibitors have been investigated by using the tracer technique.

Oxide films: The formation and breakdown of oxide films have been studied by various workers and valuable information has been obtained on the condition of film formation leading to passivation.

Rate of film formation on metals and alloys: Experimenting on non-ferrous alloys like Cu-Zn and Cu-Mg alloys a new approach is postulated to quantitively represent the rate of film growth. By taking into consideration simultaneously all the functions representing the mechanisms of the growth of the film a quantitative expression governing the growth of film on Cu-Mg alloys is formulated. The laws of film growth in similar cases may be generalised on the same basis.

Cathodic potential of inhibitants: A concept of critical potential for inhibitors have been postulated below which a particular inhibitor cannot function. A new technique for the determination of critical potential have been evaluated.

Cathodic protections: A new method of assessing the value of externally applied current for cathodic protection have been evolved which is based on the simultaneous application of a spectrum of current densities on the metal surface using the Hull Cell technique.

Cathodic protection: The defence Research Laboratories in India have carried out useful investigations on cathodic protection with the aid of prototype set up, and has studied the different parameters involved. Cathodic protection of ships hulls are being studied at the Naval Chemical and Metallurgical Laboratory Bombay.

Research on protective coatings has been extensively carried out particularly by the Indian Railways and Defence Laboratories and valuable coating preparations have been standardised.

Various metal coatings made by electrodeposition, diffusion and surface conversion have been tried and standardised. Methods for the commercial manufacture of phosphating solutions have been developed. Mica paints which have high corrosion-resisting properties and suitable at higher temperatures have been prepared.

Organic coatings: Considerable work has been carried out on the formulation of paints based on Bhilawan nut and cashew nut shell liquid which confer good corrosion resistance and at the same time satisfy other specific requirements.

Various organic paints containing cashew nut oil have been patented which have improved qualities.

Temporary protective coatings: Methods for assessing the efficiency of temporary protective coatings have been developed and correlations between field performance and laboratory tests have been worked out. The Indian Standards Institution have classified the temporary protective coatings into eight categories based on the method of application and type of film obtained.

Immersed corrosion tests: Corrosion of aluminium and its alloys in acid and alkali solutions in the presence of different cations and oxidising agents have been studied.

Electron Diffraction technique: The oxidation of copper at different temperatures has been studied by the electron diffraction method. The oxidation behaviour of zirconium and zircaloy at elevated temperatures have also been studied.

Radio-active tracer technique: Radio-active labelled chromium has been utilised for studying the mechanism of corrosion inhibition by sodium chromate.

Corrosion-resistant alloys: Various corrosion resistant alloys have been developed which have good physical and mechanical strength in addition to corrosion resistance over prolonged periods of exposure. Mention may be made of the following:

(a) Tiscrom steels — These have high yield point and ultimate tensile strength with good ductility in addition to high resistance to corrosion.

(b) Tiscor steel — The corrosion resistance of this steel is 4 to 6 times that of ordinary mild structural steel, and 2 to 3 times that of corrosion resistance copper steel.

Low Nickel and/or nickel-free stainless steels have been developed by the National Metallurgical Laboratory, CSIR.

High Mn stainless and high creep and corrosion resistant steels have been developed at the Bengal Engineering College, University of Calcutta.

Corrosion Research in Indian Railways

With the adoption of the all-steel coach as the future standard, the corrosion rate became unexpectedly high on the panels of some coaches. Consequently, the Railway Board formed a departmental corrosion committee to go into the causes of corrosion and suggest remedial measures. The report of the committee was published in 1954. It recommended some immediate steps and also suggested some long-term measures including research on a number of problems.

In pursuance of the Committee's recommendations the Metallurgical and Chemical Research Wing of the Research Designs and Standards Organisations has undertaken a number of investigations and formulated several compositions. In view of the fact that the Indian Railway purchase about 2 rupees crores of painter's materials, stress has been laid on the utilisation of indigenous raw materials such as cashew nut shell liquid, bhilwan nut shell liquid, dehydrated castor oil, waste mica, indigenous tannins unsuitable for leather industry, bauxite residues, mineral wool from slag in railway iron foundries and so on.

There have been large-scale trials on the painting of wagons and bridges using red oxide zinc chromate primer in cashew nut shell liquid, a monopoly product of India, in place of red lead primer which is based on imported lead. Similarly, in place of red lead, which is expensive, toxic, and made from imported lead, indigenous red mud which is a waste product of the aluminium industry, has become a useful alternative inhibitive primer. Surface treatment compositions for ferrous surfaces have been evolved based on tannins and a surface treatment composition based on a mixture of myrobalan and goran tannins (indigenous tannins) has been found to be superior to cold phosphating and comparable to hot phosphating. This was in service trials more than two years. Preparations for codes of practice of rolling stock, bridges, structures etc. have also been taken up with a view to ensuring correct surface preparation, proper selection of paints, and correct methods for their application for getting maximum life and minimising corrosion troubles.

As a result of these, much progress has been made in the development of new materials from indigenous sources, most of which are covered by patents.

Some of the highlights of anti-corrosive work by the Indian Railways
Red mud — An inhibitive primer

The value of annual requirements of lead in India for manufacturing red lead of primers and white lead for finishing coats amounts to 8 million rupees. The lead compounds are made from imported lead, and are toxic. As an alternative, inhibitive primers have been developed using waste products of the Aluminium industry. At present there are about 40,000 tons of this material in India and disposal has become a great problem. It will thus find a good industrial application. Some locomotives have already been painted with cashew nut shell liquid compositions based on red mud. A number of wagons are under trials with such compositions, including zinc chromate.

Dispersion resins — A quick drying primer

It is now possible to make dispersion resins from cashew nut shell liquid; when it is mixed with inhibitive pigments like zinc chromate, it dries within half-an-hour. Thus surface coatings based on those containing zinc chromate have also found use as a coating for wagons where stencilling is required within a short time.

Non-toxic inhibitive primers

Red lead primer is used as an effective method of removing rust or paint from steel surfaces before painting. There have been trials with a number of non-toxic primers based on cashew nut shell liquid (CNSL) with indigenous pigments like red mud, combinations of red oxide, zinc oxide and manganese ore, zinc dust and zinc oxide, barium potassium chromate and red mud, some of which are successful and may be used in place of red lead where welding or flame cleaning is involved.

Substitutes for etch primers

Are manufactured from imported resin. It is now possible to stabilize water in oil type emulsions based on lehilwan nut shell liquid and chromic acid which etch, passivate and protect the metal from the elements by means of an overlying chemically bonded organic coating.

Corrosion of all-steel coaches$_2$
Nature of corrosion of all-steel coaches.

Corrosion has become an acute problem on the Indian Railways due to the introduction of integral steel coaches of welded construction and steel body wagons. Railway vehicles are subjected to various climatic conditions needing special measures for surface protection.

Painting is the universal method adopted for protecting steels panels from corrosion. Exterior painting protects the panels from rust, but if corrosion starts due to moisture condensation on the inaccessible inner surface of the panels, it remains undetected until the panelling is perforated from within. The extent of corrosion in certain locations (a) turn under of the side walls; (b) body side doors; (c) ends bottom side of rough floor, at paints immediately below the wheel become severe. Thus a long-lasting paint is necessary for application to the interior surfaces besides other necessary provisions.

Recommendations of the meeting at I.C.F. in June, 1959

To overcome these troubles, a meeting was held at the Integral Coach Factory in June, 1959, and the following recommendations were made.

"(1) Provision for larger openings in the turn-under for the effective drainage of accumulated substances and water;

(2) The interior of the area below the floor level to be grit blasted and given two coats of zinc-rich primer followed by a wash primer and the normal four coats of bituminous paint. If suitable paints of this type are not available, two coats of special zinc-chromate primer should be given underneath the bituminous paints."

Substitute for bituminous emulsion type

Bitumens in solution have some inherent defects such as embrittlement, temperature susceptibility, cold flow, non-adherence to wet surfaces etc., therefore water emulsions of bitumen are used by British Railways. Attempts were made to find Bituminous Emulsion types and a process for the emulsification of hard non-emulsificable.

Bitumen aluminium type

Bitumen has been developed using indigenously available cashew nut shell liquid and bentonite in presence of Phosphoric acid.

Compositions of CNSL resin and bitumen with 6% aluminium paste have also been developed for the anti-corrosive treatment of the inside of panels of all steel MAN coaches of Hindustan Aircraft Ltd.

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DISCUSSION

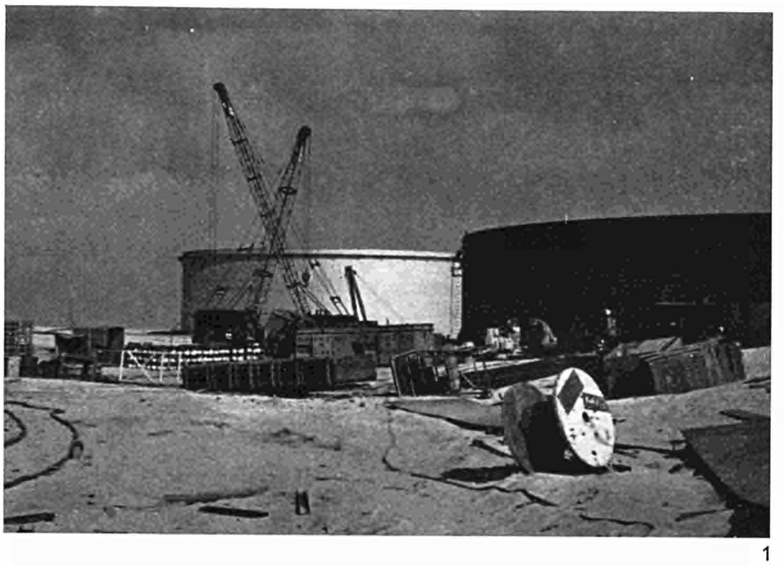
Marcel MAROY

(Translated from French)

Could a delegate at some future Congress perhaps be asked to state how closely Prof. Quintana's views are in line with the guiding principles of the U.N. Economic Commission for Latin America, the desiderata put forward at meetings of the Latin American Iron and Steel Institute and the subjects proposed for next year's Symposium on Industrialization at Santiago de Chili?

Before planning the construction of a steelworks it is always important to distinguish beforehand between ordinary steels and special steels (market research, production programmes, personnel, geographical location, power, and so on). Production of special steels should only be envisaged at a fairly advanced stage of industrialization, with appropriate, sustained and progressive technical assistance.

List of illustrations



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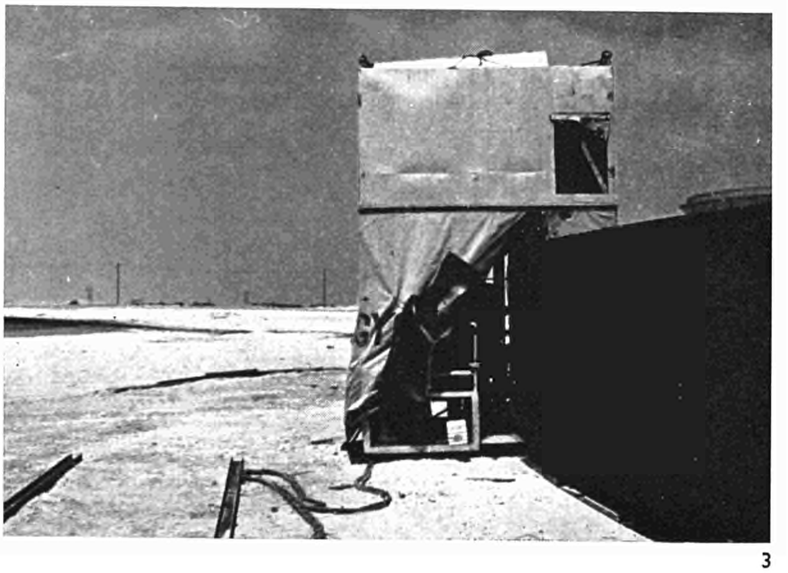

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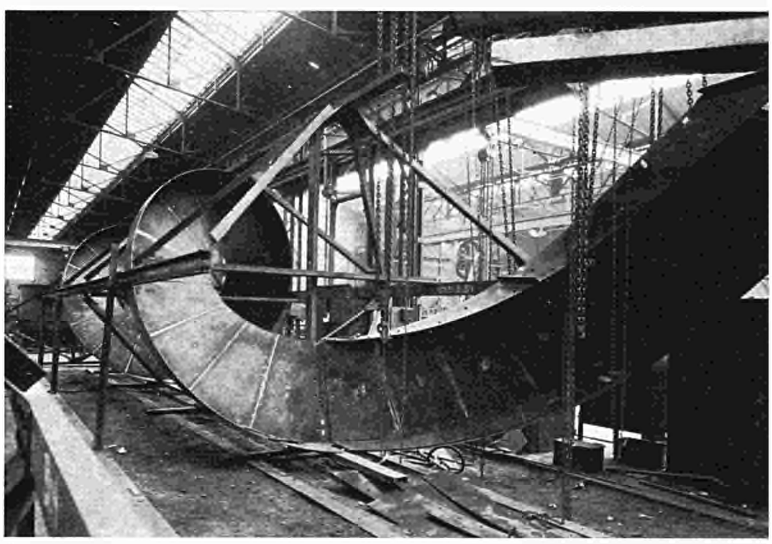

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3 *Closing Session*

Misha BLACK

Vice-Chairman of the Congress

Conclusions of Working Party I

That this Congress should have made industrial design one of the subjects of its discussions is an indication of the maturity of that new profession.

Those of us who are designers are conscious of the relatively small scale of our work. The design of a domestic refrigerator, a sewing machine, a hospital bed or even the body of a locomotive seems unimpressive when compared with the majestic problems of the design of supersonic aircraft or of a bridge, such as that elegant structure which is just being completed here in Luxembourg. But we take comfort in the knowledge of our concern with the needs of men and women, in our contribution to the daily life of ordinary people when they eat a meal from a saucepan which we have designed, or ride to work in a bus in the design of which we have participated. They may find their working day more agreeable because we have improved the ergonomics of a machine tool or the efficiency of a domestic vacuum cleaner.

The profession of industrial design is still comparatively young and much of our discussion therefore inevitably revolved round the problem of definition. We attempted to clarify exactly what the function of the industrial designer is, how his work relates to that of engineers and where he fits into the whole industrial complex.

The designers who addressed the meetings combined humility with self confidence. Their role, as they understood it, was to be concerned with the relation of the product (be it an automobile or a pre-fabricated dwelling) to the men or women who would eventually use it. It was the industrial designer's function to ensure that the product was not only efficient but that its outward form should clearly express the efficiency of its operation and manufacture; that it was easy to use, easy to maintain and beautiful within the limits imposed by mass production and by the character of the object.

These desiderata of efficient function, the fulfilment of human needs and elegant appearance are not achieved by industrial designers working in isolation. The discussion soon established that the designer can only work effectively as a member of the product development team, sharing responsibility equally with engineers and with management. The product development team, it was concluded, is incomplete if it does not contain an industrial designer amongst its other expert specialists.

Our discussions covered the whole range of human artifacts. We were shown examples of consumer goods and of capital goods in which proper collaboration between industrial designers and engineers have produced results which proved that our civilization has the capacity to use our industrial skills to fashion raw materials into objects which we can proudly compare with the handicraft work of previous generations. If, it was said, the best that we were shown could become the normal standard for design in industry instead of the exception, as it still remains, then we could be less worried about the environment which we are creating in this second industrial revolution.

We discussed the problem of automobile design where the role of the industrial designer is most clearly expressed. Vehicles, it was said, are the symbol of our epoch, the motor car is our "beloved monster," its design reflects our capacities and our weaknesses. We lavish millions of tons of steel each year on the production of vehicles, we need the best skills and creative abilities of our engineers and industrial designers to make our transport worthy of our civilization.

We were shown how designers are working for the railways to revitalize our more traditional transport systems, how they are equipping passenger ships and how their work on the interiors of aircraft can make air travel a pleasure instead of a penance.

The last session of our working party discussed pre-fabricated structures. It is here that the greatest potentiality for development resides. We were shown steel structures which matched the spider's web in their lightness and strength. We saw how prefabrication can produce homes and schools and factories in quantities, and at a speed and at a cost, which could eliminate overcrowding and make us contemplate population growth without foreboding.

Our speakers came from nine countries but if they did not share the same language, they shared the same attitude of mind. Industrial production is only of value if it fashions raw materials to meet the needs of people. design is an attitude of mind which engineers and administrators share with industrial designers. The industrial designer has been trained to make human hypotheses from technical and analytical data, he can be a link, between scientific and technical research and development, and the needs of our society.

But we remained conscious of our lack of experience before the vast responsabilities which face us, responsibility for creating the environment in which our children will grow to manhood. It was argued that more fundamental research needs to be undertaken in the education of industrial designers, in the techniques of their work and in the best use of raw materials and production processes. It was suggested that the High Autority might consider the establishment of research awards so that fundamental research projects could be undertaken on a European basis to support similar work which is already being done in some individual countries.

We reached no resolutions and even our conclusions were only partially defined, but those who participated in our Working Party are satisfied that we leave the Congress with more knowledge and with greater understanding. We return to our work more capable of doing it efficiently and for that we are grateful to the High Authority which made our meetings and discussions possible.

Albert DENIS

Vice-Chairman of the Congress

Conclusions of Working Party II

(Translated from French)

Steel is a cheap and plentiful metal with a high modulus of elasticity, and so usable for a great many purposes. But exposed to the surrounding atmosphere and temperature it is liable to corrosion by damp, taking the form, mainly, of rust, or at higher temperatures of scale. Some gaseous, liquid or igneous media can have stronger corrosive effects. In addition, steel's actual employment gives rise to other processes which impair its surface, such as grinding and binding. Hence the need for surface protection of steel used in such conditions, to enable it to retain its serviceability for as long as possible.

Until the last few years, corrosion-proofing was largely by rule of thumb. Nowadays, however, scientific methods are being used more and more, especially those based on the electrochemical approach to corrosion. The protection devices which we have heard described are of three main kinds.

1. Protection by replacing the surface of the steel itself by a more resistant coating, either of metal or of another material:

   (a) metal coatings discussed included in particular tin (notably tinplate), zinc (galvanized steel), aluminium and chrome;

   (b) non-metal coatings discussed included enamel, plastics, paints and hydrocarbons.

2. Cathodic protection, which can be done in a number of ways:

   (a) in the case of galvanized steel and tinned iron it plays an important part in the event of damage to the coating;

   (b) a separate magnesium or zinc sacrificial anode can be used;

   (c) it is also possible to provide direct cathodic protection using an external source of current.

3. Passivation, which brings the metal's own self-protecting properties into play, either spontaneously (stainless and passivable low-alloy steels) or by oxidizing surface treatment (priming coats, chromates, phosphates).

   The discussions served to emphasize

   (a) that the surface of the steel must be carefully prepared before treatment (involving checking at the plant) by fettling, sand-blasting, shot-blasting, nickelizing, decontamination (in the case of stainless steels), etc.;

   (b) that to obtain certain protections and certain forming properties the quality of the steel must be right: points mentioned included low carbon content, at any rate at the surface, the use of alloying elements (e.g. chrome, nickel, copper) as corrosion controls, and the use of titanium to help the enamel to cling.

Individual techniques were discussed in varying detail; the Working Party did not, however, dwell on methods in very common use, such as electrolytic chroming and nickelizing, or lead-coating.

With flat products in particular, which allow of continuous treatment, the processes employed necessitate special pre-protection, assembly and forming measures which were described in detail and discussed.

Speakers evinced a general tendency to favour the use of two or more protection processes in conjunction, in order to make good the deficiencies of each separately, notably galvanization prior to the final coating.

High temperature spraying with either metals (chrome) or metalloids (carbon, nitrogen, sulphur) is the principal means of giving the surface of steel the resistance to grinding and binding which it does not naturally possess.

The Working Party did not go into the extent to which the state of the surface affected the mechanical properties (brittle fracture, fatigue).

Thanks to the rapid technological advances resulting from the scientific approach to the problems, it is now possible to use thinner steels with thinner coatings, obtained by continuous or mass production.

In many cases, especially in building, the higher cost of properly corrosion-proofed steel is offset by the lower maintenance costs during service.

It is most desirable that producers, processers and consumers should co-operate, notably in order to get the properties required of the material precisely in line with the needs of the function it is ultimately to perform.

It was urged that specialists should be put in touch with consumers to impress it upon them that steel could be the answer to most of their problems.

The institution of a classification of testing methods established as being in line with the properties required in service was also felt likely to be extremely useful.

René PALMERS

Vice-Chairman of the Congress

Conclusions of Working Party III

(Translated from French)

In continuation of its campaign to promote the use of steel, the High Authority has this year invited us to discuss various aspects of "Progress in Steel Processing." In so doing, it has gone to the heart of the matter by stressing those aspects of steel's utilization that serve to make it economic, durable and pleasing.

My own Working Party's subject, "Cold Forming of Steel," has attracted a great many people, doubtless as raising new points in connection with fundamental problems which are too seldom aired and debated.

The papers and discussions have shown the immense value and importance of cold forming, both by the traditional bending and deep-drawing processes and by the more recent high-powered techniques using, for instance, the effects of explosive shockwaves and magnetic impulses. Hot and cold extrusion and drawing methods also merit attention, having the particular advantage of turning out new steel products and processing large amounts of metal.

Considerable advances have been made in the last few years in the study of the characteristic of steel plate and sheet for forming, resulting in substantial improvements in fabrication.

This research will undoubtedly enable us to gain a better understanding of the processes involved in the deformation of plate and sheet, to improve the quality of these products, and to expand their sales — a highly desirable consummation in view of the problems by the increase in world capacity in this sector.

All matters relating to cold forming are, incidentally, coming more and more to the fore in technology. Having learned to produce steels of greater and greater ductility for all kinds of uses, the steelmakers will need more and more accurate means of regulation and verification to ensure that these remain absolutely reliable in quality.

Demands are being made for an ever-widening variety of uses upon the metal's ability to assume given, sufficiently reproducible, characteristics through cold forming: the fact that it can do so has undoubtedly much to do with the constructional and civil engineers' tendency to insist on increasingly ductile steels, even for such everyday products as concrete reinforcing rods.

A number of valuable points came up in the discussions with regard to the use of various cold-forming techniques, and there was evidence of a new and forward-looking approach in a sector which had been in something of a rut for a good many years.

It was noted that building components made of cold-hardened metal would give a better performance, and that stricter and more scientific calculation would make products considerably more efficient and economic to use.

We now have an iron and steel industry which has notably extended the range of its products, as regard both the physical properties of the metal and the nature of the product itself, from the slenderest wire to the most enormously heavy beams and plates, and we have a processing industry which had radically renewed and added to its equipment, thereby opening up unlooked-for possibilities. Both have an interest in joint research on the quality of the product appropriate to each forming technique, and indeed to each individual application.

We all know that direct contact between steel suppliers and their customers is a means of dealing with these problems in a spirit of free competition, but at the same time, alongside this direct approach, our discussions have indicated the value of a more systematic exchange of information on progress in processing and in the goods processed.

To sum up, the Working Party would like to see the High Authority give practical support to the research going on in the Community on cold forming, cladding and the improvement of the metal's characteristics by cold working.

There are a great many points to be dealt with, including the changes needed in the regulations and accepted practice with regard to building in steel: this has got to be eased away from outdated rules and modes of calculation to enable steel to compete, as do the more recently-evolved building materials, on entirely new bases, taking advantage of the latest advances in civil engineering.

The High Authority could organize regular meetings of the specialists who are at present working on their own in the different countries; it could promote joint research in promising fields, and assist in disseminating their findings to the industrialist directly concerned. Publization, through specialized journals and popular treatises, of advances achieved would help to make generally known the techniques whose employment is calculated substantially to increase both steel's uses and its competitive capacity. In this way the High Authority would take a long step to further the process begun by the 1964 Congress, which first indicated the kind of co-operative action that could be taken by all those wishing to secure the most effective use of a material which lends itself to continual improvement and can be adapted to meet the most varied requirements.

The High Authority is to be congratulated most warmly. Its organization of this important occasion over which it has taken such care has been an illustration of the words put by Paul Valéry into the mouth of Socrates (Eupalines, ou l'Architecte):

> "It is fair to maintain that the works of man are designed either for his body, which is the principle we call utility, or for his soul, which is what he seeks under the name of beauty. Yet he who builds or creates, since he has to do with the rest of the world and with the processes of nature, ever acting to dissolve, to corrupt or to overset what he has achieved, must recognize a third principle that he must endeavour to infuse into his works, embodying the resistance he wishes them to offer to their destinated end of extinction. He seeks, then, solidity, duration."

There you have the very subjects of this Congress, a Congress placed in its true perspective by a mental approach according with the highest human thought.

Surely a happy augury. All credit for it to the organizers of this assembly: all credit and our very warmest thanks.

Ugo GUERRERA

Vice-Chairman of the Congress

Conclusions of Working Party IV

(Translated from Italian)

The subject of Working Party IV as you know, was "Modern Jointing and Assembly Techniques." The time allotted was of course very short for covering this wide and complex field, but the judicious selection of experiences described gave everyone a good idea of the countless potentialities of steel jointing and assembly methods, and especially of the evergreen viability of the method at present most widely used, welding, thanks to which steel construction has done better than would otherwise have been remotely possible.

The number of welding processes which have been evolved to overcome the immense variety of problems presented by the increasing complexity and boldness of building design is very considerable: there are as many as forty to fifty. Naturally we could not deal with them all, but the Congress did offer us the opportunity to pinpoint those of practical importance to the majority of constructional engineers.

I must also mention the other jointing and assembly techniques of which we were given such interesting accounts, namely adhesive bonding, the latest bolting methods and hooking, which in many cases can undoubtedly be extremely valuable. One matter came up on which quite a number of researchers and technologists have been working for years, the implications of the brittle fracture which has tended to occur at low temperatures under comparatively slight stresses in some big welded constructions carried out before and during the war.

The substantial improvement in the properties of steel thanks to unremitting research, and the adoption of specific precautions, have greatly reduced the danger of brittle fracture in welded structures, so that this is now extremely infrequent, but since the question is still very much exercising many of our technologists and scientists it was only to be expected that it should be brought up at the present Congress, where it was the subject of two interesting papers and a lively debate.

A well-known problem which was further emphasized in the course of this debate was the diversity of criteria as regards the properties required of steel in relation to the design and purpose of the structure concerned. It is not really surprising that there should be these differences, since despite often very large-scale experiments, and much study and research by eminently qualified specialists, we still have not entirely plumbed the mysteries of brittle fracture in steel structures.

It is agreed by all that standard criteria in this connection would be most desirable, particularly as the trend is towards bolder and bolder design, stronger and stronger steels, and greater permissible stresses.

Since basically these differences of view stem from continuing fundamental uncertainties, I feel it is important to step up pure research on the subject. Such research is already going on hard all the time, and each year at the annual meeting of the International Institute of Welding leading technologists and scientists discuss the matter very thoroughly in one of the Institute's working parties. As a furter stimulus to this research, E.C.S.C. might usefully organise at fairly long intervals, say every three years — perhaps jointly with the Institute of Welding — a symposium or seminar to serve as a forum for progress reports in this connection.

The present Congress has undoubtedly proved of the greatest interest to those taking part. All the same, it is felt that perhaps its terms of reference were too wide, at any rate in the case of Working Party IV, and accordingly my Working Party have urged that at future information Congresses of this kind attention should be concentrated on particular fields of application for steel, such as for instance the chemical and petrochemical industry, which is regarded as an especially worth-while sector to discuss.

Also, it was recommended that longer time should be given, to permit of really full discussions on the subjects dealt with.

I personally should like to suggest that in selecting the theme there should be consultation with other international bodies, and more especially with the International Institute of Welding, so that we shall not find ourselves with two organizations discussing similar subjects within a few months of one another. Because, inasmuch as the E.C.S.C. Congresses are focused mainly on steel, the moment they touch on its practical uses the subject of welded joints is bound to crop up to some extent of its own accord.

In conclusion, I should like to say how glad we all are that the Congress was held, and to thank the High Authority for organizing this most interesting occasion and for the generous hospitality it has extended to us.

Gaston THORN

Chairman of the Special Committee

Conclusions of the Special Committee

(Translated from French)

Our Committee was asked by the High Authority to consider the subject of steel consumption and utilization in tropical countries, and in emergent countries generally. The High Authority was, of course, aware that we could not deal in detail with all aspects of this matter. I imagine that what it wished us to do was to review, or rather to take stock of all these, to make a wide general survey, and this our special Committee of technologists, politicians and economists duly did. To my mind the great item to the High Authority's credit is that this year for the first time it has instituted a dialogue with the authorized representatives of the mergent countries. It is perfectly natural that these questions should extend beyond the purely technical into the economic and political spheres.

To start with, on the technical side, we did of course touch on the subject of corrosion, though this was dealt with on a much more expert level by M. Denis's working party. It was naturally recognized that corrosion is not a problem peculiar to tropical countries, but, as was pointed out in one paper, since in Africa in particular the major cities, and hence the largest centres of steel consumption, are usually near the coast where the air is especially humid and salt, corrosion there tends to be particularly fast and intensive. Also, as the emergent countries do not produce their own steel, the iron and steel products needed for use have to be stored for long periods and so are exposed to corrosion some time before they are actually employed, with the result that the corrosion effects are a good deal more serious still.

We also discussed a good many other technical problems, concerning which I propose to give only a brief outline. One subject dealt with was the tremendous impact produced by an earthquake on constructional steelwork in certain tropical areas, and it was noted that for the exceedingly accurate calculations which this made necessary work was now in progress on the drawing-up of international rules to ensure sound constructions and indicate the permissible stresses and forces in the light of the earthquake hazard. We were also greatly pleased to hear that Prof. Naka, to give us all the benefit of his extensive experience, was leaving a record of his work with the Congress organizers for later study in detail. We then turned to the economic aspect, which we discussed from the angle of the development drive; every one of us, I think, felt and wished to emphasize that there was no conflict between the needs of the European or other highly-industrialized countries wishing to export and the desires of the underdeveloped countries seeking to industrialize.

It was the view of us all that the solution lies in close co-operation between the industrialized and the emergent countries. We noted that some Latin American and African countries in some ways complement our own, since they have substantial labour reserves and so can concentrate on labour-intensive industries, while the industrialized countries are relatively short of labour and are thereby obliged to rely more on capital-intensive industries. Some steel-processing industries would be particularly suitable for the introduction of the kind of co-operation referred to by Prof. Quintana, provided certain factors could be got over, such as the economic difficulty of having a wide range of iron and steel products available in the countries concerned, the high cost of components needing to be manufactured or imported in unduly small quantities, and the use of complicated assembly techniques making too great demands for the existing technical level of labour and equipment. Accordingly, we think it would be desirable to have a very thorough study carried out — if only within the High Authority — of possible ways and means of simplifying, if not actually standardizing, the construction and even the basic principles of certain machine tools so as to reduce the number of different parts used to make them, and simplify their manufacture, assembly and installation.

Co-operation of this kind would not reduce the industrialized countries' export potential — far from it — since all progress in industry necessarily means increased requirements of iron and steel, which the industrialized countries' export potential will be able to meet.

To conclude, we were not able to discuss all the aspects in detail, nor, in particular, to consider appropriate ways of furnishing the capital and capital goods so essential to the emergent countries. Since this question is altogether bound up with the much wider subject of industrialization, our Committee would have been departing from the terms of reference assigned it by the very fact of its organization as part of a primarily technical Congress.

At the same time, we owe a debt of gratitude to the High Authority for enabling accredited representatives of the African authorities to establish contact on this occasion with industrial and other circles from the more industrialized countries, in order to start things moving among all those concerned. We feel that, on this year's showing, the High Authority could well go further and arrange for a Committee of more clearly-defined scope to embark at the Congress next year on a fuller discussion of the various problems which on this occasion we could do no more than briefly and incompletely enumerate.

Franz ETZEL

Chairman of the Congress

Closing Address

Mr. President of the High Authority, Your Excellencies, ladies and gentlemen, the Second Steel Congress is over. We have three days crowded with work behind us, but three days crowded, too, with human contacts, three days of generous hospitality. And so I think I must begin my closing address by expressing appreciation. First, to my Colleagues the Chairmen of the Working Parties and of the Special Committee. You, gentlemen, more than anyone else have borne the real burden of the proceedings: you sifted and clarified and summarized the lengthy, detailed debates, the proposals, the suggestions, the exhortations.

My thanks go next to the rapporteurs, whose preparatory work laid the foundations for the Congress, the initial basis without which the discussions — those in many cases refreshingly lively discussions — could not have got under way. And in thanking the rapporteurs I must also thank all those who took an active part in those discussions.

But I am sure that, in particular, I speak for you all when I emphasize to the High Authority itself, and more especially to you, Mr. President, how deeply and sincerely grateful we are for this outstanding occasion. The second Congress, like the first, was your own personal idea, and it must rightly be a satisfaction to you to see what favourable response it has evoked.

We were honoured by the presence of the whole High Authority at the great reception yesterday, where many new bonds of friendship were formed and existing ones renewed. Mr. Linthorst Homan of the High Authority and the panel of judges at the Film Parade on Wednesday brought it home to us how in steelmaking today man and plant stand in a new relation to one another, and can bring betterment to whole regions. We owe a debt of gratitude too to M. Reynaud, whose observations on the technical and economic aspects of steel processing traced out the basic concepts of our work here. And we must thank Dr. Hellwig and the High Authority's Working Party on Market Questions, who were responsible for the organizational side.

Again, I would pay warm tribute to all those helpers, including the Luxembourg public servants here at the Congress and in the background, and to the man in overall charge, Director-General Peco, who have so admirably succeeded in organizing and running the intricate machinery of an international and multilingual technical Congress. The Grand Duchy and the city of Luxembourg, in which the European Coal and Steel Community has been happily settled for thirteen years, have taken a keen and friendly interest in our activities, as was most notably demonstrated by the gracious presence of their Royal Highnesses the Grand Duke and Grand Duchess at our opening session.

The Luxembourg Government, too, most kindly held an imposing reception in our honour, which offered an excellent opportunity for making one another's personal acquaintance. And it was a special pleasure to me to see in our midst at the official opening M. Joseph Bech, Prime Minister of Luxembourg until his retirement a year or two ago, and a founding father of the Community; he stands, with Robert Schuman and Jean Monnet, Alcide De Gasperi and Paul-Henri Spaak, Dirk Stikker and Konrad Adenauer, as one of the men who with boldness and vision laid the foundation for the unification of Europe. They were the leading statesmen of an important period, who took coal and steel as a start for the building of Europe.

Even a technical Congress such as this is ineluctably called upon to make its own substantial contribution to the political unification of Europe. I do not look upon it as simply an advertisement for steel. You spoke, Mr. President, in your opening address of a public demonstration of "European community" or "European togetherness." I feel that now at this time, when frost has formed not only in the physical world around us but in the field of European politics too, the High Authority's second Steel Congress is giving fresh proof that the will to European agreement and co-operation is still very much alive.

We know that the world of tomorrow, with space travel, supersonic flight, nuclear power, automation, has made the earth so small that only the union of Europe can save us from turning into an underdeveloped and declining area. The present Congress has given concrete expression to the resolve of many Europeans to create new basic facts by working together in co-operation, to pool our knowledge, our skill, our strength in order to win our way into the future. And only by going on creating such basic facts whall we succeed in progressing towards our goal.

We have at the Congress 1,100 delegates from 44 countries. These are impressive figures. I am particularly glad to see the younger generation so strongly represented. They are the ones who will have to carry on our work.

But to me the measure of the Congress's success is above all the tremendous number of discussions and contacts. Since the subjects of the Congress were of two kinds — the specifically technical subject of surface treatment, assembly techniques and cold forming, and the comprehensive theme of industrial design — these contacts have resulted in a most valuable cross-fertilization of ideas between the steel production and processing technologists and the designers.

It was not the object of the Congress to move resolutions, issue manifestos or formulate purely philosophical reflections, but to spur the producers' imagination, to convey new insights, and so to open up wider horizons for steel. Obviously, all the specialists present would know their own particular jobs backwards: the great point was to enable a host of technologists and researchers normally working on their own to open up to one another and to evoke a mutual response.

As for the Special Committee, its proceedings clearly indicated that the technical problems posed by the use of steel in tropical climates were not so very different from those in our own. Very much more important to my mind is how to set about promoting the use and consumption, in a word the natural acceptance of and familiarity with steel in the countries now about to embark on industrialization. A number of sensible points were made to the effect that it was not a matter simply of constructing a blast-furnace, converter and rolling-mill on the equator (an aspect with which the Congress was in any case not concerned): what was needed was a broad-based drive to accustom the people and the economies of these countries to steel so that they would be able to benefit by our own standards of technology.

Perhaps the High Authority will consider what can be done to meet this urgent need for elementary technical knowhow. For only when it is met will steel be able to fulfil there too its function as a basic element in human progress.

I shall not attempt to recapitulate and evaluate the individual findings the Chairmen of the Working Parties have just outlined for us. I am not a technologist. But remembering the first day and what Mr. Swanson told us about the advances in knowledge obtained through American space research, I cannot but feel Europe will have a harder and harder job keeping up with the technological, and hence the economic progress of the United States. For financial reasons alone we shall have to join forces if we are not to become an underdeveloped area. The Americans are setting their sights higher than we are. In thinking big, the headaches are big — but the results are big too. We have got to listen to the voice of common sense: not, for us, war as the begetter of all things, but systematic, large-scale joint research. And that includes space research, the results of which can be turned to very great account in quite different and often remote technological and economic fields. Instances have been given us here of the ramifications it can have right into articles of everyday use.

I confidently entrust the many suggestions adumbrated at the Congress into the hands of the High Authority. They may not all mature. The High Authority has to select and decide within the context of the possibilities open to it. I would urge that it follow up the ideas that have been mooted and cultivate the contacts that have been established, both with individuals and with organizations. After all, it is impossible to get along without organizations in this administration-ridden world of ours.

Another point which has been borne out by this Congress is that real progress is still today the work, as Prof. Jeanneney has said, of individuals — I would add, and of individual groups. Team work is quite obviously essential also in such connections as the new methods of market strategy, as has been emphasized to us, among other things, by Working Party I.

I do not propose to offer any recommendations, But everything that has been said in the Working Parties seems to me to indicate that the continuity of the work begun last year should be ensured. It will remain for the High Authority to institute the proper machinery for handling this multifarious and growing task.

If now at the conclusion of the Congress, Mr. President, you ask me whether the occasion has been a success in this respect also, I feel certain all those who took part will support me when I say, unquestionably, yes. And if you ask me how the High Authority can best act for the furtherance of steel consumption, I will tell you in two words: "Carry on".

Dino DEL BO

President of the High Authority

Closing Speech

M. Chairman of the Congress, Your Excellencies, ladies and gentlemen, at the conclusion of the first Congress last year, the High Authority was a trifle afraid that—to use a steel men's term—the whole idea of holding such congresses was an unduly brittle structure, and that to prepare a second was asking for trouble.

We have carefully followed the proceedings on this second occasion, we have listened to the technical findings, and in particular we have weighed with care the summing-up the Chairman has just given us. We feel we can fairly conclude that from the High-Authority's point of view the second Congress represents a successful outcome to its endeavours and an encouragement to continue.

Since it falls to me to express the thanks which are due also, for its part, from the High Authority, may I first and foremost express them to you, Your standing in political affairs, your knowledgeability on the various sectors of the economy, above all your humanism, have helped to impose on this Congress—which may passibly have appeared at the outset rather too composite—the genuine unity which, by the time of its successful termination, it possessed.

We are grateful. For the rest, I would simply underscore what you have said as to the debt of gratitude we owe to Their Royal Highnesses, to the Government and administrative authorities of the Grand Duchy of Luxembourg, to the Press, who have given and are giving us their understanding and, where necessary, their active co-operation: to all those, in a word, who have, with ourselves, created the requisite background for the Congress to prosper.

But one word I would say of special appreciation, and on my side indeed warmth, to the staff of the High Authority so many of whom are present here today.

During the past year, the High Authority itself has striven unremittingly, as it must, to fulfil its many and demanding constitutional obligations, difficult and sometimes politically delicate though these are. And during that year the entire staff, from the Directors-General—and especially the Director-General for Steel—down to the executive grades and to our long-suffering secretaries, have for many months given hour upon hour to the preparation of the Congress. I feel their devotion is evidence yet again of a true European-mindedness to which they unfailingly respond. With the merger of the three Executives drawing near, I would here formally state that those in charge of the future single European Executive must bear in mind the inalienable rights of the High Authority staff, and honour these as is their due.

Our Congress this year has been attended by representatives of non-European countries, almost all of them countries in process of economic development, and many but lately arrived at political and national independence. None of them ranks as a major steel producer, although many are enthusiastically working and planning for the installation of adequate steelmaking capacity for their people too. The Chairman of the special committee on this subject has rightly emphasized that in this field political and economic problems take precedence of the purely technological side. And since such constructive contact has been established at the Congress between technologists and producers from the industrialized and representatives of the emergent countries, I would urge the former not to feel the least disquiet at seeing the newcomers forging, for the most part irreversibly, towards industrialization, and more particularly in this instance towards the construction of their own steel plants. Even within highly-industrialized countries we have seen how the industrial working-up of the more backward regions, if carried out with tact and sense, accrues also very practically to the good of the rest.

In my view, the industrialization of the emergent countries offers us and those coming after us in Europe the prospect of many years of financial activities, economic co-operation and technical assistance to ensure that alongside the betterment of conditions for the emergent peoples will go solid economic benefits to the producers of the countries already industrially developed. For that reason I feel this first encounter, serving mainly an exploratory purpose, should be carried further, here and elsewhere, to the end that the non-European and especially the emergent countries may profit by the High Authority's discharge of one of its regular duties, that of helping, by assembling and disseminating all possible relevant information, as the Congress now ending has clearly shown, is closely bound up primarily in the six member countries, but also by so doing in every country in the world.

And speaking of information—one of the High Authority's most binding tasks—I would emphasize that we plan to press ahead on this, while fully aware that at a certain level the work of information, as the Congress now ending has clearly shown, is closely bound up with the work of research.

Research, which may be divided under the two main heads of "pure" and "applied" research—or, if you prefer, of scientific and technical research—is today one of the great focal issues for the statesmen of Europe and for all those who recognize that, if democratic Europe is to retain a leading role in political councils, it must make up without delay, technologically and industrially, the leeway between itself and certain of the major industrialized countries beyond its borders.

To revert to the theme of the present Congress, I think I may add that the Directorate-General for Steel should be given definite instructions by the High Authority to initiate, promote and co-ordinate applied research, this being after all the form of research which more immediately concerns those present at this Congress and, in particular, more coincides with the High Authority's own aims and functions. I do not mean that the High Authority could or would seek to take the place of the big research centres and university science foundations of which the Europe of the Six has happily so many: I mean simply that its job is to try to see that the mass of research activities and projects do not clash or compete but complement one another, in order that European research may have the greatest possible impetus and the greatest possible prospects of success.

The point has been made that this Congress is not an end in itself, but like its predecessor must prompt the High Authority to further action. Some steps, as delegates are aware, have been taken, but they will have to be followed up by others, since, as Mr Etzel has urged, they are to lead on to a third Congress.

The complexities and inevitable difficulties attaching to this will require further study by the High Authority, but—since our decisions are necessarily taken collectively—for my part I engage to propose to my colleagues that we officially decide that the second Congress shall be followed by a third, and that Luxembourg shall remain the regular venue for such occasions, wherever the merged Community Executive may ultimately be installed.

At the present Congress we have sought, by setting going exchanges of views which may on occasion have taken a polemical, or at any rate an argumentative turn, to establish all possible contact between researchers, technologists, producers and, in particular, consumers.

We felt this to be the best composition for the Congress, since not only did it bring the co-operation of a wide range of individual energies, but also it was the basis most calculated to help achieve the essential aim of a steady increase in the use of steel in Europe and in the world. This is a point to be borne in mind in settling the theme of the third Congress. The chemical and petrochemical industry has already deputed its distinguished representatives to ask that the next Congress should deal particularly with the use of steel in this immensely important sector of basic industry. I consider this a suggestion meriting most careful thought, though of course it must be remembered that there are other major industries—transport, for instance, and agriculture —in which steel is being employed more and more, and in which wider and wider possibilities are opening up for its use in new connections. So it may well be that the third Congress will note the existence of manufacturing industries where expansion is in ull swing and making for a sustained increase in the use of steel; it may well be that the third Congress will deal with steel utilization in the growth sectors. Among other advantages, this would enable us to have the steel consumers still more fully represented. Such is after all our main aim: we want the steel consumers to be in the closest possible contact with the High Authority, at least as close as are the producers through their national representatives; we want them to stand not, as they appear to do, as merely marginal operators in this sector, but in the centre, as consumers of that indispensable product by which the iron and steel industry, so basic to the economy, can continue ever to the fore.

Such, to my mind, must be the legacy to us of the second Congress — a legacy we are bound to view in the light of the political developments, not all of them happy ones, through which the Europe of the Six is now passing. Since reference was made just now to the work of Paul Valéry, may I too paraphrase some lines of this greatest of modern French poets.

This occasion we have organized, and all the other acts of high endeavour by our own and by our sister Communities in Brussels, are intended to show to the world that, though the wind of this Community crisis is blowing, the Communities are out to live; they know that their vitality will carry the day against the uncertainties of men, the polemics of politicians, the resentments of nation-States, they know that their labours of love and faith will in time be the starting-point for renewed and ever more constructive progress. I think that, entirely irrespective of nationality, both the Europeans and the non-Europeans present agree with us that the active survival of the Communities is indispensable if Europe, having already achieved economic integration, is to turn that integration into a genuine unity and to take that unity as the basis for subsequent political integration. However, this is perhaps taking us beyond the scope of what I am here to say. I think we can end here, each of us returning to his own responsibilities — the researchers to their centres and universities, the producers to their plants and workshops, the consumers to their industrial and business activities, and we ourselves, with our staff, to the pursuit of our Community task. All of us, each in his own place, can claim to have done and to be doing our part toward getting over this undoubtedly bad patch.

As this second Congress draws to its close, our thoughts go also to one who was here with us last year, Paul Finet, a Member of the High Authority from its inception and for a while its President, who died some little time ago.

I think it fitting that we should recall the example of a man who, having given his youth and middle age to the democratic organization of working men, spent the last years of a great-hearted life directing and taking part in the activities of the High Authority.

I would also pay tribute, along with him, to those others of our number, at all levels, who are with us no more. I do not think this is a melancholy note to strike: it is, after all, one of the facts of human existence, which we have no right to seek to evade. However, since life must go on, may I say, Mr Chairman, that the High Authority will very shortly, in all probability at its next meeting — on November 10, if I remember rightly — take cognizance of the findings of the second Congress.

You may rest assured that it will take full account of the points which have been urged upon it yesterday and today, and that your rightful expectations will not be disappointed: the third Steel Utilization Congress, so far from being a "brittle structure", will be if humanly possible a completely sound and solid one and an outstanding success.

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