Fundamentals of the small steelworks

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SYNOPSIS

The paper discusses various factors affecting the location of small steelworks, the sizes of which are defined. Energy requirements for different manufacturing processes are considered. A short analysis of fundamental factors affecting the design of a steelworks to produce 50 000 tons/a of finished bars or sections is given, and highlights the economics of mechanization and profit on investment. SR78H

INTRODUCTION

THE DEVELOPMENT during the last twenty years of continuous casting, the extension of the use of the electric furnace into tonnage steel manufacture, and the ever increasing use of oxygen steelmaking techniques have all contributed towards making economically possible the installation of small steelworks.

For example, a small steel plant to make 80 000 tons/a of small diameter rod 1in–½in in alloy steel quality, working 17 shifts per week, would cost about £4·5 m. including heat-treatment and other bar-finishing facilities. An annual profit, using the continuous casting process, of £780 000 after depreciation could be anticipated. Using small ingots, however, the profit would fall to £192 000. This is a special case with a high-priced product, but it serves to illustrate the extra profit which can result from (*a*) 6% extra yield, together with (*b*) the capital saving of the heavy mill and soaking pits as against the lower capital cost continuous casting plant and (*c*) the conversion cost saving in the pit side.

The purpose of this paper is to highlight some of the fundamentals that must be considered in assessing the viability of such small steelworks. But first the meaning of the term 'small' must be defined.

A few years ago 1 m. tons/a, corresponding to 150 tons/h, was considered the smallest economic size for an 'integrated' steelworks. Today 3 m. ton works are not only planned but in existence, with corresponding hourly rates up to 450 tons/h. It may be misleading to define a 'small' works by its annual output, as such an output may be achieved on a large plant by de-rating and working less than full time. It is suggested, therefore, to define the size of the works in terms of average hourly output under sustained conditions of operation. On this basis a 'small' works might be defined as one whose capacity is normally up to 25 tons/h, and in certain cases possibly up to 50 tons but not more. The middle range 50 to 150 tons/h covers works which may be considered as enlarged 'small' works or works of intermediate size, possessing certain special economic justification but generally less intrinsically efficient than the fully integrated works.

Reverting now to the consideration of small works making iron or steel primary products, in relation to the traditional form of development of an agricultural into an industrial country, a pattern emerges. Sand foundries can be economically operated at production rates of 2 or 3 tons/h upwards. So also can light forges and drop-stamps shops. Cast-iron centrifugal pipe-spinning plants customarily range from around 15 tons/h to about double that capacity. Wire-rod mills and simple 'cross-country' or continuous mills for producing round bars, merchant bars, and light sections from billets, billet-sized ingots or continuous-cast billet-sized stock range from 10 to 25 tons/h; but more sophisticated mills with roughing facilities to take 1½-ton ingots range up to 50 tons/h, and begin to merge into the territory of intermediate size.

In sheet production small mechanized 'hand' mill plants consisting of one 3-high breakdown and several 2-high finishing mills rate around 10 tons/h, but the reversing Steckel mill brings it up into the 30 tons/h range, which is about the limit of the small works in this field.

THE PATTERN OF INDUSTRIALIZATION

The early growth of industrialization in any hitherto agrarian country generally follows a certain fairly well defined pattern.

First comes the demand for hand tools and simple agricultural machinery, e.g. spades, shovels, picks, ploughs, harrows, etc. Such tools and simple implements may be produced from imported steel bars in simple smithies and small sand foundries.

As yet the need for power mechanization of agriculture has not made itself felt. Or, if felt, it can only be supplied by outside aid; and this is a recent development which introduces external factors which may profoundly alter the normal traditional course of development. Coincident with the use of improved tools comes the demand for improved dwellings: the enclosure of land, the growth of small towns and the setting up of small urban industries. These, in their turn, create a demand for rolled steel concrete reinforcing bars, for steel structural sections, for fencing posts and wire, light castings and forgings, iron pipes and steel tubes for carrying services and disposing of waste.

Once small towns are developed, communications follow. These create the requirement for heavy structurals for bridges and the demand for rails, whilst communications, when they are established, encourage industrial growth creating the demand for more heavy structurals for factories, offices, banks, hotels, blocks of flats, and other massive buildings.

These developments are inter-reacting and self-energizing so that at this stage urban development and the pressures of social demand for a higher standard of living encourage the construction of factories. Factories, in their turn, demand special castings, high-quality drop-stampings and forgings, special bar steel from which machine parts can be machined, special steel for cutting tools, special steel for dies, non-corrodible steels and heat-resisting steels.

If we consider the particular case of India, plants to meet the early requirements for castings, shaped forgings, concrete-reinforcing bars, wire rods, light sections, iron pipes, and steel tubes are well established. The integrated steelworks in the Public Sector of the first two plans, and corresponding developments in the Private Sector, have

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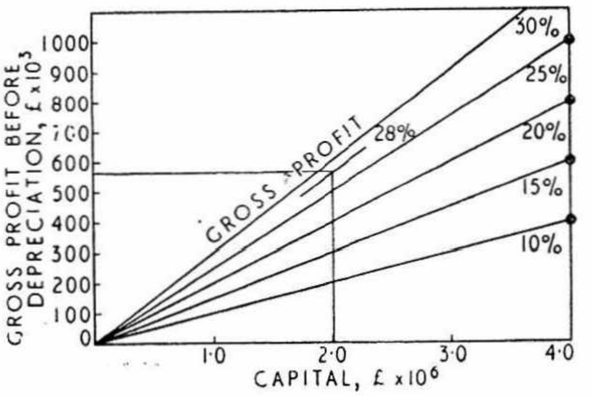
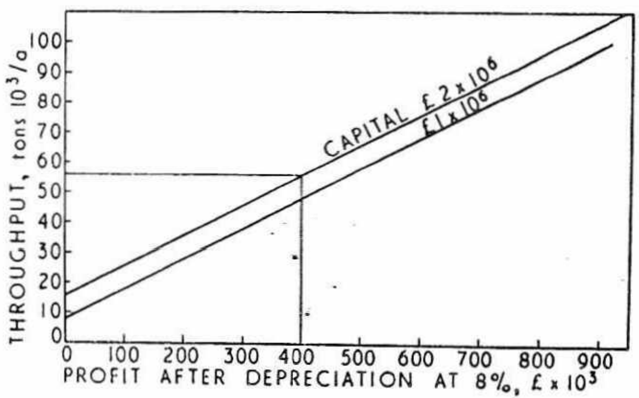


1 *Gross profit before depreciation* v. *capital invested*



2 *Profit after depreciation* v. *throughput, for notional £10/ton profit*

increased the production of 'tonnage' steel or 'common' steel by a factor of about four.

The most modern plant is in use for production of heavy structurals, billets for re-rolling, light bars and sections, heavy plates and sheets, and the time has come for a corresponding development in the facilities for making special steels for the construction of machines, as well as the steel to make tools and the machines necessary to breed further machines; in fact, to develop an alloy steel trade. But parallel with this is the additional need for the installation of small steelworks to serve isolated local demands, particularly in a country the size of India, and also to make the 'specials' required by a rapidly diversifying industrialization.

GENERAL CONSIDERATIONS AFFECTING LOCATION OF STEELWORKS

In an industrializing country the centres of iron and steel production tend first to develop at strategic points close to natural resources.

The traditional ironmaking area in England in the Middle Ages was in Sussex, where oak forests provided a source of charcoal for smelting. Later the opening up of the coalfields, and the ability to smelt lower grade ironstones, developed ironmaking in the midlands and in the north of England, whilst the water power from fast-flowing streams coming off the hills was used to operate tilt hammers, which was a significant factor in developing the Sheffield forging trade.

Corresponding developments in India centre around the coal in the Damodar Valley and the Orissa orefield, whilst in Mysore traditional iron smelting was also based (until quite recently) on charcoal fuel.

In more recent times, however, other factors beyond the location of raw materials have combined to produce an overriding effect upon the location of iron and steel plants all over the world, as well as in the United Kingdom.

The basic pattern of all iron and steel industry is generally : iron-ore to blast-furnace, iron to steelmaking process, steel to hot-working process, and steel products to consumer. Eventually steel products deteriorate, and steel scrap becomes available in quantity. Cold metal steelmaking then makes its appearance.

The economy of any iron and steel industry is, therefore, based upon iron ore, scrap, fuel and water, using 'fuel' in the widest sense of the word to embrace both 'energy' and carbonaceous reductant.

The factor of distance between producer and consumer is an important one, though not so significant in the UK as in the USA where distances are such as to lead to the situation where, at one time, it was cheaper to import seaborne steel into the west coast than to use rail-borne home-produced steel from Pittsburgh, with the result that the west-coast steel industry developed. It would seem that the similar development of a west coast iron and steel industry is not wholly impossible, under like conditions, in India today.

In the UK a variety of factors has influenced the choice of sites for steelworks. For instance, Stewarts and Lloyds Corby works and the Appleby-Frodingham works of United Steels are both located on home ore fields to which coal is imported, whilst the Steel Company of Wales Margam works, and Richard Thomas and Baldwins Llanwern works, are sited so as to facilitate the landing of imported ore.

Round Oak steelworks and the Patent Shaft steelworks in the 'black country', in the midlands of England, both employ the cold metal process, and are situated in the centre of a heavily industrialized area which produces some 800 000 tons/a of scrap.

The Jarrow re-rolling mills were established to combat unemployment in that area, in spite of the fact that the billets to feed the mills had to be transported at least 30 miles. In this case social considerations overcame economic requirements.

Whilst, hitherto, the London area has not been considered suitable for heavy industry, a new steelworks is now being planned on the south bank of the Thames, primarily to utilize the scrap arising in the area, and to meet local demands for steel bars and light sections.

The circumstances conditioning the siting of the three new steelworks at Durgapur, Rourkela, and Bhilai are well known, whilst the logistics relating to the siting of further new steelworks in India are now under active consideration.

ECONOMIC CONSIDERATIONS

In a developing country the first step in initiating an investigation into the need for an industry is to investigate the demand for the products of that industry.

Any industry, whether it be nationally sponsored for strategic or social reasons or initiated by private enterprise to meet market needs, is fostered by finance and metered by costs. Sooner or later someone, somewhere, must answer the questions : 'How much is the project going to cost?' and 'What profit can we, its backers, hope for?' Immediately one asks these quantitative questions the problem must be dimensioned. What is the size of the industry that the population can support and what is the size of industry the people can afford?

It is always difficult to enunciate general principles which, while broad enough to meet all fundamental requirements, can yet evaluate individual problems with such accuracy that the results are meaningful. The data which follow have been developed from the detailed consideration of certain specific cases.

The first essential in dimensioning an industrial undertaking is to decide what return on capital justifies the investment.

The profit on the undertaking is the difference between the value of sales and the manufacturing costs, less amortization of plant. Amortization usually averages around 8% on total fixed assets, being the weighted average of 2% on buildings and foundations and 10% on plant.

Figure 1 shows the plot of gross profit before depreciation against capital invested, with a family of straight lines corresponding to percentage profit ranging from 10 to 30%. Postulating an acceptable profit after depreciation of 20%, this means that £560 000 must be earned on an investment of £2 m. in order to yield a gross profit of 28% before depreciation, or £400 000 after depreciation.

Figure 2 shows the profit after depreciation plotted against throughput for a notional £10/ton net profit. The family of straight lines shows the plot corresponding to various capital values.

From these graphs it will be seen that the particular project under consideration must have an annual output of 50 000–60 000 tons to be economically viable.

In Fig. 3 the value of sales and works costs are plotted against output. A capacity of 56 000 tons/a has been assumed, with a selling price of £40/ton, so that the total value of sales will be £2 240 000.

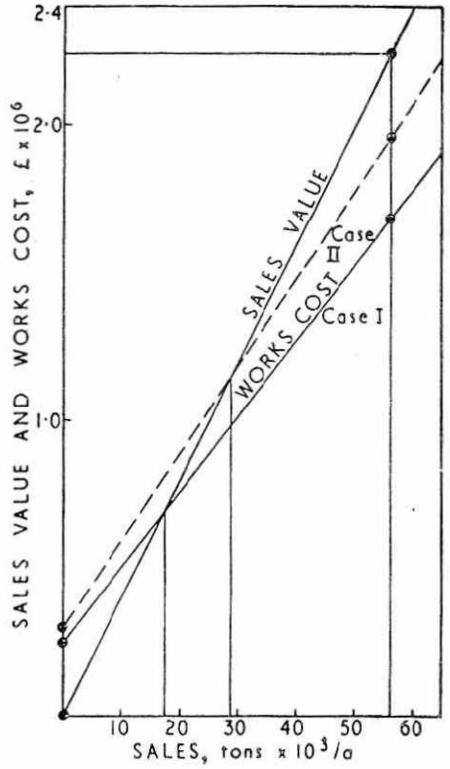
Standing charges on such a plant are likely to be of the order of £250 000, and anticipated profit before depreciation an average £10/ton making a gross annual profit of £560 000 and an equivalent works cost of £1 680 000/a. It will be appreciated, however, that the output of the works, and hence the standing charges per ton of product and the profit, will vary with the product mix being rolled over any particular period.

Under the conditions postulated the works will break even at 17 500 tons/a production, equivalent to 30% capacity (case I). But if, for example, the standing charges went up to £300 000 and the profit fell to £5/ton, then the break-even point would rise to around 55% capacity (case II).

The works location must now be considered in relation to supplies of ore, scrap, fuel, water, and labour; and the varying incidence of these factors may influence, probably critically, the method of manufacture to be selected. For a small works the most difficult problem is often one of raw materials, since there may not be available an economic supply of either pig iron or scrap. Such a shortage need not, however, prove insuperable. Depending upon raw material costs, a 12 ft dia. blast-furnace, or other plant, might be considered. It is estimated that such a small blast-furnace installation including raw materials handling facility, sinter plant, pig casting, and engineering would cost annually about £58/annual ton of liquid iron but, even with such a capital charge, the furnace might be economic in appropriate circumstances. Its adoption depends, however, upon the supply of suitable coke, itself something of a problem in India, and if a good grade metallurgical coke is not available other methods of production must be considered.

A modification of the conventional blast-furnace, the lowshaft blast-furnace, is one such alternative if the available coke has not sufficient crushing strength to support the burden. This type of furnace might alternatively be operated on 'char' produced either from soft coal or lignite.

Assuming that an ample supply of cheap electricity is available, then an electric smelting furnace could be installed for a capital cost around £28–£32/annual ton of liquid iron. The lower figure is for a single large furnace, and the higher for two small furnaces. In both cases the index includes raw materials handling facility, pig casting and engineering.



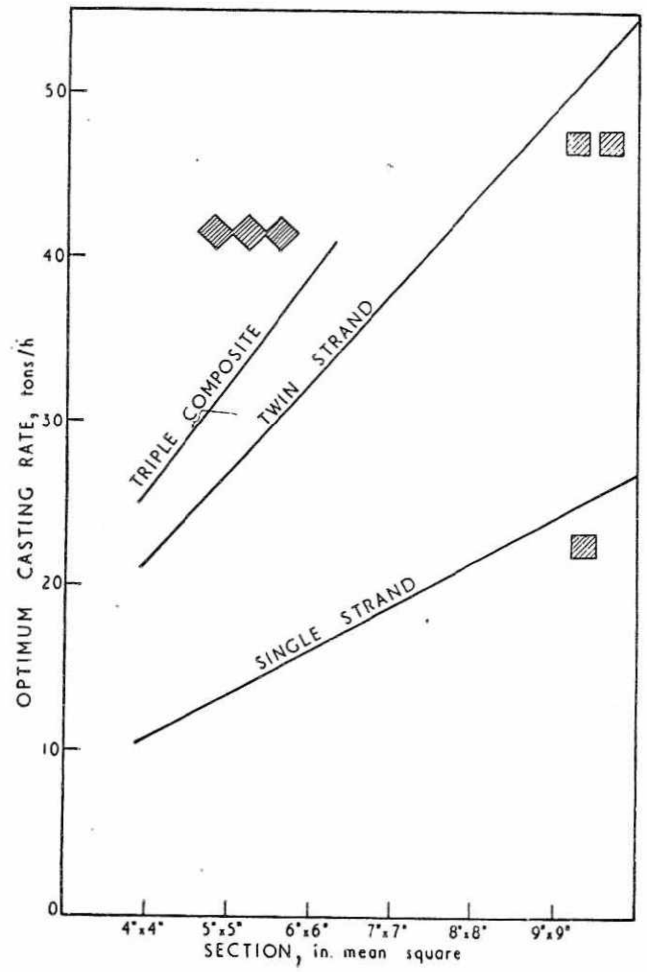
3 *Value of sales and works costs v. output*

Another alternative is a sponge-iron plant; the cheapest capital cost of such a plant would be about £12/annual ton of sponge iron, but the investment cost more often ranges from £15 to £25 or more per annual ton. Such sponge-iron plants can be operated on solid fuel, natural gas or gas generated from oil; and the relative operational costs of different processes in any given circumstances must be carefully evaluated.

The theoretical requirements of carbon for iron reduction, in the form of metallurgical coke (or other suitable carbonaceous reducing agent), are of the order of 5 cwt/ton of iron reduced; but, in fact, the blast-furnace normally requires some 12–16 cwt of coke per ton of iron to cover its heat requirements; and a shade over 10 cwt is the practical minimum target for the largest furnaces under the most favourable conditions.

An electric-arc furnace requires about 8 cwt of coke, coal, char, or other convenient carbonaceous reductant, and around 2 350 kWh of electrical energy. Equating the electrical energy against coke on a direct thermal basis, this is equivalent to an overall quantity of 5 000 kWh or about 14 cwt respectively. On the count of direct thermal efficiency there is, therefore, little to choose between them, though other considerations may determine the choice without question. The economic changeover-point between the blast-furnace and electric furnace on an energy basis depends upon a variety of local factors. In general it may be said, however, that at $4½ mils (2 nP or about 0·4*d*) electric smelting has the advantage. At $6 mils (3 nP or about 0·5*d*) the economics are marginal, and at 1*d* (5·5 nP or $ 11·5 mils) electric energy for smelting is not for serious consideration.

In such straightforward electric smelting, 60% of the total energy has to be supplied in the form of electricity,



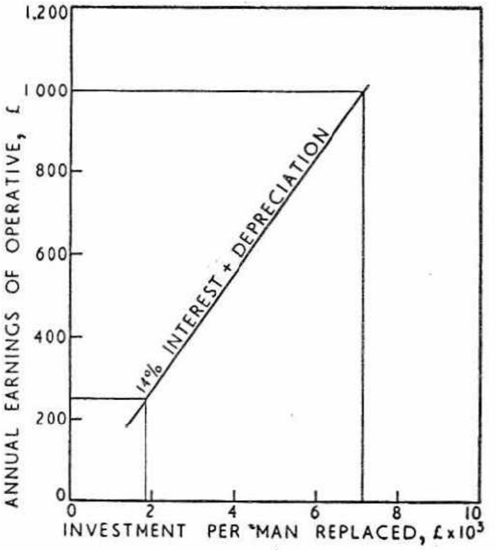
Casting speeds in tons/h for individual pieces and composite billets as indicated

d the corresponding electricity requirement is of the
der of 0·45 kVA connected load per annual ton of iron
oduced, i.e. a furnace of 9 000 kVA nominal capacity
required to produce 20 000 tons/a of iron.

Between the blast-furnace on the one hand, using 100%
ke, and the straightforward electric furnace on the
her, taking 45% of its total energy requirements in the
rm of electricity, lie a number of intermediate solu-
ons to the problem. For instance, by collecting the
rnace gases and using them to 'pre-reduce' the iron
e in a kiln, the electricity consumption can be almost
lved. Since the solid fuel in such a process can be
most any form of chemically reactive carbon of reaso-
ble grain size, this compromise may be exceedingly
tractive when metallurgical coke and electricity are
short supply, though the capital cost of the installa-
on will be increased by the cost of the kiln. If natural
s is available, then practically the whole requirement
n be supplied in this form.

The intention, at this stage, is simply to indicate that
ithin the general parameters indicated above, there is
nsiderable scope to adapt the iron ore reduction pro-
ss to the forms of energy economically available; and
detailed economic study should be made in each case.

We will now consider the next stage: that of pro-
ucing steel from iron. If the iron is available in the
olten state, one of the relatively recent oxygen steel-
aking processes should be investigated. The economic
ge in these processes derives from the fact that the
rbon required for heat generation is already present in the iron, and it is necessary only to supply the oxygen to burn it.



5 *Annual earning of operative v. capital invested in mechanization*

On the other hand, if only cold pig iron, sponge iron, and/or steel scrap are available, then a combination of cupola melting and pneumatic steelmaking, open-hearth melting, or electric arc furnace melting provides the answer. The basic requirement for electric arc melting may be expressed as around 600 kWh of electrical energy per ton of steel or iron melted.

If electricity is available at a price equivalent to around 1*d* (5·5 nP) or less, the lower capital cost of the installation and its greater flexibility in operation makes the electric furnace preferable to, say, the open-hearth. But electric power must also be available in sufficient quantities. Nominal connected load requirements for straight melting common steel range from 0·18 kVA/annual ton in the smaller furnaces to 0·165 kVA/annual ton in larger furnaces, with corresponding figures of 0·33 to 0·27 kVA for low sulphur and phosphorus 'quality' steels made by the slower double-slag method.

When dealing with the ensuing liquid steel, it has already been shown that the continuous casting process has many advantages which outweigh the casting of the steel into ingots for the manufacture of blooms or billets for rolling into bars and sections, though free-forming forging presses and certain tube mills will continue to use ingots.

Electrical connected load requirements for the rolling of steel are of the order of 0·05 to 0·07 kVA/annual ton of production. Rounding this figure off to 0·10 kVA/annual ton includes an average allowance for auxiliary requirements. Thus a steelworks to produce 50 000 tons/a of common steel by the cold metal process would require a minimum of 15 MVA of installed capacity, or more than 25 MVA if required to produce the same quantity of 'quality' steels. In addition, a further 10 gal of oil/ton of steel, or equivalent solid fuel, is required for reheating the blooms or billets in the rolling mill.

The use of any method other than electricity for driving the rolling mill is not for serious consideration, except in cases where grid power is not available, whilst the adoption of electrical energy for direct or induction heating of ingots and billets is an alternative which may be worth considering wherever relatively cheap electrical energy is available.

A vital service requirement in any steelworks, irrespective of the forms of melting, reheating and rolling adopted, is that of water. The circulating water requirement for an electric arc furnace is of the order of 2 000–3 000 gal/ton of steel produced. A continuous casting machine requires some 2 500–4 000 gal/ton of steel cast, whilst medium and small section rolling mills may require as much as 8 000–12 000 gal/ton, including such variables as the use of fabric bearings, scale flushing, roll cooling, high pressure descaling, etc.

Thus it is necessary, in a steelworks producing a postulated 50 000 tons/a, to deliver water to the electric furnace and rolling mill installations at a rate of the order of 100 000 gal/h, and to the continuous casting plant at a rate approaching 150 000 gal/h. The combined make-up requirements may be at least 5 000 gal/h, i.e. around 2¼ tons water/ton steel. In most cases it will, therefore, prove necessary to make a careful study to compare the costs of piping sweet water over possibly a considerable distance, on the one hand, with the costs of recirculating, cooling, and perhaps filtering the circuit water, on the other.

The means of cooling, whether by spray pond, forced or induced-draught tower, are also a matter for careful study in a country where high wet-bulb temperatures, coupled with periods of calm, occur during the critical months preceding the monsoon.

The above index figures per annual ton of production assume the customary full utilization of the plant, and must be adjusted to specific local conditions.

CONSIDERATION OF A TYPICAL SMALL STEELWORKS

If we assume manufacturing procedure as follows:

Scrap
↓
Electric furnace
↓
Continuous casting plant
↓
Billet stock
↓
Reheat
↓
Roll to finish size

the overall yield in such a works would be: 93% from scrap to liquid steel; 96% from liquid steel to billet; 92·5% from billet to finished bar, equivalent to an overall yield of about 82%.

Such a works would require 61 000 tons of scrap, making 57 800 tons of liquid steel, to produce 50 000 tons of saleable product per year. The capital cost of the plant would depend to some extent upon how the plant was to be operated. For example, working a continuous week of 21 shifts assuming 90% availability of steelmaking plant, and allowing three weeks for holidays, the net rate would be 7¾ tons/h. Since the average time for a heat of steel (single slag) in the electric arc furnace is 4 h, a 30-ton furnace is indicated, although a single furnace plant is vulnerable, and with continuous casting the whole 30-ton heat would have to be cast in about 45 min at a casting rate of 40 tons/h.

The casting speeds in tons/h for a number of sizes are shown in Fig. 4 for individual pieces cast singly or twin strand, and for composite billets cast as a single piece comprising three such billets, or blooms. As a machine to cast a triple billet is not much more expensive than one to cast a single billet, the lower capital cost per ton of steel cast by the composite method is clearly indicated.

It will also be seen that 7in × 7in blooms would have to be cast rather faster than is normally desirable in order to reach the required rate of 40 tons/h through a twin-strand machine, whereas this rate can be comfortably achieved with a triple 6in × 6in bloom. On a 45-min cast the casting machine will actually be in use for rather less than 1 h in every four, and the balance of the time is more than sufficient to make ready for the next cast. In fact the machine could cast twice every 4 h if the molten metal were made available.

The next question to be answered is whether a 6in × 6in or 7in × 7in bloom can be rolled down in one reheat by a mill of economic size, to such dimensions as will meet the smallest sized product that is to be offered for sale. One inch square is likely to be the smallest size required either for forge or bar trade, with much of the demand lying around 3in square, so that a 20in roughing stand followed by a train of 16in finishing stands will be sufficient. With a standard bloom feed, these could conveniently be 3-high mills.

At this stage the availability of the items of plant should be considered. It has been assumed that the melting unit is occupied gainfully for 90% of the total time. On the other hand the mill can roll a 10 ft bloom from 7in × 7in to 1in × 1in in about 5 min. That is at a rate of 9 tons/h compared with a steelmaking rate of ¾ tons/h. It follows that the mill can keep pace with the melting shop, working a week of 18 shifts, at 77% utilization. If, on the other hand, the works was making concrete reinforcing rod at 1in to ⅜in dia., then the 7in bloom would be too large, and a 4in billet would be required. This immediately limits the melting furnace size to 10 tons capacity, and necessitates the installation of three such furnaces. The mill might be any one of the following types:

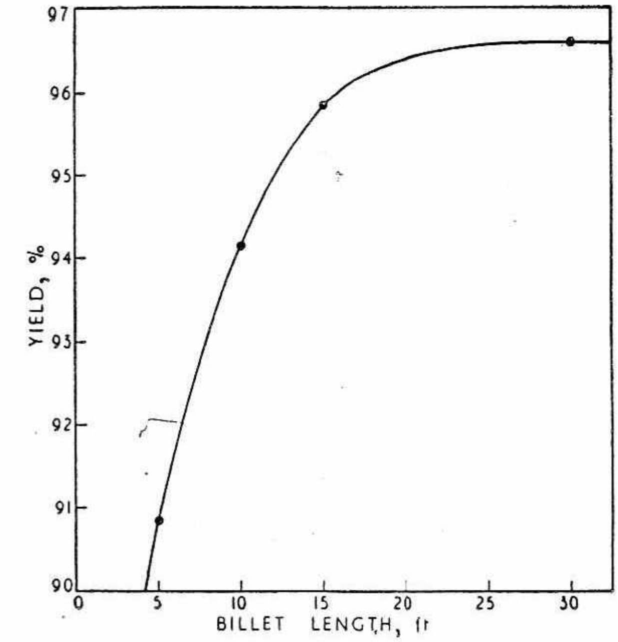
(*a*) Belgian, 'cross country'; (*b*) straightaway, or continuous mill; (*c*) combination of (*a*) and (*b*).

The length of billet to be rolled should next be carefully considered.

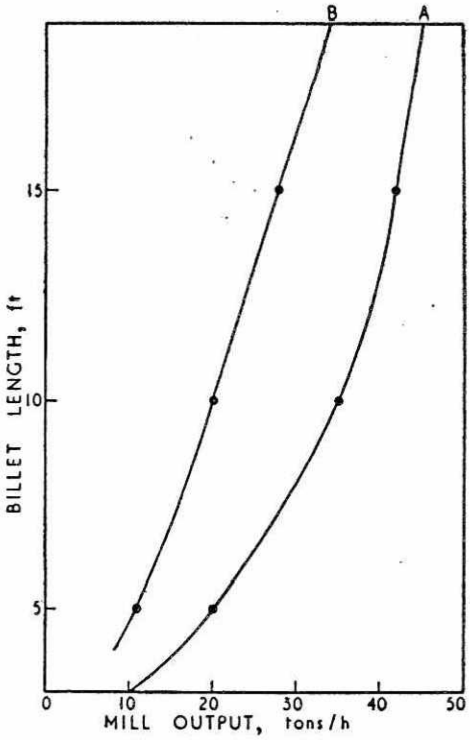
Without mechanization a man can handle about 250 lb weight of steel billet or bar, and offer it to a mill. This represents only a 5 ft length of 4in square billet, and the question of the mechanization of the mill must be considered. For example, in a mill designed to roll 50 000 tons/a, 1% increase in yield as a result of mechanization represents 500 tons more material for sale. Postulating a notional £10/ton profit, this additional production would be worth £5 000, which means that if the return on capital is fixed at 20% before depreciation, a sum up to £25 000 can economically be spent on mechanization to secure this 1% yield.

The extent to which mechanization to replace manpower can be gainfully adopted in a steelworks may be examined by reference to Fig. 5 which plots the annual earnings of an operative against the capital which can economically be invested in mechanization to replace him. It will be seen that if it is necessary under local conditions to pay an operative £2 000/a then, with loan interest at 6% and depreciation at 8%, the grossed up cost is equivalent to a sum of £7 150, so that the investment of such an amount in capital equipment to replace this operative will have a nil overall effect on the company's profit. If on the other hand the cost of mechanizing the particular job is less than £7 150 (say £6 000) then the company profits to the extent of the combined interest and depreciation on the difference in capital between £7 150 and £6 000, namely on £1 150, equivalent to £160/a.

If the operatives earn only the equivalent of £250/a, the corresponding break-even investment to justify their replacement is around £1 800 each.



6 *Increases in yield with increase in billet length*



7 *Increase in mill output with increase in billet length*

No account is taken here of other advantages of mechanization such as faster operation, less down time due to personnel fatigue etc. which express themselves as a lower capital investment per annual ton of output.

Billet length exerts a significant effect upon productivity. Figure 6 shows how the yield increases from 91% to 96% with an increase in billet length from 5 ft to 25 ft, whilst Fig. 7 shows how, in a certain case, the mill output similarly increases from 10–20 tons/h (for a 5 ft billet) to 30–40 tons/h with a 15 ft billet.

The actual example taken for the construction of Fig. 7 is the case of a 5in × 5in billet rolled to 3in × 3in or equivalent area, curve *A* assuming a total manipulation time of 30s and curve *B* a total manipulation time of 60s. In practice, however, complications with the reheating furnace roof, and the necessity to consider a suspended roof, set an economic limit to the increase in billet length which, in installations of the type here being considered, is around 15 ft.

The reduction in area from bloom or billet to finished bar or section determines the number of passes required for the mill to perform its work. In general, the greater number of passes required for rolling a light section demands a higher production rate for the mill. Otherwise the stock will be excessively chilled. For example, a 4in × 4in billet can be rolled into a 3in × 1½in channel in nine passes, which could be readily done in a two-stand 16in 3-high mill. On the other hand if the same billet is to be rolled into a ⅜in dia. rod, then about eighteen passes are required ; and this involves a continuous mill, or at least a continuous finishing train, in order to get the material through the mill before it cools too much.

The relationship between billet size and finished product, and the rolling sequence, will determine the physical dimensions of the mill layout and the choice of special equipment. The more diversified the product the more difficult the task of choosing equipment that will be of general use throughout the range; and there is a limit beyond which the initial process equipment diverges into individual process channels, each suitable for finishing only a section of the final products.

From the arguments and examples given in this paper it will be appreciated that having first established the viability of a scheme, a series of approximate calculations will serve to show how an effective economic compromise between capital to be invested and anticipated return on capital can be obtained by variants of plant layout and product range.

Having thus planned the project as a whole on fundamental lines, the way is opened to consider specific items of plant and the detailed layout and detailed engineering of the plant.

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