NATIONAL METALLURGICAL LABORATORY

ANNUAL REPORT

1958-1959

COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH

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JAMSHEDPUR, BIHAR, INDIA

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FOREWORD

I HAVE great pleasure in presenting the Report of the Director, National Metallurgical Laboratory, for the year 1958-59.

The National Metallurgical Laboratory has now entered its eighth year and is enlarging its activities in many directions closely allied with problems of direct interest to Indian mineral and metal industries.

The Laboratory's research, development and pilot plant programmes have been oriented to meet the requirements of general expansion of metallurgical industries during the successive Five Year Plans of the Government of India. It is heartening to note that more and more emphasis is being laid on the development of pilot plant projects. The Low-shaft Furnace Project which was mentioned in the last year's Report has made further progress. The Pilot Plant was inaugurated by the Hon'ble Sardar Swaran Singh, Union Minister for Steel, Mines and Fuel, early this year and is now in operation yielding valuable data on the use of non-metallurgical fuels for smelting iron ore. Other pilot or semi-pilot plant projects which have made further progress during the year relate to ore-dressing, thermal beneficiation of low-grade ores, production of steel by the L.D. process, aluminizing of steel wire and sheets, refractories and electrolytic manganese and manganese dioxide.

Research on fundamental metallurgical problems has continued during the year. Considerable fresh ground has been broken and consolidation of the work already in hand has been *pari passu* with the development of various pilot plant projects. An atlas for Indian steels is being prepared on the study of isothermal transformation characteristics. Quench-ageing and strain-ageing of some Indian steels, phase studies on electro-deposited alloy, structure of carbides in alloy steel, preferred orientation in rolled sheets, study of sigma phase in alloy steels are among the many fields on which work has been carried out. I would commend the creditable efforts put in by this Laboratory in having fabricated a number of laboratory scientific apparatus and pilot plant equipment which have saved valuable foreign exchange notable amongst which are the vacuum fusion gas analysis apparatus for the determination of gases in alloy and plain steels, apparatus for the micro determination of hydrogen in steels of the order of 0·000005 per cent hydrogen, equipment for studying the comparative life of electric resistance and heating alloys, special set-up for accelerated fatigue test, vertical gaseous reduction and horizontal rotary furnaces for upgrading low-grade ferruginous manganese ores and apparatus for hot stage microscopy for studying high temperature phase equilibria of refractories, glasses, slags and cements.

Further valuable development work on nickel-free austenitic stainless steel has been undertaken during the year and tonnage steel ingots and sheets have been produced. The sheets have shown deep drawing qualities and corrosion resistance against specific media. Likewise, work is being actively pursued on nickel-free coinage alloys, nickel-free electrical heating elements and nickel-free manganese brasses. I also find that useful work has been taken in hand on the development of clad metals and bi-metals, production of magnesium by electrolytic method from magnesium chloride and by vacuum distillation technique using dolomite.

During the year under review, the Laboratory has taken several patents and today it has a total of 36 patents to its credit. I would like to make a special mention that some of these processes were released free of royalty for the benefit of the industries and periodical demonstrations were held to provide technical ' know-how ' of these patented processes.

From the large number of enquiries attended by this Laboratory and short-term investigations undertaken on behalf of the industries, it is apparent that considerable importance is being given to technical aid to small and medium scale industries as a means of solving their problems. The Liaison and Information service in general to industries and the government bodies have been enlarged both in scope and in actual service rendered. The Laboratory is to be congratulated for bringing out the N.M.L. Quarterly Technical Journal which should provide a forum for disseminating scientific data from various investigations and projects undertaken in the Laboratory.

Early this year, as in previous years, the National Metallurgical Laboratory arranged a symposium on ' Iron and Steel Industry in India ' which was inaugurated by Prof. M. S. Thacker, Director-General, Scientific and Industrial Research. The Laboratory has always enjoyed the support and goodwill of the Director-General, Prof. M. S. Thacker, who has taken a keen personal interest in its affairs.

In the ensuing years, the pilot plant projects should yield data of considerable value and many new schemes of importance would be undertaken. I am glad that the National Metallurgical Laboratory is occupying a prominent place today amongst the National Laboratories of the country which are making their usefulness felt in various spheres of national activity. Much of the credit goes to the hard work and organizational ability of its Director, Dr. B. R. Nijhawan, and his colleagues. I am sure the Members of the Executive Council and others would join me in placing on record our appreciation of their commendable and excellent work as well as their devotion to research.

J. J. GHANDY
Chairman
Executive Council of the
National Metallurgical Laboratory

Jamshedpur
August 13, 1959

INTRODUCTION

With the inauguration of the 15-ton/day pilot low-shaft furnace, one of the largest pilot plants established anywhere, the National Metallurgical Laboratory has now embarked upon the implementation of research results and pursuit of pilot plant projects on current metallurgical subjects of vital importance. The field thus vigorously enlarged relates to the development of nickel-free stainless steel, nickel-free coinage alloys, production of electrolytic manganese and manganese dioxide on a substantial scale. Steel, by oxygen injection technique, has been made for the first time in India on a pilot plant scale, in the L.D. oxygen converter at the National Metallurgical Laboratory. Semi-pilot plants for beneficiation of low-grade manganese ore went into operation treating almost a ton of ore per day. The pilot plants relating to aluminizing of steel wire and refractories, thermal beneficiation of ores, etc., are now also taking shape. Work on raw material assessment for the new steel plants, studies on Salem iron ores concerning their beneficiation, reducibility and sintering characteristics have also been done.

The year under review has, therefore, been one of intense and ceaseless activity attacking problems of direct development interest to industry. Fresh ground has been broken in pursuing work on low-alloy high tensile structural steels, electrical resistance alloys for heating elements, development of clad metals, bi-metals, production of magnesium by electrolytic method from magnesium chloride and by vacuum pyrometallurgical technique using dolomite; production of ferro-alloys and high manganese nickel-free coinage alloys and manganese brass based on electrolytic manganese made at the National Metallurgical Laboratory. Considerable emphasis has also been given to fundamental problems such as, on the study of isothermal transformation characteristics, quench-ageing and strain-ageing of some Indian steels, phase studies of electro-deposited alloys, structure of carbides in alloy steel, mechanical properties of stressed materials, preferred orientation in rolled sheets and study of lattice parameter of iron-chromium alloys, study of sigma phase in alloy steels, development of short-time fatigue testing method, etc.

Mention should be made of a number of scientific equipment that have been fabricated by the Laboratory, such as, vacuum fusion apparatus for the determination of gases like oxygen, hydrogen and nitrogen in metals and alloys, apparatus for the determination of elastic constant of metals by ultrasonic excitation, apparatus for hot stage microscopy for studying high temperature phase equilibria of refractories, glass, slag, cement, etc. It goes without saying that foreign exchange worth several lakhs of rupees has thus been saved.

The liaison and information service to industries and government bodies has likewise been considerably enlarged both in scope and actual service rendered and is full of activity rendering useful service within and outside the Laboratory. As much as 200 technical enquiries were attended and 20 short-term investigations and specification tests were conducted by this Laboratory on behalf of the industries. Such investigations have not only helped the industries to solve their difficulties but have also resulted in efficient production.

Early this year, a modest beginning was made in creating a link between the industry and scientific organizations by the inauguration of a quarterly technical journal. The response to this journal from advanced metallurgical and scientific organizations in the world has been not only inspiring but also encouraging. Mention should also be made of the other publications such as the proceedings of the Symposium on "Recent Development in Foundry Technology" organized by this Laboratory and also on the monograph embodying the valuable work done on the beneficiation of low-grade manganese ores. Similar monographs on Indian foundry moulding sands and bonding clays including bentonites and on upgrading of low-grade chrome ores are under preparation.

During the year under review, the following patents have been filed:

(1) A process for recovering zirconium dioxide from zircon
(2) Improvements in or relating to hot-dip aluminizing of steel
(3) An improved method for the production of Cr-Mn alloys by alumino-thermic reaction
(4) A process for electrolytic production of Fe-Cr alloys from chromite ore

Patents for the following processes have been applied:

(1) A process for the production of chemically bonded metal clad or unclad basic refractories
(2) A process to produce carbon pastes for use in the continuous Soderberg electrodes of electric ferro-alloy furnaces and electric cells used in the manufacture of metals like aluminium

Non-technical notes on the following patented processes were prepared and circulated to the interested parties:

(1) Refractory compositions comprising graphite and alumino-silicate materials and glazes to render such compositions resistant to oxidation
(2) Improvements in or relating to hot-dip aluminizing of steel
(3) Improvements in or relating to mullite refractories from kyanite
(4) A process for the stabilization of dolomite and a method of making refractory bricks from stabilized dolomite
(5) A process to produce dense carbon aggregates from carbonaceous materials of varied volatile contents
(6) Hot-dip aluminizing of ferrous materials
(7) Improvements in or relating to magnesium silicate refractories and use of the same

Early this year, the Director of this Laboratory, Dr. B. R. Nijhawan, was deputed by the Government of India as an official Member of the Steel Delegation to China and Japan for studying the iron and steel industry in those countries. Besides studying the salient features of the integrated steel works and machine building plants in China, the Director observed the working of small blast furnaces with a view to examine whether these could be adopted to Indian conditions in supplementing production from large steel works, particularly in areas which have considerable reserves of iron ores but are far remote from the sources of metallurgical coke.

Collaborative research is continued to be maintained with scientific organizations and Railway Testing & Research Centre and ordnance factories. Efforts are being made to make substantial portion of the Defence requirements in respect of strategic ferro-alloys, magnesium, etc.

A brief résumé of the highlights of important problems under progress is given in the following pages.

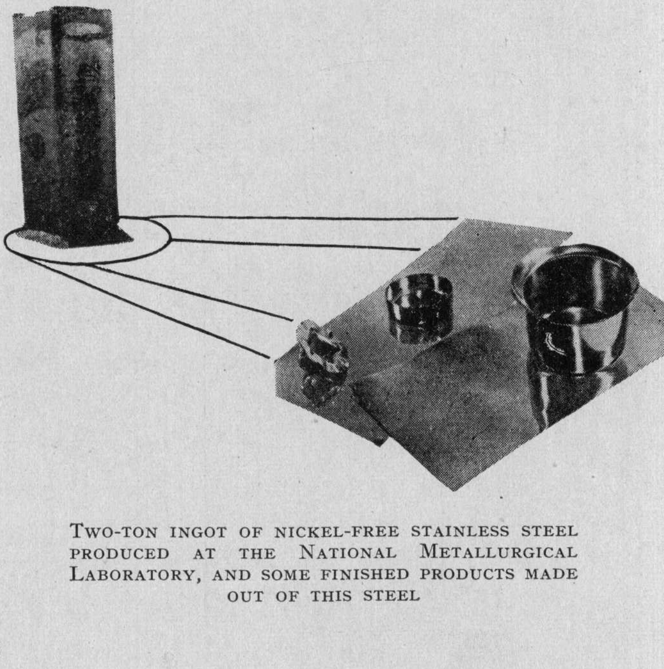
RESEARCH PROJECTS

1.0 Nickel-free Austenitic Chromium-Nitrogen-Manganese-Copper Stainless Steels

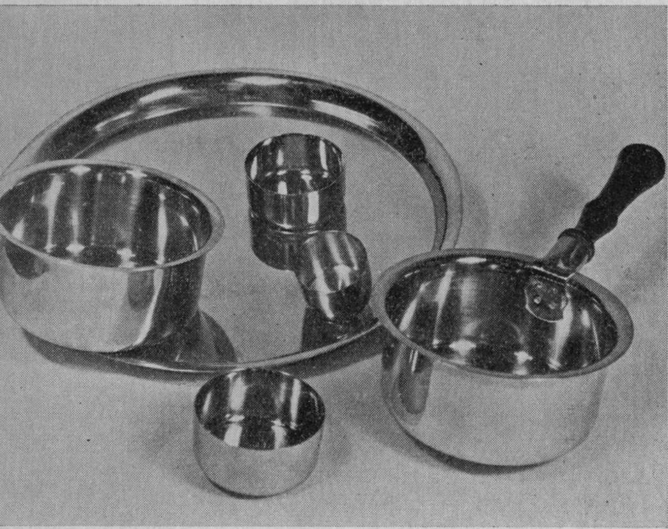
Comprehensive investigations on the determination of mechanical and corrosion resistance properties of austenitic nickel-free stainless steels in various media were continued. As a next step towards determining the feasibility of producing these stainless steels on a commercial scale, a number of heats were made in the direct arc electric furnace. From the experience gained with the production of these laboratory scale heats, a two-ton melt was successfully made in the direct arc electric furnace at the works of the Tata Engineering and Locomotive Works at Jamshedpur. The raw materials used were mild steel scrap, ferro-chrome, nitrided manganese and nitrided Fe-Cr-Mn alloy, and all of them excepting the former were made at the National Metallurgical Laboratory starting from their respective ores.

The mechanical, physical and corrosion resistance properties of the nickel-free stainless steel were determined in cold worked condition. The steel work hardened rapidly and attained exceedingly high strength values required for ultra-high strength steels used for multifold applications. The sheets after cold reduction of 48 per cent attained a tensile strength of over 110 tons/sq. in. both in and across the direction of rolling. No breakdown in austenite was observed and the cold working did in no way adversely affect the corrosion resistance of the steel in different media, as revealed by extensive tests in vinegar, lime juice plus 1 per cent sodium chloride solution, 5 per cent citric acid plus 1 per cent sodium chloride solution, 65 per cent boiling nitric acid and 5 per cent aerated sulphuric acid.

The iron-chromium-manganese-nitrogen system was studied in the range of Cr, 10-33; Mn, 5-25; and nitrogen, 0·3-1·2 per cent. Several dozen heats were made in this series. Alloys prepared in this range were investigated in as cast, cold rolled and forged conditions and their physical and corrosion resistance properties were evaluated, which led to the establishment of a critical compositional range. The results of these investigations showed that with chromium content in the range of 25-30 per cent, the steels were never fully austenitic irrespective of their manganese content in the range of 5-35 per cent manganese and nitrogen in the range of 0·3-1·06 per cent. It was further observed that at high manganese levels, the steels became brittle. With chromium content at



TWO-TON INGOT OF NICKEL-FREE STAINLESS STEEL PRODUCED AT THE NATIONAL METALLURGICAL LABORATORY, AND SOME FINISHED PRODUCTS MADE OUT OF THIS STEEL



UTENSILS FABRICATED OUT OF THE NICKEL-FREE STAINLESS STEEL DEVELOPED AT THE NATIONAL METALLURGICAL LABORATORY

about 22 per cent and the manganese kept at 10 per cent level, the steels again failed to become austenitic. In steels containing 15 per cent chromium, a manganese content of 10 per cent produced martensitic steels. On increasing the manganese content to 14 per cent, the steel became more stable but underwent phase transformation on cold working. The steels containing 10 per cent chromium had very poor corrosion resistance, on account of their low chromium content. Further development work in this connection is actively being pursued.

2.0 Studies of the Properties of Indigenous Foundry Moulding Materials

Considerable progress was made on this project which has been in progress since the last few years to assess the moulding characteristics of Indian foundry sands and determination of their suitability for various types of castings.

During the period under review 15 sand samples were studied and the following are the findings on the suitability of the sands investigated:

(i) Three types of sand, e.g. snow-white silica sand, medium silica sand and yellow moulding sand received from Messrs Premier Automobiles Ltd., Bombay, were studied. The snow-white sand is a high silica sand and could be successfully employed for cast iron as well as steel foundry jobs for making moulds and cores. The medium silica sand with appropriate addition of bentonite and dextrine could be satisfactorily employed for cast iron and steel castings. The yellow moulding sand, due to its low refractoriness and high lime and alkali content, could not be considered suitable for grey iron castings.

(ii) A sand sample from Gidni was received from Messrs A. K. Roy, Calcutta. The sample was of poor refractoriness and as such was unsuitable for steel and iron castings.

(iii) Two sand samples, Londha 1 and Londha 2, were received from Messrs Cooper Engineering Ltd., Bombay. Both the samples were found to be suitable for cast iron jobs.

(iv) Three sand samples, Bhavnagar 1, 1A and 1B, were sent by the Engineering Association of India, Bombay. In view of the very low permeability and refractoriness, the samples were not found useful for cast iron foundry jobs without admixture with silica sand of more open type.

(v) Investigation was conducted on Durgapur sand, a high silica sand of coarse variety supplied in the form of sandstone by Messrs Hindustan Steel (Private) Ltd., Durgapur. The quartzitic sandstones were found difficult to crush and a sand grade suitable for light steel castings when bonded with silica flour, Bihar bentonite and dextrine, was obtained with much difficulty. For a big foundry, however, it would be difficult to maintain the grading, as fines would increase after each milling.

(vi) Goriali and Tyadi moulding sands sent by the Associated Cement Co. Ltd., Bombay, were investigated. Due to the low refractoriness and low permeability, the sands could not be used for cast iron castings without admixture with a silica sand of more open type.

(vii) Samples of Yadgiri sand and Bhavnagar sand received from Messrs Ruston and Hornsby (India) Private Ltd., Poona, were studied. The Bhavnagar sand, due to its low permeability, could not be used for iron castings.

(viii) The zircon sand from Travancore was studied for its suitability as a moulding material. The sand had a fineness number of 124 and was found to possess high sintering range and high dry strength when employed in suitable admixture bonded with bentonite. It can be used for steel casting purpose.

(ix) A sample of bentonite supplied by Messrs Premier Automobiles Ltd., Bombay, was studied. It had very poor swelling index. The casting characteristics, which were studied by pouring molten cast iron in green and dry moulds prepared with Rajmahal medium silica and Madras silica sand and 5, 8 and 9 per cent addition of bentonite, revealed poor surface characteristics with adhered sandy layers.

3.0 Aluminizing of Steels

During the year under review, several samples were aluminized for service trial such as auto-muffler parts of Fiat 1100B and Fiat 1100E car for Messrs Premier Automobiles Ltd., Bombay. Articles of Post and Telegraph pole line hardware were aluminized with a good measure of success. Threading was found to be perfect on aluminizing pre-threaded stalks, etc. Plumber's hardware samples were also aluminized. On the operational side, alkathene has been adopted as a lining material for pickling tanks for hydrochloric acid at temperatures up to 70°C.

3.1 Aluminizing of Stainless Steel

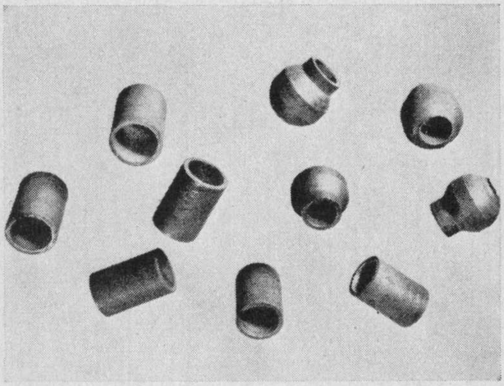
18: 8 stainless steel samples were aluminized to obtain scaling resistance for high temperature applications. Heat resistance tests at 800°C. were carried out. On heating, aluminium was found to diffuse into basis metal and no loose scale was formed. Unprotected stainless steel deteriorated under similar conditions as the scale was not adherent. Deep drawing qualities of aluminized 18: 8 stainless steel were quite good. Dome height of 0·44 in. was attained for 0·036 in. thick sheets in the Olsen cupping test. In this test, the coating and the base metal failed simultaneously and there was no cracking or peeling-off of the coating. Scaling resistance by aluminizing could not be conferred upon nickel-free Cr : Mn : N (developed in this Laboratory) stainless steels as during heating instead of diffusing into base metal, the coating spalled off after oxidation, presumably due to the formation of a barrier layer of aluminium nitride, although no evidence could be obtained by microscopic examination.

4.0 Tinless Bronze

The bonding characteristics of the Zn-Al-Cu bearing alloys with different backing materials were studied. Two cylindrical bars machined from gun metal and steel were held $\frac{1}{4}$ in. apart in a special mould, in which the bearing alloy was poured. The bars were then removed, machined and tested in a tensile testing machine to determine the bonding strength. The bars were always coated with tin, zinc or the bearing alloy itself before assembly in the mould. So far complete success has not been achieved in bonding this bearing alloy. It has, however, been noticed that diffusion of the bearing alloy did occur when sheets of steel, brass, gun metal, phosphor-bronze were dipped in the molten bearing alloy. Further work is in progress.

5.0 Powder Metallurgy — Manufacture of Porous Bronze Bearings

Manufacture of porous bronze bearings is based on the use of Cu, Sn and graphite powder mixtures which are moulded into bearings and subsequently sintered. The



SELF-LUBRICATING BRONZE BEARINGS MADE BY POWDER METALLURGY TECHNIQUE AT THE NATIONAL METALLURGICAL LABORATORY

results obtained depend on the characteristics of metal powder used as raw material as well as on the conditions of moulding and sintering. During the year under review, the problems relating to the conditions for obtaining uniform bearings from different mixtures based on varied composition and sieve analysis were studied and investigated. Manufacturing conditions for making uniform bearings of two different shapes were studied and successful experiments were completed on the making of porous bronze bearings of self-aligning and plain-shaped cylindrical types. Feasibility of commercial application of these bearings in table fans is being determined.

6.0 Dephosphorization of Indian Pig Iron

Experiments were done in the basic lined baby cupola for the dephosphorization of the pig iron. Different oxidizing agents and basic fluxes like iron ore, manganese ore, mill scale, sodium carbonate, limestone and lime were tried. With high silicon pig iron, dephosphorization was only limited while better results were obtained when low silicon pig iron made by oxygen lancing of the high silicon pig iron in the direct arc furnace was charged. With the cold blast, phosphorus removal up to 40 per cent was achieved. Dephosphorization of the pig iron with preheated blast is under study.

7.0 Study of Isothermal Transformation Characteristics of Some Indian Steels

This project was taken up with a view to study the isothermal transformation characteristics of some selected Indian steels.

A dial gauge dilatometer has been set up to study the transformation characteristics of slow transforming steels. The specimen is held between two pointed silica rods, one of which presses against the specimen by spring pressure. This rod communicates its movement to the dial gauge which thus gives the change in length occurring during transformation. The movements of the dial gauge needle and stop-watch are simultaneously recorded on a film by Shackman Auto camera. The apparatus requires the dilatometer to be transferred from the soaking furnace to the quenching furnace manually which takes some time and obviously only very slow transforming steels can be studied by this apparatus.

The dilatometer has been standardized by using two alloy steels, e.g. nickel-steel and molybdenum-steel, whose T.T.T. curves are known. Ac_1 and Ac_3 temperatures were determined from continuous heating dilation curves. The dilatometer and test specimen used were of the same types as those used for the isothermal tests. A standard heating rate of 100°C. per hour above 500°C. was adopted. Ms temperature was determined theoretically by Nehrenberg formula for calculating Ms temperature from chemical composition. The transformation characteristics of the laminated spring steel of the composition: C, 0·85; Si, 0·19; S, 0·015; P, 0·04; and Mn, 0·60 per cent have been determined.

The Ms temperature will also be determined experimentally by the metallographic method described by Greninger and Troiano.

For fast transforming steel, the metallographic method is used. At present the transformation characteristics of low-alloy steel of composition C, 0·083; Mn, 1·4; Si, 0·25; S, 0·037; P, 0·024; Cu, 0·21; and Cr,-1·21 per cent are being studied. The line of work further proposed is to study the isothermal transformation characteristics of the nickel-free austenitic chromium-manganese-nitrogen stainless steel.

8.0 A study of the Quench-ageing and Strain-ageing Embrittlement in Steels

The steels of the following compositions were prepared in high frequency furnaces:

Al-Killed Steel

%	A_1	A_2	A_3	A_4
C	0·010	0·015	0·03	0·03
Si	0·011	0·024	0·008	0·015
N_2	0·015	0·02	0·02	0·004
Al	—	0·012	0·023	0·19

Boron-containing Steels

%	B_1	B_2	B_3	B_4	B_5
C	0·02	0·025	0·02	0·025	0·02
Si	0·047	0·034	0·031	0·026	0·022
N_2	0·007	0·006	0·006	0·007	0·007
Al	0·034	0·029	0·029	0·026	0·026
Mn	0·035	0·023	0·019	0·025	trace
Cr	0·018	0·018	—	—	—
Boron	0·005	0·005	0·005	0·007	0·008

These steels were forged and rolled and the rolled specimens were taken for measurement of electrical conductivity, hardness and tensile strength at predetermined strains. For quench-ageing, small specimens were cut and quenched at different temperatures. Hardness and electrical conductivity of these specimens are being recorded. The tests will be continued for an ageing period of six months.

9.0 Development of Nickel-free Coinage Alloy

The shortage and absence of nickel ores in India pose a real problem in coinage production. Work has, therefore, been taken up to develop a suitable alloy containing manganese as one of the constituents, which will be suitable as a coinage material. Preliminary experiments showed that alloys of 3 different nickel-free compositions possess similar physical properties as required in coinage metal containing nickel. In collaboration with the Mint, coins were stamped out of these compositions and were found to be very satisfactory and the alloys showed similar properties as that of cupro-nickel.

To determine the rolling properties under actual industrial operation of the alloys developed, various compositions were cast in slabs of size $2\frac{1}{2} \times \frac{1}{2} \times 24$ in. and then rolled in the rolling mills of Indian Copper Corporation, Ghatshila. About 12 slabs of the same size were also sent to India Government Mint to study the working properties of the alloy under conditions encountered in the various stages of making of coins. Both hot rolling followed by cold rolling and direct cold rolling were tried. Hot rolling followed by cold rolling showed that the rolling properties of all the alloys are comparable to that of cupro-nickel. It was found that some of the alloys can even be directly cold rolled to reduce the slab from 0·5 in. to a value of 0·07 in. thickness.

Recently two melts weighing 21,304·5 tolas were made in oil fired furnace at the Government of India Mint, Alipore. Surface characteristics of all the ingots were studied jointly by the Mint authorities as well as the representatives of the National Metallurgical Laboratory and found to be extremely satisfactory. Further work on rolling, blanking and stamping of these ingots are in progress at the Mint.

9.1 Production of Manganese-bearing Substitute Brass for Utensils

With a view to replace or reduce the percentage of copper and zinc in brass, various compositions containing copper, manganese and zinc were cast and rolled in the Laboratory rolling mill. The results of the mechanical properties of the alloys were found to be very encouraging; some showed very good deep drawing properties. Further work is in progress.

10.0 Preparation of Battery Active Manganese Dioxide from Low-grade Domestic Ores by Chemical Process

Laboratory scale experiments for the production of manganese dioxide from low-grade manganese ores from Joda, Orissa, were successfully carried out. The optimum conditions leading to the maximum reduction of ore by coke oven gas in a minimum time were studied and conditions of maximum leaching were established. In order to increase the percentage of manganese and decrease the amount of iron in the leach liquor, leaching was carried out in cycles with appropriate strength of nitric acid. Decomposition of the manganese nitrate solution was carried out at about 200°C. 95 per cent of nitric acid was recovered in a suitable strength for recycling. Battery activity tests of this material were found to be satisfactory.

11.0 Electro-winning of Chromium

Experiments were carried out for deposition of chromium from chromic acid bath, with lead anode and aluminium cathode. The deposition was done at various temperatures at constant current density. At high temperatures, the current efficiency was low. At a temperature of 30°-35°C., the current efficiency obtained for a run lasting for 8 hrs. was 22 per cent. The deposition at still lower temperatures was done by external cooling of the electrolytic cell.

11.1 Preparation of Electrolytic Ferro-chrome

During the year under review, the problem of the digestion of chromite ore with sulphuric acid at atmospheric pressure was studied thoroughly. The optimum conditions for the digestion of the ore were determined and it was found possible to extract 90-95 per cent of the chromium from the ore. For study of pressure digestion of chromite ore, a pressure digester was improvised in the laboratory and a few experiments were done. As cylindrical porous pot diaphragm presented certain difficulties, it was decided to standardize the conditions for electrolysis with rectangular porous pot diaphragms. The electrolytic cell was redesigned and experiments are now being done in the new set-up, to standardize the conditions of electrolysis with a view to its projection into bigger scale at a later date.

12.0 Studies on Corrosion

(i) *Studies on Atmospheric Corrosion of Various Metals and Alloys* — To study the effect of exposure on the atmospheric corrosion of mild steel and TISCOR, samples were exposed in the months of July, January and April representing rainy season, winter and summer seasons respectively. Subsequent to the exposure of mild steel and TISCOR samples in the month of June 1957 and January 1958, further set of samples were exposed in the month of April 1958. Samples were removed after 2 months, 6 months and 1 year exposure to determine the loss in weight. The surface of the descaled samples was studied to determine the nature of attack, i.e. whether the attack is uniform or of pitting type. The attack on mild steel was found to be of pitting type. The attack on TISCOR was, however, found to be uniform in nature. In the period under review, samples of mild steel, TISCOR, brass, copper, etc., were also removed and corrosion rate was determined after the completion of two years exposure.

(ii) *Corrosion of Cast Iron by Fused Caustic Soda* — The cast iron pots used for the fusion of caustic soda were found to crack during operation. It was desired to find out the causes of this type of failure. Investigations in this connection showed that the premature failure of the C.I. crucibles occurs due to the combined effect of stress caused by uneven heating and cooling and penetration of attack by fused caustic soda along the grain boundaries and graphite flakes.

Necessary tests carried out at 520°C. in fused caustic soda showed that the corrosion of C.I. increases threefold by the addition of 0·1 per cent S (from 0·56 to 1·7 gm/dm^2) but decreases slightly by the addition of 0·1 $NaNO_3$ (from 0·56 to 0·52 gm/dm^2).

(iii) *Corrosion of Pump Impeller Installed at Tallah Tank of West Bengal* — The pump impeller installed at Tallah Tank was found to corrode heavily. It was desired to find out the cause of the same and the possible remedies.

The investigation showed that the deep pitting type of localized attack was due to cavitation erosion. This type of attack occurs due to the formation of cavities in the low pressure areas and their subsequent collapse at high pressure areas, due to conjoint action of mechanical and chemical agencies. Measures against this type of attack were suggested.

(iv) *Erosion of Induced Draft Fan at Bokaro Thermal Power Station* — Heavy damage was encountered in the induced draft fan of the Bokaro Thermal Power Station boilers where high ash coal was used as the heating media. The fly ash from different positions was analysed by sieving for particle size distribution and also analysed for SiO_2, Al_2O_3 and Fe_2O_3 content. Iron oxide was found to be present in the fly ash in magnetic form and petrological study of the fly ash further indicated that the particles consisted predominantly of magnetite. Free iron was also found to be present inside the magnetite grains.

As the temperature prevailing in the induced draft fan is of the order of 163° to 180°C., no chemical corrosion due to deposition of sulphuric acid is probable at the existing SO_2 content of the flue gas. So it was concluded that the damage was primarily due to erosion, and that the iron particles dislodged by the erosive action of the fly ash particles have been converted to magnetite by oxidation.

On the basis of the above conclusions, it was suggested that the efficiency of dust catcher should be increased to reduce the amount of fly ash and bigger-sized particles reaching the induced draft fan. It was also suggested to increase the hardness of the steel used for the construction of fan parts.

(v) *Brown Spot Defects on Aluminium Circles* — Annealed aluminium circles, when stored in stack formation, develop brown spots. The causes of this type of attack were investigated to offer suitable remedies. The form of brown spots indicated that this type of attack is in some way connected with the deposition of water in the capillary space formed between the stacked circles. Consequently tests were carried out on stacked aluminium samples under conditions simulating to works practice. The bunch of stacked aluminium samples were placed inside a desiccator and temperature and humidity inside the desiccator were changed in such a way as to produce alternate condensation and evaporation of moisture inside it. By this method it was found possible to develop brown spots similar to those which occurred in actual storage conditions. From the results of various tests, it was concluded that formation of brown spots was favoured by the condensation of moisture during the daily fluctuation of temperature inside the storage room. On the basis of the investigation, it was suggested that the temperature inside the storage room should be such as to cause no condensation of moisture. It was also suggested that a good circulation of air should be maintained inside the stores as the stagnant atmosphere will lead to the condensation of moisture very easily.

13.0 Production of Magnesium by Electrolytic Method from Magnesium Chloride

About 1·1 million tons of magnesium chloride are annually produced in India as a byproduct from salt industry. Attempts are now being made to utilize this waste material for production of metallic magnesium, which finds considerable use in defence services, chemical industries and light metal alloys for aircraft and automobile industries.

Several cells of different designs were tried for electrolytic work. Ultimately, a cell of particular design was chosen in which every precaution was taken to reduce the corrosion of the diaphragm and the mild steel shell. The metal obtained by electrolysing was found to be 99 per cent pure. Improved cells are now being designed and fabricated and continuous work on electrolysis would be taken up shortly.

14.0 Liquid Gold

With gold bullion and mostly indigenous material, liquid gold has been produced on laboratory scale. The quality of the product was tested on glass and ceramic surface and texture of the writing with the product developed in the Laboratory appeared to be of better quality than the imported material. Large quantities of liquid gold are being prepared for sending to interested parties for trial purpose.

15.0 Electroplating on Aluminium and its Alloys and Plating on Non-metals

The patented processes were standardized and their operative conditions were found to be satisfactory for working on commercial scale. The processes which have been released free of royalty were demonstrated for a week before a large number of representatives from small-scale industries so as to impart the working knowledge for commercial exploitation.

15.1 Brass Plating from Non-cyanide Bath

The method of plating brass (70 Cu: 30 Zn) from the non-cyanide bath containing sodium cupric tartrate and sodium zincate was standardized and worked out on a commercial scale. The process was demonstrated before a large number of representatives from the small plating industries and the working knowledge was imparted for its proper exploitation by the industries.

16.0 Deposition of Copper on Mild Steel Wire

Different methods were tried for the deposition of copper on mild steel wire. Coils of mild steel wire after descaling and pickling were electroplated with bright copper from an alkaline cyanide bath containing various brightners. The copper coatings as observed with certain brightners were bright and firmly adherent under bending and twisting tests. The coated wires were drawn with reduction of 25 and 50 per cent in area. The coatings were observed to be bright and firmly adherent without any discontinuity even after drawing.

Another series of experiments on electroless copper coating were conducted and uniform adherent coatings of copper on mild steel wires were obtained. The thickness of coatings in most cases was observed to vary from 0·0002 to 0·0003 in. Further studies to improve their brightness and adhesion are in progress.

16.1 Recovery of Copper and Nickel from Cu-Ni Alloys

An electrolytic method to recover copper and nickel as electrolytic copper and pure nickel sulphate from copper-nickel alloy has been developed. Sulphuric acid is the only important raw material used for the purpose. Further work on improvement of the process for large-scale application is in progress.

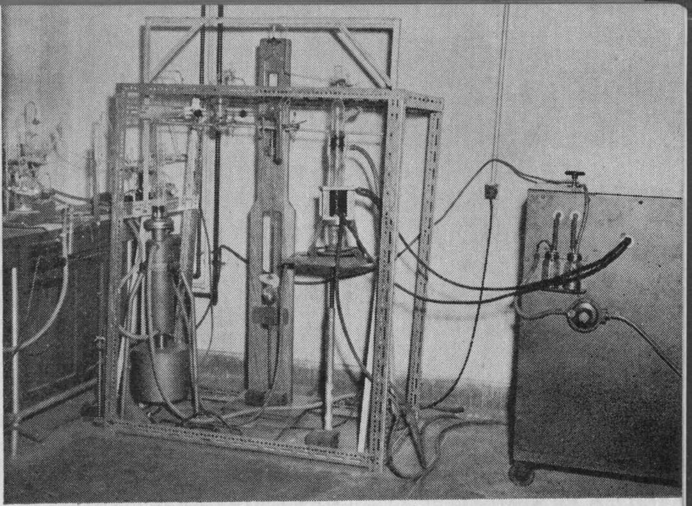
17.0 Determination of Gases in Metals

An apparatus with all the necessary accessories was fabricated and a wide range of metals and alloys like electrolytic Mn, coinage alloys (Cu-Mn brass), low-alloy steel, nickel-free stainless steel, chromium-manganese-iron alloys, copper sheets, rail piece, welded steel, etc., were analysed for hydrogen with good accuracy even when the hydrogen content was as low as 0·000005 per cent.

By assembling this apparatus foreign exchange worth about Rs. 10,000 has been saved.

The fabrication of the vacuum fusion apparatus for the determination of oxygen, nitrogen and hydrogen was also completed. The working principle of the apparatus is based on the fact that at temperature nearly 1600°C. and in high vacuum, the reduction of oxides takes place in presence of an excess of dissolved carbon which diffuses in the molten bath from the graphite crucible. Subsequently carbon monoxide is formed *in situ* and is removed simultaneously by pumping. Hydrogen is fully extracted within a very short period. Nitrides are decomposed by thermal decomposition and nitrogen is evolved from the melt. The evolved gases are collected into a Toepler Pump and led to a gas analysis apparatus (which has also been fabricated in the National Metallurgical Laboratory) and analysed for CO, N_2 and H_2.

A ready-made assembly of this apparatus costs foreign exchange worth about Rs. 60,000 and under the present economic position it was decided to save major part of this foreign exchange by fabricating the apparatus in the Laboratory.



VACUUM FUSION APPARATUS FOR DETERMINATION OF GASES IN METALS, DESIGNED AND FABRICATED AT THE NATIONAL METALLURGICAL LABORATORY

18.0 Beneficiation of Low-grade Manganese Ore

(i) *From S-G-B-K Mines, Keonjhar Dt., Orissa* (*Sample* 1) — A sample of low-grade manganese ore from S-G-B-K Mines, Keonjhar District, Orissa, was received from Messrs Serajuddin & Co. for beneficiation tests. This sample assaying Mn, 30·18; Fe, 10·58; SiO_2, 17·72; Al_2O_3, 4·1; P, 0·03; and CaO, 1·1 per cent was reported to be from the rejects obtained after hand-picking of high-grade ore. The principal manganese mineral was psilomelane followed by wad and pyrolusite. Ferruginous minerals (goethite, hematite and lateritic mineral) and siliceous minerals (partly stained quartz and feldspar) were the chief gangue in the sample. The manganese minerals got fairly liberated from the gangue at about 100 mesh size.

Reduction roast followed by low intensity magnetic separation of the reduced ore at 28, 65, 100 and 150 mesh sizes yielded manganese concentrates with Mn to Fe ratio of 7: 1. The manganese recovery in the non-magnetic product was highest (i.e. 58·5 per cent) at 100 mesh size for a Mn/Fe ratio of 7: 1. Cationic flotation of quartz from non-magnetic product at 100 mesh yielded a manganese concentrate assaying Mn, 57·06; Fe, 6·16; SiO_2, 10·23; Al_2O_3, 1·65; and P, 0·032 per cent with a manganese recovery of 48·5 per cent.

(ii) *From S-G-B-K Mines, Keonjhar District, Orissa (Sample 2)* — Another sample of low-grade ferruginous manganese ore assaying Mn, 28·1; Fe, 24·9; SiO_2, 8·9; Al_2O_3, 5·61; BaO, 0·13; and P, 0·145 per cent was received from Messrs Serajuddin & Co. from their S-G-B-K Mines in Keonjhar District, Orissa, for beneficiation tests.

Petrological examination of the sample showed that pyrolusite was the predominating manganese mineral followed by psilomelane and hollandite. The chief gangue was goethite followed by lateritic material quartz, ochre, hematite, feldspar and traces of muscovite, etc. Most of the gangue got liberated at about —28 mesh size. After preliminary washing, the ore was subjected to low-temperature magnetizing reduction roast. Wet magnetic separation tests at —3, —10, —28, —48 and —100 mesh of the reduced ore yielded manganese concentrates assaying 57·5, 58·0, 58·5, 56·8 and 57·5 per cent manganese with manganese recoveries of 42, 55, 69, 66 and 62 per cent respectively for a Mn/Fe ratio of 7 : 1.

(iii) *From Kurro-Madai Mines, Jabalpur, Madhya Pradesh* — A low-grade manganese ore from Kurro-Madai Mines, Jabalpur District, M.P., assaying Mn, 33·5; Fe, 9·6; SiO_2, 19·5; Al_2O_3, 5·8; and P, 0·175 per cent was received from Messrs Karnidanji Dhadiwal, Nagpur, for beneficiation tests. The ore was very fine grained and dense in character and had a shaly appearance. Psilomelane was the chief manganese mineral followed by pyrolusite and braunite. Quartz and hematite were the chief gangue minerals followed by feldspar and calcite.

Reduction of a —3 mesh sample followed by magnetic separation at —65 mesh yielded a manganese concentrate assaying 40·9 per cent Mn and 23·2 per cent SiO_2, with a recovery of 68·5 per cent Mn for a Mn/Fe ratio of 7: 1. The silica present in the sample being very fairly disseminated with the manganese minerals (liberation only at 8 micron size) could not be eliminated by ore-dressing methods.

(iv) *From Chitaldrug, Mysore* — A sample of low-grade ferruginous manganese ore from Chitaldrug, Mysore, received from Messrs Jyoti Brothers, Calcutta, for beneficiation tests assayed Mn, 35; Fe, 24·7; SiO_2, 1·67; Al_2O_3, 1·4; BaO, 0·41; and P, 0·105 per cent and consisted of lumps of 2 in. size down to fines. Pyrolusite was the chief manganese mineral accompanied by psilomelane and jacobsite; goethite and lapidocrosite were the chief gangue minerals. There was a fair liberation of manganese minerals at about 28 mesh size. Reduction roasting of —3 mesh sample followed by magnetic separation at —10 mesh, —48 mesh and —100 mesh sizes yielded manganese concentrates assaying 59, 61 and 61 per cent Mn, with recoveries of 70·5, 71, and 62·5 per cent respectively for a Mn/Fe ratio of 7:1. Magnetic separation of the magnetic products obtained from —10 mesh sample after demagnetizing and grinding to —100 mesh size yielded a combined concentrate assaying 59·5 per cent Mn, with an improved recovery of 78 per cent for a Mn/Fe ratio of 7:1.

(v) *From Kumsi, Mysore* — A low-grade manganese ore from Kumsi in Shimoga District, Mysore, received from the Bureau of Mineral Development, Government of Mysore, assayed Mn, 34·4; Fe, 4·5; SiO_2, 30·3; Al_2O_3, 3·0; and P, 0·07 per cent. Psilomelane was the principal manganese mineral followed by pyrolusite and manganite. The chief gangue mineral was quartz followed by feldspar, goethite, muscovite, hematite and traces of zircon. High intensity magnetic separation at —100 mesh and flotation of the slime yielded a manganese concentrate assaying 48·2 per cent Mn with a recovery of 88·5 per cent Mn. Cationic flotation of siliceous minerals yielded the best results. The manganese concentrate obtained assayed 47·0 per cent Mn, 3·92 per cent SiO_2 with a recovery of 92·4 per cent Mn.

(vi) *From Jhabua, M.P.* — Beneficiation of a complex low-grade manganese ore from Jhabua, M.P., assaying Mn, 28·8; SiO_2, 22·38; Al_2O_3, 2·37; Fe, 5·9; P, 0·19; CaO, 10·73; and BaO, 2·45 per cent was studied employing various mineral dressing processes. Braunite was the principal manganese mineral in the ore, followed by psilomelane and pyrolusite, while quartz, calcite and iron oxide (hematite and goethite) constituted the chief gangue. Of the various methods employed, a combined process employing jigging, tabling and reduction roast treatment of the gravity concentrate followed by wet magnetic separation yielded a manganese concentrate assaying Mn, 48·89; Fe, 5·6; and SiO_2, 12·12 per cent with a manganese recovery of 57·7 per cent. High intensity magnetic separation to remove the siliceous and calcareous gangue followed by reduction roast and magnetic separation gave a concentrate assaying Mn, 47; Fe, 5·3; and SiO_2, 11·9 per cent with a slightly better manganese recovery of 59·7 per cent. These concentrates can be employed for the production of standard grade ferro-manganese after blending with ores of slightly lower phosphorus content.

(vii) *Low-grade Manganese Dioxide Ore from Amritapura in Chitaldrug District, Mysore* — A sample of low-grade manganese dioxide ore from Amritapura in Chitaldrug District, Mysore, was received from Messrs Devidayal (Sales) Private Ltd., assaying Mn, 29·87; MnO_2, 46·62; Fe, 6·86; SiO_2, 35·45; Al_2O_3, 3·80; P, 0·06; alkalies, 1·12; and BaO, 0·33 per cent. Pyrolusite was the chief manganese mineral while quartz was the predominant gangue. The other gangue minerals were goethite, muscovite, feldspar, garnet and biotite. Tabling of the sample gave a good grade of concentrate but the recovery was only 23·5 per cent. Flotation employing fatty acid yielded satisfactory results. A concentrate assaying 55·11 per cent Mn (containing 86·36 per cent MnO_2) could be obtained with a recovery of 60·9 per cent Mn.

18.1 Recovery of Ferro-manganese from Joda Electric Furnace Slag by Tabling Method

Five samples of ferro-manganese slag from the Electric furnace at Joda were received from Messrs Tata Iron & Steel Co. Ltd., for recovery of ferro-manganese by tabling. It was found that except for two samples in which the metallic contents were very low, high grade concentrates with good ferro-manganese recoveries could be obtained from the samples by tabling at about 20 mesh size.

19.0 Sintering Studies on the Magnetic Concentrate Produced from Low-grade Salem Magnetite Ore

Laboratory studies were made on the sintering characteristics of magnetic concentrate obtained after upgrading of low-grade Salem magnetite ore. The effects of variables such as basicity, coke and moisture contents in sinter mix on the quality of sinter produced, were studied with a sintering unit designed and fabricated in the Laboratory. Results showed that the optimum amounts of coke and water contents were 7·0 and 9·0 per cent respectively for producing a self-fluxing sinter with a basicity ratio of 0·85.

20.0 Beneficiation of Fluorspar

(i) *From Ramorwali Mine, Rajasthan* — A sample of fluorspar from Ramorwali Mine, Rajasthan, received for beneficiation tests assayed CaF_2, 21·14; SiO_2, 58·80; $CaCO_3$, 2·10; Al_2O_3, 10·02; Fe_2O_3, 0·76; Pb, 0·31; and S, 0·12 per cent with traces of Zn, Ba, Cu and W. The principal gangue minerals were quartz, feldspar and muscovite with minor amounts of calcite, galena, biotite, etc. Xanthate flotation for the removal of galena followed by fatty acid flotation for fluorspar, after thickening produced a rougher fluorspar float assaying 70·09 per cent CaF_2 and 0·12 per cent Pb with a recovery of 88·3 per cent CaF_2. One cleaning and four cleanings of the rougher fluorspar float yielded concentrates of metallurgical and acid grades assaying 84·9 and 96·63 per cent CaF_2 with recoveries of 87·2 and 49·4 per cent CaF_2 respectively.

(ii) *From Bhagatwali Mines, Rajasthan* — A sample of fluorspar received for beneficiation tests from Bhagatwali Mines, in Rajasthan, assayed CaF_2, 56·48; SiO_2, 34·70; $CaCO_3$, 3·58; Pb, 0·29; Fe_2O_3, 0·96; Al_2O_3, 2·46; and S, 0·06 per cent with traces of Ba, Zn, W and Cu. Quartz and feldspar were the principal gangue minerals in the sample. Fluorspar got fairly liberated at about 100 mesh.

Optimum conditions for flotation of fluorspar were determined for production of high grade of concentrate. Flotation employing warm water yielded the best results. The refloat concentrates obtained after one cleaning and four cleanings produced concentrates of grades 89·84 per cent CaF_2 and 97·66 per cent CaF_2 with recoveries of 91·2 and over 67·3 per cent CaF_2 respectively. The former could be used for metallurgical purposes and the latter for acid manufacture.

21.0 Studies on the Beneficiation of a Nickeliferous Ore from Ranakpur Mines, Pali District, Rajasthan

A sample of nickeliferous ore from Ranakpur Mines, Pali District, Rajasthan, was received from the Government of Rajasthan for beneficiation tests. As received, the sample assayed Ni, 0·25; Fe, 5·25; S, 0·14; SiO_2, 37·5; MgO, 39·6; and Al_2O_3 1·1 per cent. The ore consisted of a green-coloured serpentinous rock chiefly antigorite with minor amounts of magnetite. The nickel was present as (i) nickel silicate, possibly nepounite which closely resembled antigorite, (ii) pentlandite and (iii) in the magnetite itself. Major amount of the opaque minerals was liberated at —65 mesh, though interlocked particles measuring up to 0·0029 mm. were also present. Straight magnetic separation of the sample at —65 mesh did not give encouraging results. Tabling the sample at —100 mesh followed by magnetic separation of the table concentrates produced a combined concentrate assaying 0·6 per cent Ni with a recovery of only 17·4 per cent. A few flotation tests were conducted under varying conditions employing different reagent combinations but without success.

22.0 Beneficiation of Low-grade Garnet Sample from Nellore, Andhra

A low-grade garnet sample from Nellore, Andhra, was received from Messrs Inden Biselers, Madras, with a view to upgrading it for abrasive purposes. As received, the sample contained 75 per cent garnet. Almandite was the principal garnet mineral. Quartz and muscovite were the predominant gangue minerals. Tabling of —20 mesh sample after hydraulic classification followed by magnetic separation of table middling products yielded a combined concentrate containing 92·5 per cent garnet and 0·68 per cent free gangue with an overall garnet recovery of 89 per cent. Heating the concentrate to 700° and 800°C. for varying lengths of time improved the capillarity of the product considerably. The heat treated as well as unheated concentrates after sizing were sent to Messrs Inden Biselers for finding out their suitability for abrasive manufacture, by service trials with the paper and cloth abrasives made with these concentrates.

23.0 Beneficiation of Limestone

(i) *From Toli Village, Garhwal District, U.P.*— A low-grade limestone sample from Toli village, Garhwal District, U.P., received for beneficiation tests assayed CaO, 35·4; SiO_2, 31·8; MgO, 1·1; Fe_2O_3, 2·05; and Al_2O_3, 1·16 per cent. Quartz which was the principal gangue in the sample was liberated at — 150 mesh. Optimum conditions for flotation of limestone were determined for production of a concentrate suitable for cement manufacture. Flotation employing sodium silicate, oleic acid and pine oil produced a concentrate assaying 47·15 per cent CaO with a recovery of 96·5 per cent. Cleaning of the primary floats improved the grades to 49·2 and 51·4 per cent CaO with recoveries of 92·5 and 80·5 per cent respectively.

(ii) *From Village Pundras, District Garhwal, U.P.*— A sample of sandy limestone from village Pundras, District Garhwal, U.P., assaying CaO, 35·10; SiO_2, 31·00; Al_2O_3, 0·90; Fe_2O_3, 2·43; CO_2, 29·02; and SiO_2, 0·15 per cent was studied for its amenability to beneficiation to make it suitable for cement production. The principal minerals in the ore were calcite and quartz. Flotation tests employing sodium silicate, oleic acid and pine oil yielded products assaying about 46 to 48 per cent CaO with recoveries of about 92 to 82 per cent respectively.

24.0 Pre-concentration of Lead-zinc Ore from Zawar, Rajasthan

A sample of run-of-mine lead-zinc ore from Zawar, Rajasthan, assaying 2·77 per cent Pb and 5·35 per cent Zn was received from the Metal Corporation of India Ltd. for a study of the possibilities of pre-concentrating the ore by heavy media separation. Continuous tests in a laboratory unit, fabricated at the National Metallurgical Laboratory, employing media of specific gravities 2·75 and 2·80, showed that 23·7 and 43·3 per cent by weight of the ore could be rejected at 1 in. size with losses of 7·4 and 18·0 per cent zinc respectively and losing practically no lead.

25.0 Recovery of Metallics from Gun Metal Ash by Tabling Method

A sample of gun metal ash weighing 174 lb. was received from Messrs Empire Industries, Tatanagar, with a request to recover the metallics by tabling. The sample as received was already in the form of fines. The sample was passed over a laboratory shaking table yielding a concentrate of grade 61·0 per cent copper with a recovery of 28 per cent Cu. The recovery could be improved to 43·2 per cent for a grade of 50·4 per cent Cu.

25.1 Recovery of Metallics from Low-grade Aluminium Powder

A low-grade aluminium powder assaying Al, 27·6 and Al_2O_3, 43·7 per cent was received from Messrs Devidayal Metal Industries Ltd. for the recovery of metallics. The sample consisted of a grey-coloured powder mostly passing through a 65 mesh screen. Alumina was the principal gangue with small quantities of quartz and graphite. Electrostatic separation of the ground deslimed sample produced a concentrate assaying 57·3 per cent Al with a recovery of 31·7 per cent. Flotation using oleic acid and pine oil yielded a concentrate assaying 57·4 per cent Al with a recovery of 39·0 per cent. The grade could be further improved to 85·67 per cent Al with increased collector addition for a recovery of only 10·3 per cent.

26.0 Production of Basic and Special Refractories from Indigenous Sources

(i) *Studies on Almorah Magnesite* — Work has been taken up on a 10-ton sample of Almorah magnesite, received from the Indian Bureau of Mines for evaluation and pilot plant studies on the production of magnesite refractories. Laboratory scale study carried out previously on samples received from this locality has indicated that this type of magnesite which is more like Austrian magnesite could be advantageously used for the production of magnesite bricks than that of the well-known magnesite deposits from Salem.

(ii) *Studies on Dolomites* — A larger batch of stabilized dolomite was prepared. Work has been taken up on the study of determining optimum conditions for semi-stabilizing dolomite with tar and the use of it in L.D. converter.

(iii) *Chrome-magnesite Refractories* - Chrome-magnesite bricks using Orissa and Bihar ores were prepared and tested for their refractory properties. Bricks made of these ores had very low iron oxide bursting expansion, high spilling resistance and high refractoriness underload. Laboratory evaluation of these bricks has shown that these could be used in the open hearth furnace wall, roof, soaking pits, electric arc furnaces, copper-reverberatory furnaces, etc. A sample of chromite received from the Bureau of Mines, Mysore, is being investigated. Results so far obtained show that it is inferior to Orissa or Bihar ore and further work to improve the properties such as iron oxide bursting and spalling resistance is in progress.

(iv) *Utilization of Low-grade Chrome Ore*- Refractory bodies comprising of low-grade chrome ore occurring at Salem and calcined magnesite were developed and tested. By controlling the grain size and addition of high-grade ore and calcined magnesite, improvements to the texture, spalling resistance and refractoriness underload were affected. This project is of importance because both chrome ore and magnesite occur near by in Salem District, Madras State. The Salem chrome ore has good potentialities for use as a refractory raw material. The possible use of these refractories is for iron and steel furnaces, cement and lime kiln, cupolas and electric arc furnaces.

(v) Development of Chemically Bonded and Metal Clad Basic Refractories - In order to counteract any lowering of strength of chemically bonded basic brick when it is heated in service through the temperature range of 500°-1000°C., the effect of small additions like sodium perborate and sodium silicate on the crushing strength of the brick was studied. It was observed that while these small additions improved the crushing strength of specimen fired within the range of 500°-1000°C., they lowered the refractoriness underload of the brick to some extent. It was also observed that specimen without any addition also withstood the normal load of 28 lb./sq. in. when passing through the range of 500°-1000°C. in the refractoriness underload test. Some full-size bricks with and without metal clad were made.

(vi) *Magnesite Crucible for High Frequency Induction Furnace* - Small size magnesite crucibles for high frequency induction furnace for experimental melts were imported till recently for use in the Laboratory. But due to foreign exchange difficulties these imports were restricted and hence to meet the local requirements, work on the developments of magnesite crucible was undertaken. By careful selection of the raw materials and controlling the grade firing temperature, etc., crucibles comparable to those imported, as regards performance, were developed and successfully used. This work has obviated the necessity for the import of crucibles for use in the Laboratory and thereby helped in the conservation of foreign exchange, though in a small way.

(vii) *Development of Super-duty Silica Brick* - From a preliminary study of a number of quartzite samples collected from different localities, silica stone from Mihijam area which is currently used for silica brick manufacture, Jamda quartzite and Delhi quartzite were selected for further study. After carrying out packing density studies with each of the quartzites crushed and graded to different grain sizes, silica brick specimens were pressed and hand moulded using the densest packing mixes and adding lime and iron oxide in requisite proportions. These were fired according to a predetermined schedule and the physical properties of the specimen were determined. From the results it appeared that the Delhi quartzite could be used for making common type of silica brick with porosity of the order of 20 to 22 per cent. With silica stone and Jamda quartzite super-duty quality silica brick could be produced with at least 20°-30°C. higher refractoriness underload as compared to the common type of silica brick. But the porosity of the products was of the order of 25 per cent. Further efforts are directed towards reducing the porosity. A consignment of 5 tons of quartzite from Jamda area has been received. Large-scale trials with this material are in progress.

(viii) *Production of Mullite Refractories from Bladed Kyanite* — In view of the interest expressed by a number of kyanite mine owners and refractory manufacturers in the patent taken on the process, semi-pilot plant trials on fitting this process to various types of kyanites available in this country were taken up during this year. A massive kyanite of the Lupsa Grade, so-called 'D' grade kyanite which finds no market at present, and course bladed kyanites from the Srinageri area in Mysore were studied. All of them appeared to respond to this process well, though certain slight modifications were necessary in the case of one or two of them. Large-scale trials have to await rigging up of the pilot plant.

(ix) *Zircon Refractories from Travancore Beach Sands* — Work on zircon refractories has been continued during this year, the stress being given on the semi-pilot plant studies of manufacture of refractory shapes from the compositions finalized earlier. Different methods of forming bricks, namely, pneumatic hand ramming, pneumatic tamping and hydraulic pressing, and their effect on the properties of the finished product were studied. Experiments have shown that cheaply available molasses and sulphite lye could also be usefully employed as temporary binders, in place of dextrin, for the manufacture of zircon refractories.

Another aspect of this investigation that has been actively pursued during this year is the phosphate bonding of zircon refractories. The chief advantage of phosphate bond in refractories is the development of a dense and mechanically strong refractory mass at comparatively low temperature, without impairing the original refractory properties of the starting materials. So far the effect of additions of phosphoric acid alone and in combination with minor quantities of chromic oxide on the curing characteristics and physical properties of zircon bodies was studied. Experiments on the load-bearing characteristics of these phosphate bonded refractory compositions are in progress.

(x) *Development of Calcium-aluminate Cement* - After developing a calcium-aluminate cement similar in properties to the imported " Cement Fondu " the work on development of a high temperature cement of the composition of calcium di-aluminate from aluminium tri-hydrate and calcium oxide has been taken up. As the melting point of calcium di-aluminate is very high, i.e. 1720°C., sintering process was tried and a few compositions were made. Partial and total conversions of the reactants, i.e. Al_2O_3, $3H_2O$ and CaO, were observed under the microscope and the hydraulic setting of these compositions was studied. Further work to make bigger batches is in progress. Designing of a suitable furnace to carry out the above experiment has been taken up. This cement would be similar to high temperature alundum cement useful for giving a refractory coating over electric furnace windings as well as other high temperature applications.

(xi) *Graphite Crucibles* -

CARBON BONDED - The patented process on carbon bonded graphite crucible has been sold to a firm engaged in graphite manufacture. Considerable assistance is being given to the party in the form of drawing up specifications for the machinery and furnace. A training programme for their staff to acquaint them with the intricacies of the process was also undertaken. A series of tests to fit this process to their raw materials was also done and an active interest is being taken to enable them to put up the plant as expeditiously as possible.

CLAY BONDED-This aspect of the project reached a final stage with the filing of the patent. However, a number of factors particularly on the fabrication aspects are now receiving attention.

STUDY OF GRAPHITES - It has previously been reported that a fresh set of standard for crucible grade graphite is necessary, if Indian crucible grade graphites are to be used. In a comprehensive study instituted for the purpose, the effect of grain size of graphite, the properties in bulk of graphite itself and of the properties of clay graphite mixes both in the raw and in the fired state was studied. A few more steps are necessary for complete evaluation of the data so far collected.

(xii) *Possible Use of Assam Sillimanite as Steel Plant Refractories* - While sawn blocks of Assam sillimanite have established their superiority as glass tank refractories, their use in metallurgical furnace has been particularly nil. One main obstacle is the very high cost of sawing the naturally occurring boulders using diamond saws. With a view to find a wider market for their product, the Assam Sillimanite Co. referred this problem to find any possible use for Assam sillimanite blocks in metallurgical industries.

A major possible application of these refractory blocks would be in the blast furnace as linings for the hearths, where very high temperature and severe service conditions demand a highly stable and impervious refractory lining. As such, some of the physical properties of these natural sillimanite blocks at temperature around 1600°C. have been studied, as also the action of molten pig iron on these blocks along with some bonded sillimanite bricks for comparison. Results so far obtained from these laboratory tests indicate that unless large-scale trials are carried out under actual working conditions, their suitability for this purpose cannot be fully assessed.

(xiii) *Study on Clays* - Two samples of clays from Bansi, Mirzapur District, which were sent by the Glass Technologist of the Government of U.P., were studied with a view to assess their suitability for refractory purposes. Chemical analysis and particle size as well as physical properties in the raw and fired state were studied. The preliminary study revealed that while the non-plastic clay, which seemed to be partially dehydrated in the natural state itself, would probably be suitable for making medium heat duty refractories, the other plastic clay has very low refractory properties.

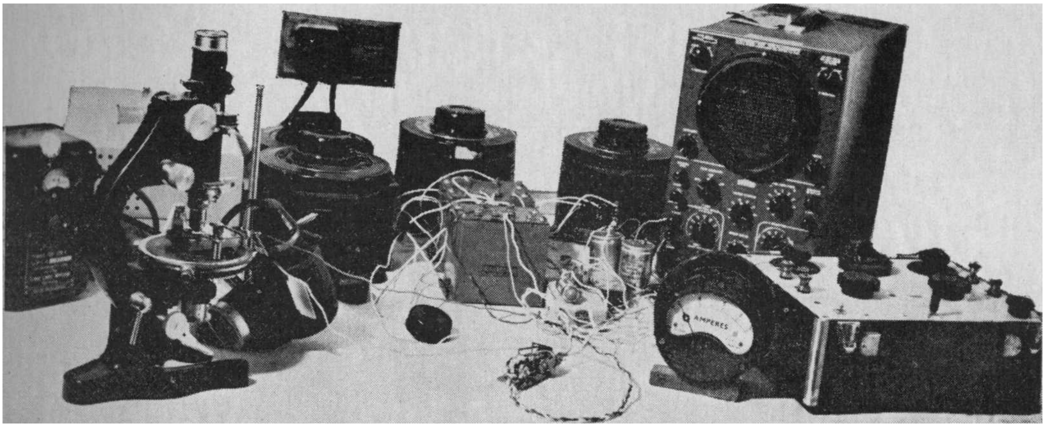
27.0 Study on Soderberg Paste

The work on kinetics of coal pyrolysis using a thermal balance was completed. The data collected were evaluated both by the classic method adopted for first order reactions and also by Madorsky's method. The latter yielded better conclusions which are now being checked. It appears that in this coal, what can be called primary decomposition sets in at about 410°C. and proceeds with increasing velocity up to 433°-438°C. Beyond this temperature there is a significant fall.

An important offshoot of the work is its applicability in the production of low temperature chars having predetermined residual volatile contents. These chars are necessary as diluent of the parent coals in the production of dense aggregates of carbon. The other features being studied under this project are the effect of blending the softening point of binders, effect of catalysts on their binding characteristics and the possibility of utilization of coke oven tar after such catalytic treatments.

28.0 Flux for Union Melt Welding

Flux for union melt welding is imported to the extent of 80 tons per annum and is expected to rise to about 250 tons per year by 1961. At the present market price this involves a foreign exchange of Rs. 160,000 to Rs. 500,000 per annum. As yet there is no organized manufacture of this type of flux in this country. The flux is mainly calcium silicate glass with a critical chemical composition and grain size and is used in the submerged arc welding process. Work on the development of the flux has been carried out in this Laboratory and after a systematic study of all the factors, a product has been developed which stood practical trial in the union melt welding machine very satisfac-



APPARATUS FOR HOT-STAGE MICROSCOPY FABRICATED AT THE NATIONAL METALLURGICAL LABORATORY, FOR STUDYING HIGH TEMPERATURE PHASE EQUILIBRIA OF REFRACTORIES, GLASS, SLAGS, CEMENTS, ETC,

torily. The welded joint obtained by using this flux has passed all the vigorous tests like tensile, bend, impact, etc. Radiographic tests for detecting porosity or any other defects in the structure of the welded metal were also carried out on samples of welded joint using the flux developed in the Laboratory and the results were found highly satisfactory.

29.0 Development of Permanent Magnet Materials

The work is initially concerned with the preparation and study of alloys of the well-known Alni and Alnico types and the development of permanent magnets from wholly indigenous materials will be taken up at a later stage.

Several melts with compositions in the range nickel, 13-27; aluminium, 10-15; copper (in a few), 3-5; cobalt, 5-22 per cent and balance iron were made and the magnetic properties were determined after various heat treatments. The alloy containing 27 per cent nickel and 12 per cent aluminium, after suitable heat treatment, is found to have a coercive force of about 540 oersteds and a remanence of about 6,500 gauss. The magnetic properties of these alloys are very sensitive to composition and heat treatment. It was found that alloys containing nickel and aluminium only have to be cooled relatively faster than those containing copper and cobalt addition.

A new solenoid was constructed, during this period, which was capable of giving uniform magnetic fields of the order of 3,000 oersteds over lengths of nearly 8 in., and with sufficient space inside to insert a tubular furnace for continued operation up to 1250°C. This solenoid was used to heat treat alloys of the Alcomax type in strong magnetic fields.

30.0 Electrical and Magnetic Properties of Some Low-manganese, Low-aluminium Steels

Work was taken up to develop low-manganese low-aluminium steels suitable for use as core material in transformers and electrical machines, with a view to improve upon, if possible, the conventional 4 per cent silicon steel sheets now generally employed.

During the period under review, samples of an earlier heat relatively high in carbon (0·1-0.2 per cent C) were tested to enable comparison to be made with those low in carbon. This steel had a coercive force greater than 1·0 oersted for an induction of 10,000 gauss. The specific resistance is of the order of 70-80 micro ohm/cm. Two melts analysing (i) aluminium 4 per cent, manganese 2·5 per cent and balance iron, and (ii) aluminium 3 per cent, manganese 4 per cent and balance iron were made. These were deoxidized with calcium. The magnetic properties of these alloys determined after forging were found to be encouraging.

31.0 Preferred Orientation in Rolled Sheets

The usual method of determining the preferred orientation produced on cold rolling sheets is based on the study of the nature and intensity of X-ray reflections. This method could advantageously be replaced, if possible, by methods based on the values of the electrical conductivity and the velocity of propagation of stress waves in rolled sheet as a function of direction.

As a preliminary and also to first obtain quantitatively the extent of preferred orientation present in cold rolled sheets the standard method using X-rays was followed and during the period under review the preferred orientation in cold rolled aluminium sheet was exhaustively studied for various rolling procedures.

In the course of studies a convenient method was devised in which some of the handicaps experienced in the conventional method of measurement, e.g. contact resistance and large sizes of specimen, were eliminated by using a somewhat different principle for the measurement of the electrical resistivity. In this method, a momentary electromotive force is induced in an annular specimen of suitable dimensions of the rolled sheet when the homogeneous magnetic field in which it is suspended is suddenly removed. The resulting ballistic throw together with a knowledge of the inertia of the suspension, its periodic time and the magnetic field enables the resistivity of the material to be calculated. Preliminary results were quite encouraging and work is. being steadily conducted on these lines.

32.0 Mechanical Properties of Stressed Materials

Several modifications to the original experimental set-up, which were found necessary, were carried out during this period. The elastic constants of a wide variety of commercial metals and alloys were determined. When the required metal or alloy was not available in a suitable form for study by this method, small ingots were made and suitable specimens prepared after necessary forging and grinding. Quartz wedges of different cuts (X-cut, Y-cut and 18°-cut) were also cut and ground, for suitable excitation and vibration of the metallic sheets.

33.0 Structure of Carbides in Alloy Steels

Studies on the structure of carbides in a 5 per cent Cr and 0·8 per cent C steel were continued during the period under review. The carbides were extracted and examined by X-rav diffraction after isothermal transformations for various lengths of time at several sub-critical temperatures in the range 700° to 250°C. The transformations were in all cases followed by hardness as well as microstructural examination and in many cases were continued for periods as long as 600 hrs. to make sure that the transformations were really complete.

The general inference is that carbides in this steel are of a Cr_7C_3 type. It was evident, however, from close examination of the X-ray photographs that a steady displacement of iron atoms by chromium atoms occurred as the transformation period lengthened. This is in conformity with the existing knowledge of the subject and confirmation was also obtained by chemical analysis of the extracted carbides and spectroscopic analysis of the pickling electrolyte. Further work on different compositions of chromium and vanadium steels including the effect of prolonged soaking at higher temperatures is in progress.

34.0 Lattice Parameters of Iron-chromium Alloys and Study of the Sigma Phase in Alloy Steels

Work has been taken up with a view to determine the nature and structure of the sigma phase arising in alloy systems of the transition elements. The importance of this investigation can be appreciated from the fact that the presence of sigma phase generally renders steel unsuitable for fabrication and cold deformation. The lattice parameters of iron-chromium alloys have also been shown to vary in a somewhat unexpected fashion and an accurate study of these lattice parameters of iron-chromium alloys can also throw light on certain fundamental aspects of alloy formation, such as short range order, existence of Brillouin zone overlaps, stacking faults, etc., besides helping in the clarification of a recent report that ageing takes place in iron-chromium alloys.

Arrangement for the preparation of pure metals using the technique of zone refining was set up. Preliminary experiments were conducted using al ıminium of commercial purity and modifications of the experimental set-up are being made to carry out the entire refining in vacuum to avoid pick up of impurities.

35.0 Utilization of Vanadium-bearing Titaniferous Magnetite Deposits of Singhbhum and Mayurbhanj

Experiments were undertaken for the recovery of vanadium by (i) salt roasting and (ii) chlorination with a view to produce vanadium pentoxide and subsequently ferro-vanadium from the vanadiferous-titaniferous- magnetite deposits of Singhbhum and Mayurbhanj.

(i) *Salt Roasting* — The studies on the optimum conditions for the precipitation of vanadium pentoxide were carried out and it was observed that maximum recovery of 80 to 85 per cent from the leach liquor could be obtained at the *p*H 1·5 to 2.3. A study on the solubility of vanadium pentoxide in sulphuric acid solution at room temperature was carried out. It was found that the solubility varied between 5·08 and 7·58 per cent in the sulphuric acid concentration range from 0·01 to 0·05 per cent corresponding to a PH range of 1·5 to 2·3. The details of a small pilot plant producing 20 lb. of vanadium pentoxide per day are being worked out and a plant will soon be set up.

(ii) *Chlorination* – The preliminary experiments have indicated that it is possible to recover 80 to 90 per cent vanadium by chlorinating the vanadium ores at 150° to 200°C. An assembly where the hydrochloric acid gas is being produced *in situ* over the ore bed by burning hydrogen and chlorine was completed and the effect of particle size, binders, fluidized bed, and the addition of sodium chloride is under study.

36.0 Production of Iron-chromium-manganese Alloy

Work **was taken up to produce iron-chromium-manganese alloy of suitable composition to be utilized in the production of nickel-free stainless steel. The preliminary experiments carried out have indicated that it is possible to produce an alloy containing 50 to 55 per cent chromium and 30 to 35 per cent manganese. The experiments were initially carried out in a small graphite crucible** where **500 gm. of alloy was produced. During the period under review, the size of the reaction vessel was gradually increased, and by a suitable modification it was possible to produce up to 800 lb. of alloy in the vessel. A total of about I tons of alloy was produced for use in the production of nickel-free stainless steel.**

36.1 Nitriding of Iron-chromium-manganese Alloy

Investigation was taken tip to incorporate nitrogen in the iron-chromium-manganese alloy for its utilization as a master alloy for producing nickel-free stainless steel. Preliminary experiments were conducted with the crushed iron-chromium-manganese alloy and the optimum conditions of size, temperature and time of nitriding were determined. Suitable nitriding vessels were designed to nitride 40, 60, 80 and 120 lb. of iron-chromium-manganese alloy respectively per batch. With these vessels nitriding was also carried out continuously running three shifts a day in gas-fired furnaces. One ton of iron-chromium-manganese alloy and 500 lb. of electrolytic manganese were nitrided.

37.0 Thermal **Beneficiation of** Low-grade Chrome Ores

With a view to utilize the large deposits of low-grade Indian chromite ores for the production of high-grade ferro-chrome, thermal beneficiation studies were taken up as the conventional ore-dressing processes were not found suitable due to the chemically associated presence of FeO and Cr_2O_3. Attempts are being made to upgrade the ore by preferential reduction of FeO by gaseous and solid reduction methods and its subsequent removal by acid leaching.

(i) Gaseous Reduction - The studies on the gaseous reduction method indicate that **it is** possible to upgrade the ore to the standard specification after roasting for one hour at 1100°C. with about 0·6 litre of gas per gram of ore, and leaching the reduced product with 10 per cent H_2SO_4 for one hour. This gave a residue with a Cr: Fe ratio of 3: 1 and a Cr recovery of 80 per cent.

(ii) *Solid Reduction - A* sample of low-grade Mysore chromite with Cr: Fe ratio 1·65 : 1 was subjected to a series of reduction tests with charcoal as the reducing agent, and a product with Cr: Fe ratio 4·8 and a Cr recovery of 79 per cent was obtained. It was also observed that a Cr: Fe ratio of 3: 1 could be obtained with more than 90 per cent recovery when reduction was carried out with an additional quantity of charcoal at lower temperature for a longer time.

37.1 Thermal **Beneficiation of** Low-grade **Manganese Ores**

The ferruginous manganese ores as such are not suitable for the production of standard grade ferro-manganese and, therefore, thermal beneficiation studies were undertaken to upgrade it by preferential reduction of iron thereby producing a manganese-rich slag. The iron which is obtained in the metallic form would be a useful byproduct.

The ore sample from Koraput, Orissa, assaying Mn, 38·9; Fe, 10·9; and P, 0·35 per cent was crushed to -7 mesh and smelted at different temperatures for various periods of time with varying amounts of coke powder. No flux was used. In the smaller scale experiments, the best results were obtained by smelting the ore in a carbon bonded graphite crucible with 5 to 6 per cent coke dust at 1350°C. for 3 hrs. It gave a manganese-rich slag assaying Mn, 48·26; Fe, 2·5; SiO_2, 21.0; and P, 0·05 per cent and a metal assaying Mn, 20·9; Fe, 70·6; and P, 2·5 per cent with a recovery of 93 per cent Mn in the slag having Mn: Fe **ratio** of 19. In larger scale experiments, the best result was obtained by smelting the ore with 7·5 per cent coke dust for 3½ hrs., other conditions remaining the same; it gave a slag assaying Mn, 46·97; Fe, 5·26 per cent and a metal assaying Mn, 20·35; and Fe, 71·08 per cent with a recovery of 95 per cent Mn in the slag with a Mn: Fe ratio of 8·9.

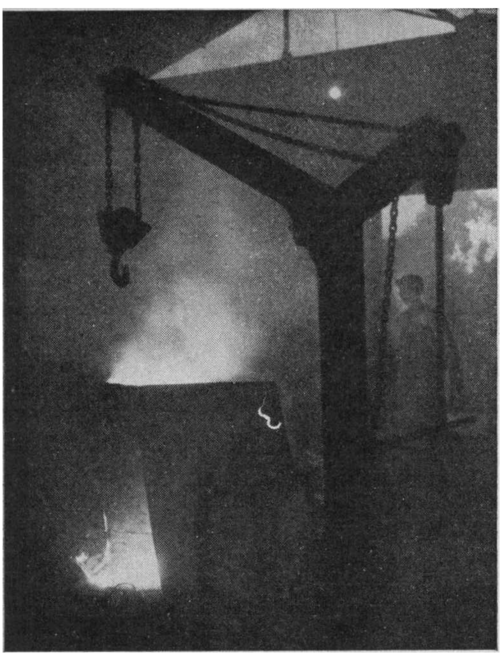
38.0 Production of Low-carbon Ferro-chrome

Low-carbon ferro-chrome is not manufactured in the country and investigations were taken up to produce low-carbon ferro-chrome containing up to 0.1 to 02 per cent carbon for use in alloy steels.

Experiments were made by pouring high-carbon ferro-chrome lumps preheated to 600°C. into the furnace containing molten ferro-silicon. Some practical difficulties were initially encountered and overcome, and low-carbon-chrome silicide assaying 0·04 per cent carbon was obtained. Further work is in progress.

38.1 Production of Carbon-free Ferro-alloys by Alumino-thermic Reaction

Preliminary experiments were conducted to produce carbon-free ferro-alloys by carrying out alumino-thermic reaction and ferro-manganese, ferro-titanium and pure metals like chromium and manganese, were produced. The carbon-free ferro-chrome produced analysed Cr, 69·2; Fe, 22·96; Si, 3·73; Al, 0·5 per cent and S and P trace. The ferro-titanium contained 52 per cent titanium.



PRODUCTION OF FERRO-ALLOYS BY ALUMINO-THERMIC REACTION AT THE NATIONAL METALLURGICAL LABORATORY

39.0 Recovery of Zinc from Coinage Alloys

The old brass coins containing 20 per cent zinc, 1 per cent nickel and the rest copper have been withdrawn from circulation and it is desired that zinc should be recovered leaving the copper-nickel alloy. Distillation of the coins was carried out under a vacuum between 0.1 and 0·05 mm of mercury varying the time and temperature factors. It was observed that at 1000°C. only 4·5 per cent of zinc could be separated even after a period of 90 minutes, while at 1050°C. nearly 18 per cent of zinc was separated just under 30 min. A mechanism to introduce the specimen into the hot zone of the furnace and withdraw the same after a specified period was incorporated to study the distillation kinetics.

40.0 Production of Magnesium from Dolomite

The investigation was taken up to produce magnesium by the silico-thermal reduction of dolomite. The pure magnesium so obtained will find varied applications especially in light structural alloys.

Preliminary experiments were carried out in a small tubular furnace by heating under vacuum briquettes formed by pressing a mixture of finely ground ferro-silicon and calcined dolomite. The briquettes were previously preheated to avoid the absorption of moisture. The magnesium vapours were condensed on a split type condenser maintained at a temperature of about 450°C. The deposit of magnesium was quite massive and very little of the pyrophoric form was obtained at the cooler end of the tube. Further work is under progress to study the optimum conditions and the suitable temperature for the best form of condensate. A vacuum furnace has been designed and fabricated to yield about a pound of magnesium per batch.

41.0 Development of Low-alloy High-tensile Structural Steels

The first phase of the work on development of low-alloy high-tensile steels was focussed on those having ferrite-pearlite structures. For increased strength the alloying elements were selected mainly for (1) increasing the strength of ferrite; (2) for increasing the pearlite/ferrite ratio; and (3) for refining grain size of the resultant steel.

A number of experimental heats were made using Mn, Si, Cr, Cu, P, Al, Ti, B, etc., as alloying elements on the above-mentioned considerations. These heats may be grouped as (1) those similar to TISCOR (Tata's steel) with increased carbon and silicon content; (2) medium manganese-chromium-phosphorus steels; and (3) manganese-chromium class with addition of copper.

The experimental heat belonging to the last group showed unusually high strength combined with fair elongation value. The steel seemed to be of air-hardening type which is rather unusual for this range of composition. Experiments are in progress to establish the exact cause of this unusual behaviour of this steel by imparting various heat treatments to the steel and its metallographic studies.

A sub-zero impact testing equipment was rigged up for evaluating the impact properties at low temperatures of the low-alloy steels prepared. Liquid air and petroleum ether were used for the low temperature bath. Some of the low-alloy steels have recorded exceptionally high impact figures even at lower temperatures. Another apparatus for testing weldability of the low-alloy steels base! on their transformation characteristics has been designed and is being fabricated.

42.0 Development of Clad Metals

A process for cladding aluminium on mild steel was developed. The composite material can have good use in automobile, aircraft, shipbuilding and railway coach industries due to its good corrosion resistance and surface finish properties combined with high strength.

The process consisted of preparation of a special block of properly cleaned mild steel plate and two aluminium sheets of proper thicknesses - the former being sandwiched between the latter. The block so prepared was subjected to cold rolling and subsequently to hot rolling at 500°C. with proper care. The composite sheet was finally annealed at 500°-600°C. for suitable period of time. Mechanical tests (cupping and bend) showed good bond strength between the metals and good deep-drawing quality of the clad sheet. Metallographic examination of the bond zone revealed thorough diffusion of metals across the interface. Attempts are now being made to evolve a suitable method for continuous production of clad sheets by using aluminium foil of suitable thickness.

43.0 Development of Electrical Resistance Alloys for Heating Elements

Almost all the electrical resistance heating elements are imported in India. The more common types of these alloys, viz. nichrome and kanthal, contain high percentages of nickel and cobalt, neither of which is available from indigenous resources. The aim of this project is to develop substitute alloys with alloying elements available from indigenous resources which can be used for domestic and industrial heating purposes.

In the initial stage a complete survey of the available literature on the requisite mechanical and physical characteristics of common alloys for electrical heating elements was made. The development work on resistance heating alloys in other countries, particularly in the U.S.S.R., has indicated the desirability of developing the ternary iron-chromium-aluminium alloys which have higher resistivity and are often more resistant to oxidation and scaling at high temperatures. The present work has been, therefore, centred around Fe-Cr-Al system.

A number of experimental heats were made with the addition of Cr, Al, Ti, Mn, Si, etc., in high frequency furnace. Some of the alloys showed very good cold workability and could be cold rolled into thin strips. The material after sufficient cold rolling could further be cold-drawn into wires down to 30 s.w.g. size. The electrical resistivities of some of these experimental alloys were found to be greater than that of nichrome. Simple service performance test based on continuous heating at about 1000°C. of these elements when compared to that of nichrome has shown sufficient scaling resistance as well. An apparatus for standard accelerated life test of the electrical resistance alloys according to the A.S.T.M. specifications has been set up.

44.0 Development of Technique for Production of Bi-metals

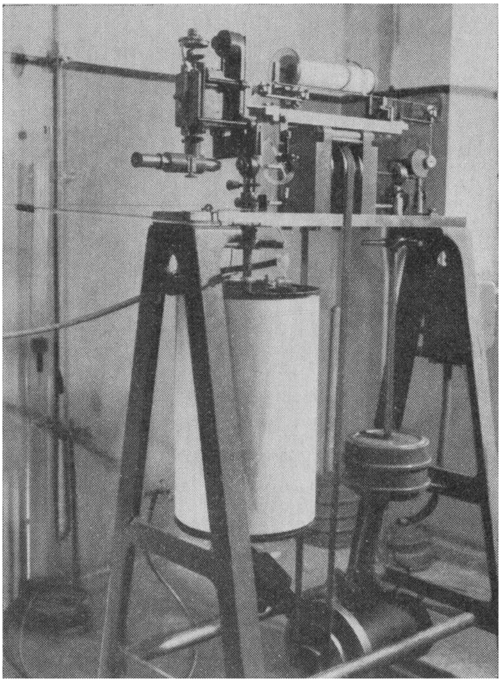
Bi-metals are extensively used in various kinds of temperature controlling devices, electrical contact switches, etc. The manufacturing methods for Bi-metals are closely guarded secrets. In view of the interest shown by the Indian industries in production of Bi-metals, the project has recently been undertaken with a view to develop a suitable technique for the production of the same.

A few experimental heats of some iron-nickel alloys with varying amounts of nickel were made and their mechanical and physical properties are being determined. An interferometric method is being used for determining the coefficient of thermal expansion of these metals.

45.0 Development of a Short-time Fatigue Testing Method

Conventional methods of fatigue testing are very time consuming, requiring several months to determine the fatigue limit of a single material. It was, therefore, thought advisable to evolve a short-time fatigue testing method. For this purpose a new attachment to the standard Amslar fatigue testing machine was designed and fabricated for recording automatically the load-deflection curve of the rotating beam under progressively increasing load.

The load-deflection curves obtained during the test showed a sudden deflection at a certain stage. The corresponding stress was found to be identical with the fatigue limit of the material which was also determined by means of conventional fatigue methods for checking the results. Several types of steel responded within close limit of this test. Thus this accelerated fatigue testing method can profitably be used for ferrous materials.



A VIEW OF AN ATTACHMENT TO THE STANDARD AMSLAR FATIGUE TESTING MACHINE FOR SHORT CYCLE FATIGUE TEST, DESIGNED AND FABRICATED AT THE NATIONAL METALLURGICAL LABORATORY

PILOT PLANTS

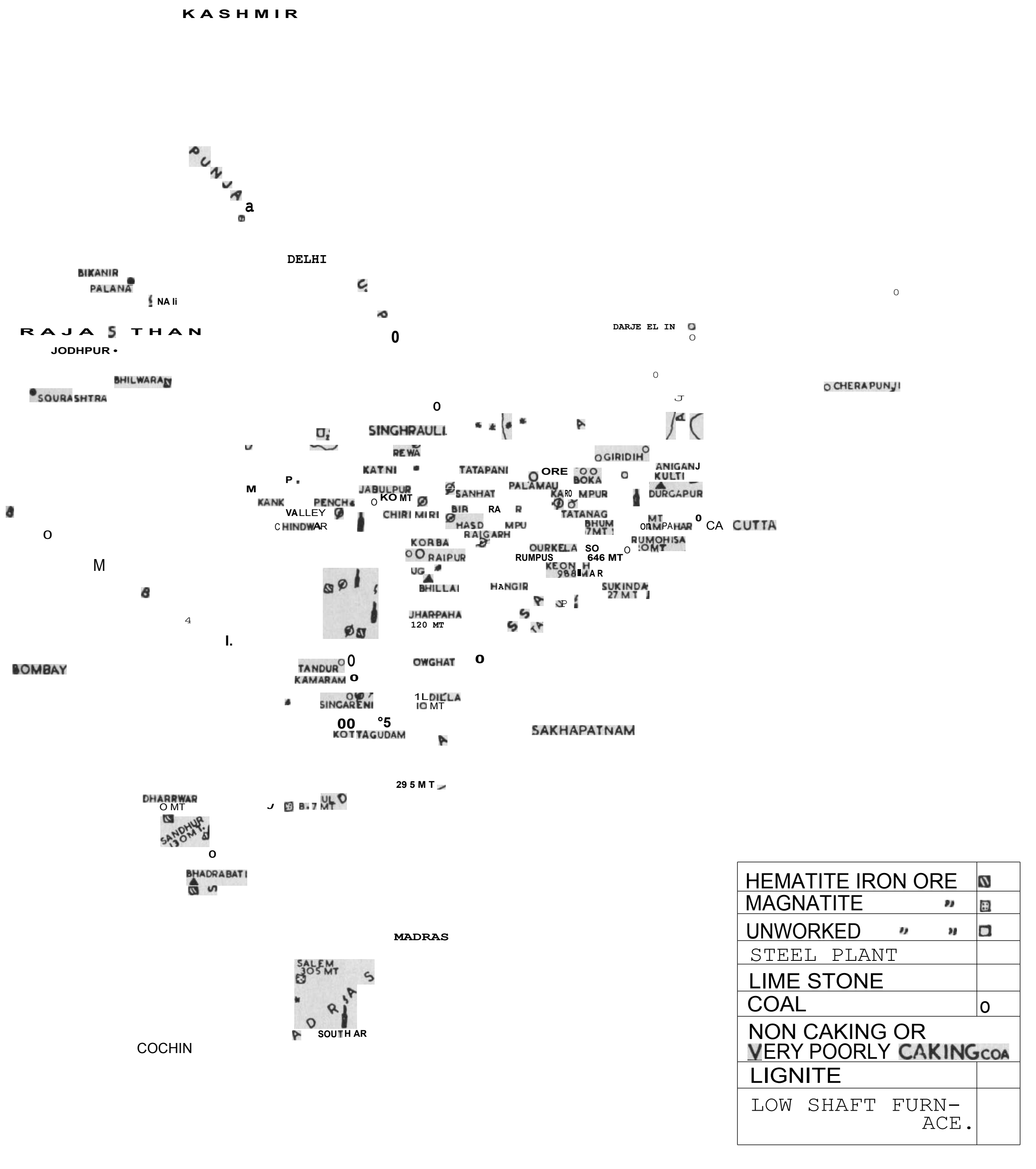
46.0 Low-shaft Furnace Project

Before a large gathering of Indian and foreign scientists and technologists, the Low-shaft Furnace Pilot Plant, the first of its kind installed in the East, set up by the National Metallurgical Laboratory at Jamshedpur, was inaugurated on the 5th February 1959 by Hon'ble Sardar Swaran Singh, Union Minister for Steel, Mines and Fuel.

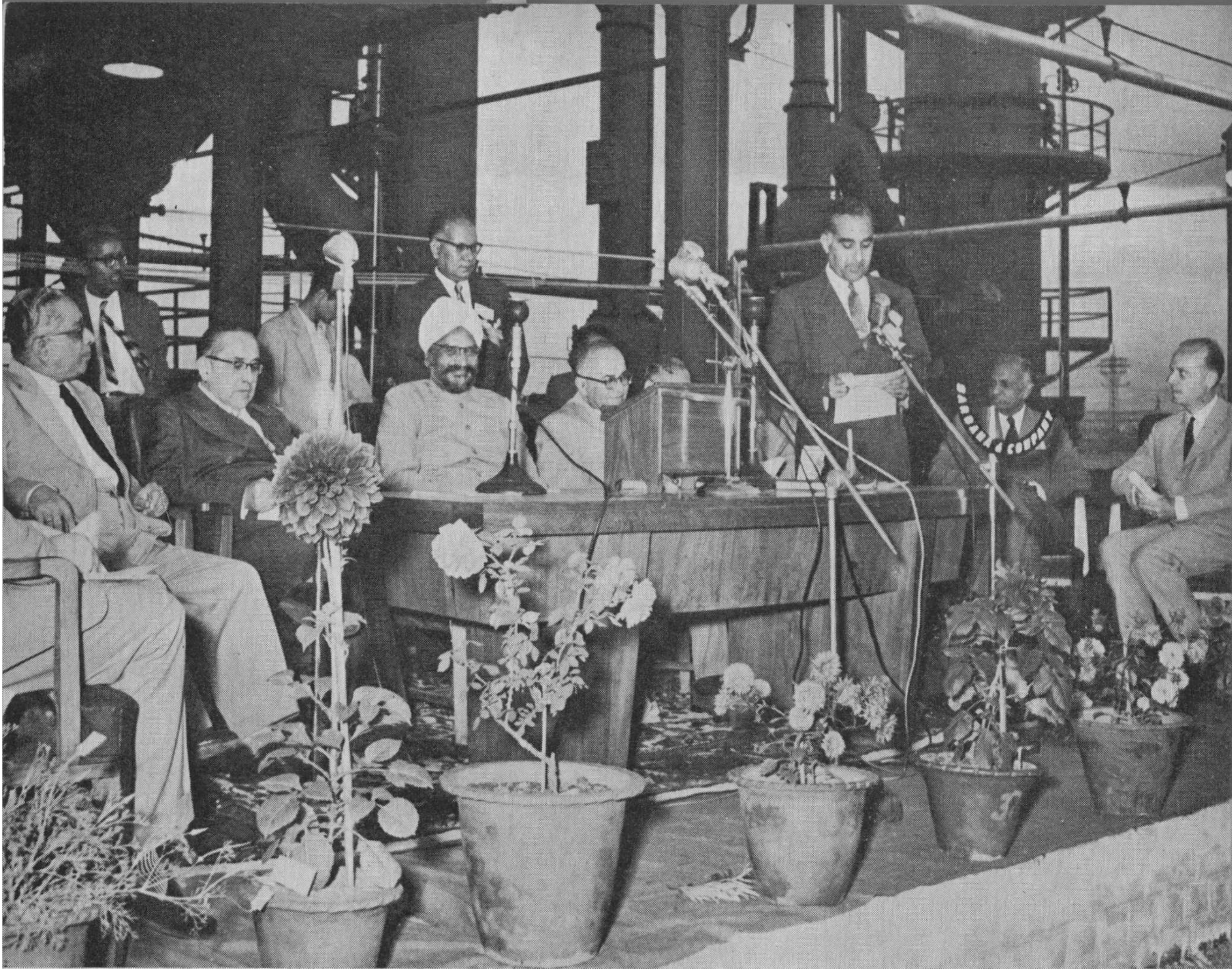
The capital cost of the Low-shaft Furnace Plant Project has so far amounted to about Rs. 27 lakhs. Actual construction work started in April 1957 and was virtually completed by the end of 1958. The site of the plant has the facilities of an industrial siding, unfiltered and filtered water mains, availability of power and other essential services. An appropriate layout of the plant including all its ancillary equipment with arrangements for stacking the raw materials and their handling, office-cum-laboratory, railway siding, and water circulation system was made after partial levelling of the site and provision was kept for future expansion. Considerable difficulty was experienced while excavating for foundations, as water was met with at about 5 ft. below the ground level and the micaceous soil necessitated deeper foundations. More than 400,000 cu. ft. of earth were moved and 18,000 cu. ft. of cement concrete poured. Structurals for the briquetting plant were welded and besides the supplies of the DHN, about 160 tons of structural steel were procured from indigenous sources for the briquetting plant and the various reinforced concrete foundations.

Scope and Function - The Low-shaft Furnace Pilot Plant of the National Metallurgical Laboratory has a production capacity of 15 tons of pig iron per day and will be able to treat different inferior grades of raw materials. The object of the comprehensive investigations is to assess the possibilities of making commercial grades of pig iron with raw materials like soft iron ores, iron ore fines, beneficiated magnetite iron ore, with various non-coking high ash coals or carbonized lignite, plentiful supplies of which exist in India but are unsuitable for exploitation in conventional blast furnaces. The production of standard and exportable grade of ferro-manganese is also envisaged. The results of these extensive investigations will be of great value and enable the establishment of small units for iron and steel production in different parts of India.

The Raw Materials and the Furnace Operation - The 15-ton per day Low-shaft Furnace Pilot Plant, supplied by the Demag-Humboldt Niederschachtofen, Duisburg, West Germany, operates on iron ore, limestone, non-coking coal briquettes. The daily operating of the plant needs over 100 tons of raw materials. The plant has provision for crushing the raw materials which are then elevated by bucket elevator and stored in five storage bunkers. These are drawn from the bunkers in calculated proportions by a moving trolley with a bin and dumped in a hopper. The mixed raw materials are lifted by bucket elevator and fed into a vibrating screen and thence into mixers where coal-tar pitch is added. The intimate mixture of ore, coal and limestone passes through dough mixers and then briquetted under pressure in a roller briquetting machine. About six tons of briquettes will be necessary to produce a ton of iron. The weighed amount of briquettes is charged into the furnace by a system of belt conveyer. The furnace is lined with carbon-blocks up to the hearth



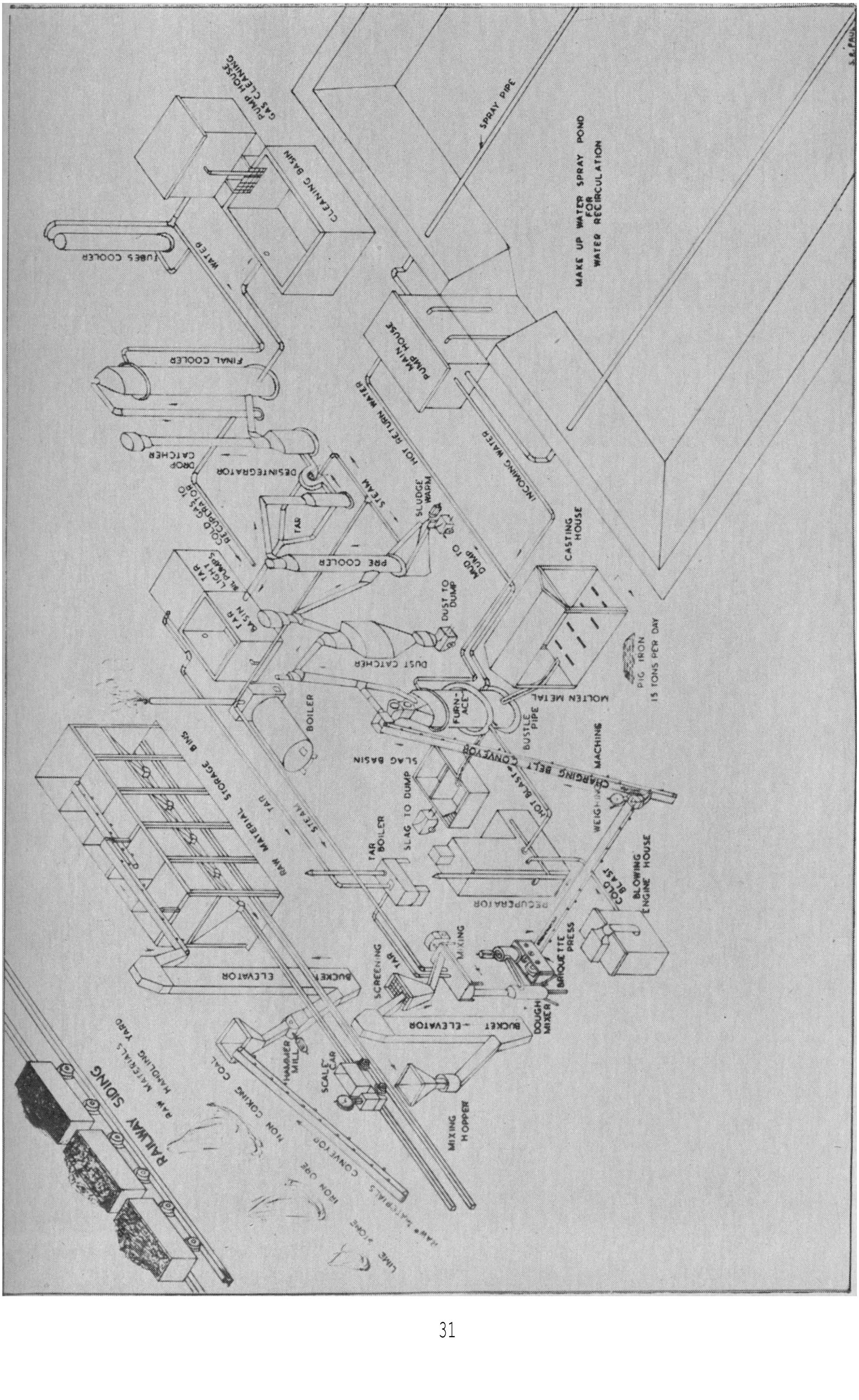
MAP SHOWING THE DISTRIBUTION OF RAW MATERIALS FOR IRON AND STEEL MANUFACTURE AND PROBABLE SITES FOR LOW-SHAFT FURNACES

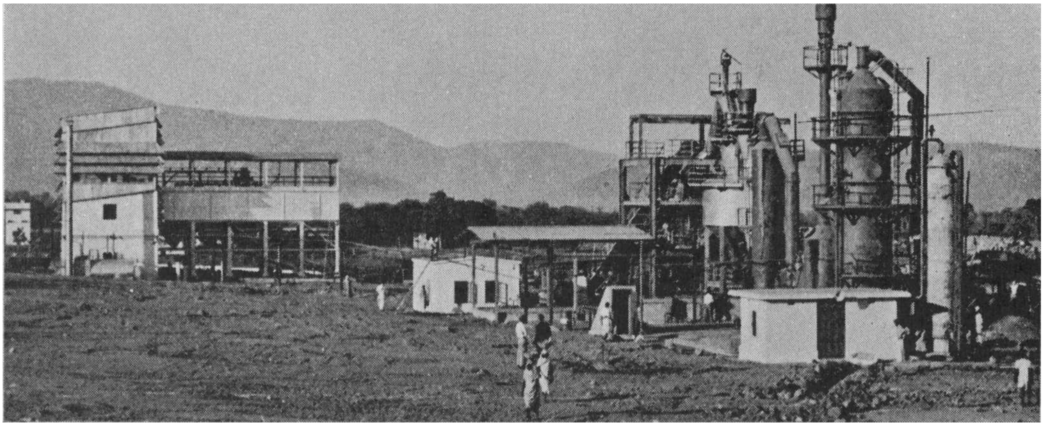


INAUGURATION OF THE PILOT LOW-SHAFT FURNACE OF 15 TONS'/DAY CAPACITY BY SARDAR SWARAN SINGH, UNION MINISTER FOR STEEL, MINES AND FUEL, ON 5TH FEBRUARY 1959. DR. B. R. NIJHAWAN, DIRECTOR, IS WELCOMING THE DISTINGUISHED GUESTS. SIR J. J. (;HANDY, CHAIRMAN, EXECUTIVE COUNCIL, NATIONAL METALLURGICAL LABORATORY, AND PROF. M. S. THACKER, DIRECTOR-GENERAL, SCIENTIFIC & INDUSTRIAL RESEARCH, ARE SEATED ON THE HON'BLE MINISTER'S RIGHT AND LEFT

level. The blast supplied by a turbo-blower will be pre-heated to about 600°C. in a metal tube recuperator. At the start of each individual campaign, the blast will be pre-heated by an oil burner in the recuperator. When furnace gas becomes available, it will be used for pre-heating the blast. The slag from the furnace will be granulated for further use. Molten pig iron will be cast in the form of pigs in the casting house.

The raw gas will be thoroughly cleaned by its passage through the dust catcher, primary cooler, drop-catcher and final cooler and a part of it will be utilized for heating the blast in the recuperator whilst the balance will be bled off at this stage. The recovered tar and dust will be utilized for making briquettes. The power required for the operating of the plant will be supplied from a 500 kVA transformer which will step down the voltage from 6600 to 450 volts. The total cooling water requirements for cooling the furnace and for gas cleaning are about 1 million gallons a day. With the installation of water cooling and circulating tanks, make-up water to the tune of 100,000 gallons


RAILWAY SIDING
RAW MATERIALS HANDLING YARD
COAL
NON COKING COAL
IRON ORE
LIME STONE
RAW MATERIALS CONVEYOR
HAMMER MILL
SCALE CAR
MIXING HOPPER
BUCKET ELEVATOR
BUCKET ELEVATOR
DOUGH MIXER
SCREENING
TAR
MIXING
BRIQUETTE PRESS
BLOWING ENGINE HOUSE
COLD BLAST
RECUPERATOR
TAR BOILER
SLAG TO DUMP
WEIGHING MACHINE
CHARGING BELT CONVEYOR
HOT BLAST
SLAG BASIN
BUSTLE PIPE
FURNACE
BOILER
RAW MATERIAL STORAGE BINS
STEAM
TAR
DUST CATCHER
DUST TO DUMP
MOLTEN METAL
PIG IRON
15 TONS PER DAY
CASTING HOUSE
MUD TO DUMP
PRE COOLER
TAR BASIN
TAR LIGHT OIL PUMPS
COLD GAS TO RECUPERATOR
TAR
SLUDGE WARM
STEAM
DESINTEGRATOR
DROP CATCHER
HOT RETURN WATER
INCOMING WATER
MAIN PUMP HOUSE
FINAL COOLER
WATER
TUBES COOLER
CLEANING BASIN
GAS CLEANING PUMP HOUSE
SPRAY PIPE
MAKE UP WATER SPRAY POND FOR WATER RECIRCULATION



A PANORAMIC VIEW OF THE 15 TONS/DAY CAPACITY LOW-SHAFT FURNACE PILOT PLANT INSTALLED AT THE NATIONAL METALLURGICAL LABORATORY

per day will be needed. Water from the furnace will be utilized for slag granulating and water from the gas-cleaning system and tuyere cooler will be recirculated after cooling through sprays so as to bring down the make-up water consumption to its minimum. Processed steam will be supplied by coal-fired steam boiler which will supply 1 ton of steam per hour, at a pressure of 7 atmospheres with a degree of superheat of about 350°C. It has also been provided with filtration and water-softening units.

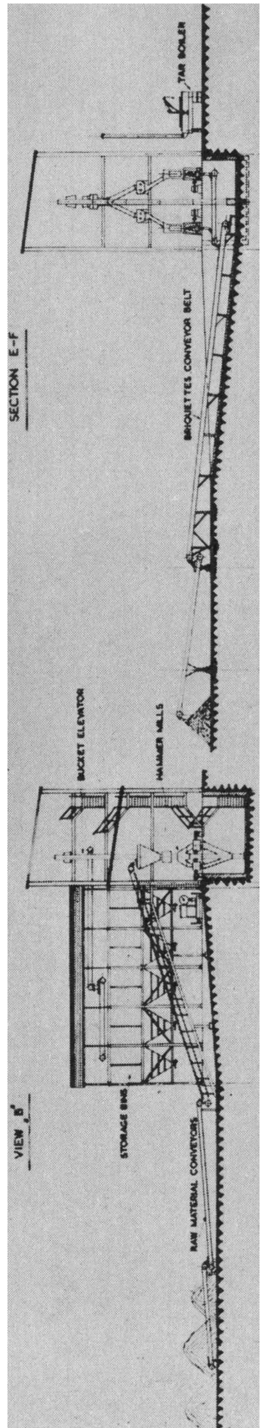
The furnace was blown in for the first time on 15th of March 1959. During the first campaign the following quantities of raw materials were used:

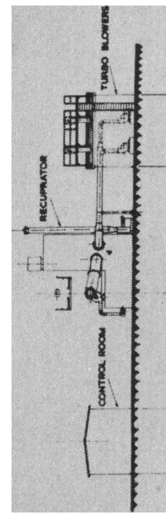
Size, mm.	*Kg.*
Iron ore (10-30)	6,300
Coke (25-50)	15,995
Limestone (15-30)	3,070
B.F. slag (20-40)	9,900
Quartz (15-30) (Only at the beginning)	100

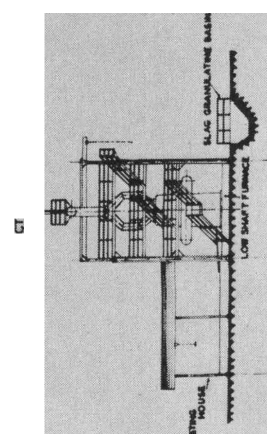
The next campaign was carried out for four days in which 65 per cent of the coke in the burden was replaced by the lumpy non-coking coal of Raniganj coalfield. The following amounts of raw materials were charged:

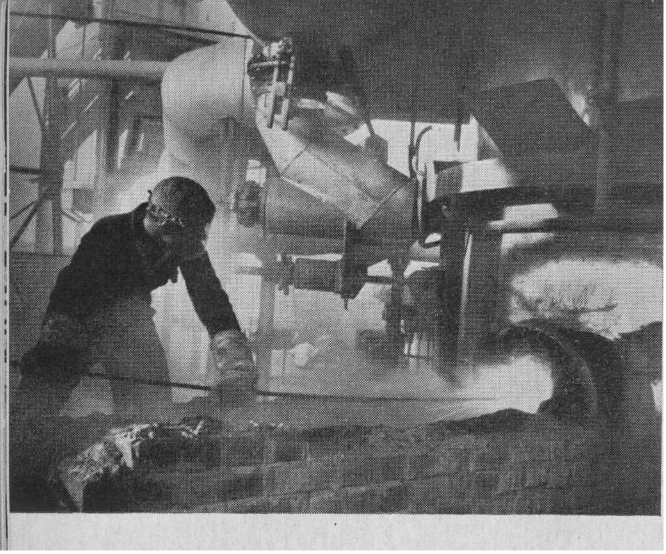
Size, mm.	*Kg.*
Iron Ore (15-30)	40,240
Coke (25-50)	90,800
Limestone (15-30)	30,115
B.F. slag (20-40)	9,110
Non-coking coal (20-40)	6,030

The pig iron produced showed an average analysis of total carbon 3.0 per cent, graphitic carbon 1·8 per cent and silicon 3·2 per cent. The microscopical examination of the pig iron revealed a normal structure. The basicity of the slag was nearly 1·0. In the next campaign, attempts would be made to carry out smelting operation with 100 per cent non-coking coal from Raniganj and Hazaribagh coalfields.


SECTION E-F
TAR BOILER
BRIQUETTES CONVEYOR BELT
BUCKET ELEVATOR
HAMMER MILLS
VIEW "B"
STORAGE BINS
RAW MATERIAL CONVEYORS


TURBO BLOWERS
RECUPRATOR
CONTROL ROOM


CT
SLAG GRANULATING BASIN
LOW SHAFT FURNACE
CASTING HOUSE



TAPPING OF PIG IRON FROM LOW-SHAFT FURNACE **INSTALLED** AT THE NATIONAL METALLURGICAL LABORATORY

46.1 Comprehensive Tests on Self-fluxing Briquettes for Smelting in the Low-shaft Furnace

A large number of self-fluxing briquettes containing 44 per cent iron ore (hematite -5 mm. size nearly), 34 per cent non-coking coal (2 mm. size nearly), 14 per cent limestone (2 mm. size nearly) and 6 per cent pitch with addition of varying amounts of moisture were made under the forming pressure ranging from 3 to 10 tons/sq. in. load. The room temperature crushing strength of the briquettes was found to increase with higher forming pressure. The DHN testing machine was assembled and properly calibrated. The deformation of the briquettes under a definite static load during heating from 350° to 650°C. was studied. In the DHN testing machine the results of the tests have shown that other constituents and conditions being the same, the briquettes having the higher forming loads tend to crumble under a higher applied pressure and at a higher temperature. Under a comprehensive programme several hundreds of briquettes using magnetite, hematite, limestone, dolomite, coal, coke-dust, sulphite lye, coal-tar pitch, etc., were prepared and their testing is in progress.

47.0 Pilot Plant Production of Steel by L.D. Process

Investigations on top blowing with oxygen were conducted for the standardization of the " Double Slagging Technique " of refining the normal high silicon, medium phosphorus Indian pig iron as well as to catch carbon at a desired level during the process of refining. The first stage of lancing was conducted to eliminate most of the silicon and retaining the phosphorus and carbon in the bath. The second stage of lancing was then adjusted to obtain highly reactive basic fluid slag for the early removal of phosphorus without too much oxidation of carbon, which can be kept at a desired value. Lime/limestone/millscale were added in suitable proportions for obtaining the desired slag. The process was demonstrated in ' India-1958 ' Exhibition when 22 actual blowings were shown. Typical results are as follows :

Percentage	*Average composition of pig iron*	*Steel produced*
C	3·5	0.50
Si	2·0	0.025
P	0·36	0.05
Mn	0·80	0.04
S	0·035	0.025

48.0 Semi-pilot Plant Production of Electrolytic Manganese

The manganese plant continued to meet the heavy demand for manganese metal for the alloy development programme of the Laboratory. Each time the cell plant was started, the cell was run at a stretch for three weeks and more, cathodes being replaced at the end of 32 hrs. and more. The cell plant has been completely mechanized and has proved complete success in long duration of work. Progress has been made with the setting up of the 100 lb./day manganese plant in the new pilot plant building. A new cell, capable of taking 1000 amps, was designed and fabricated. This cell differs radically in several features from the present ones. These new features, viz. sludge box, diaphragm frames, diaphragm positions and anolyte removal, are introduced to favour smooth working and simplicity in construction of cells.

49.0 Semi-pilot Plant Production of Electrolytic Manganese Dioxide

The manganese dioxide plant was worked alternately with the manganese metal plant. The cell was generally run for 15 days and more at a stretch. The thick shiny deposits of manganese dioxide obtained on the graphite anodes were found to be absolutely pure and contained no impurities other than traces of graphite, which were only beneficial in use of manganese dioxide for dry cells. Setting up of the 100 lb./day manganese dioxide plant in the new pilot plant building is under progress. A single cell, capable of producing 100 lb. of manganese dioxide in a day, is being designed.

50.0 Semi-pilot Plant Studies on the Beneficiation of Ferruginous Manganese Ore from Joda West Mine of Tata Iron & Steel Co. Ltd. and Proposals for a Plant of 600 tons/day Capacity Employing the Low-temperature Magnetizing Reduction Process

An ingenious process based on low-temperature magnetizing gaseous reduction has been developed which economically produces high-grade manganese concentrates from ferruginous low-grade manganese ores. This process excludes external heat for the reduction process and yields a friable product which can be very easily crushed and ground for the subsequent magnetic separation. A concentrate of grade about 52 per cent Mn with a Mn: Fe ratio of 7: 1 was obtained from a low-grade ore from the mines of Tata Iron & Steel Co. Ltd., in Keonjahar District, Orissa, assaying Mn, 27·2; Fe, 24.2; SiO_2, 7.53; Al_2O_3, 7.43; and P, 0.09 per cent with a manganese recovery of 62·0 per cent. Three tons of low-grade ore are required to produce a ton of manganese concentrate suitable for making standard grade ferro-manganese. The cost of this concentrate is estimated at about Rs. 85 per ton inclusive of cost of mining, upgrading treatment, briquetting and depreciation on the basis of an estimated capital outlay of Rs. 90 lakhs required for a plant to upgrade 600 tons of low-grade ore per day. A plant of this size can produce enough concentrate to feed a plant with a production capacity of 36,000 tons of standard grade ferro-manganese per year. Proposals are put forward for a plant to beneficiate 600 tons/day of this ferruginous ore and suggested machinery required for the purpose and capital cost for same.

50.1 Pilot Plant Studies on the Beneficiation of Low-grade Ferruginous Manganese Ore from Siljora-Kalimati Mines, Orissa

A concentrate of grade 52·3 per cent Mn with a recovery of 79 per cent Mn for a Mn to Fe ratio of 7: 1 was obtained from a low-grade ferruginous ore from Siljora-Kalimati mines, Keonjhar District, Orissa, assaying Mn, 37·5; Fe, 16·4; SiO_2, 12; Al_2O_3, 9·0; and P, 0·08 per cent. 1·8 tons of run-of-mine ore are required to produce a ton of manganese concentrate suitable for making standard grade ferro-manganese or for export purposes. The magnetic reject obtained during magnetic separation could be used as the starting material for the production of manganese sulphate.

Based on the results a' proposal has been put up for a beneficiation plant of capacity 100 tons/day to treat the ferruginous manganese ore giving flow-sheet, list of machineries and their cost estimate, etc.

50.2 Pilot Plant Studies on the Beneficiation of Ferruginous Manganese Ores by the Patented Process Developed at N.M.L.

(i) Sample from Joda, Orissa - The sample as received assayed Mn, 27·2; Fe, 24·2; SiO_2 and A1203, 14·9; and P, 0.09 per cent. As there was no selective separation of manganese minerals from the ferruginous gangue, which was mostly present as bauxitic limonite, this sample was not found to be amenable to the patented process.

(ii) *Sample from Nagri-Joida, Mysore*- The sample from this locality assayed Mn, 34·2; Fe, 16·5; SiO_2 and A1203, 15.0; and P, 0.06 per cent. This sample had almost the same characteristics as those of the Joda ore. The ferruginous gangue was present as bauxitic limonite and, therefore, could not be eliminated to any appreciable extent by straight magnetic separation.

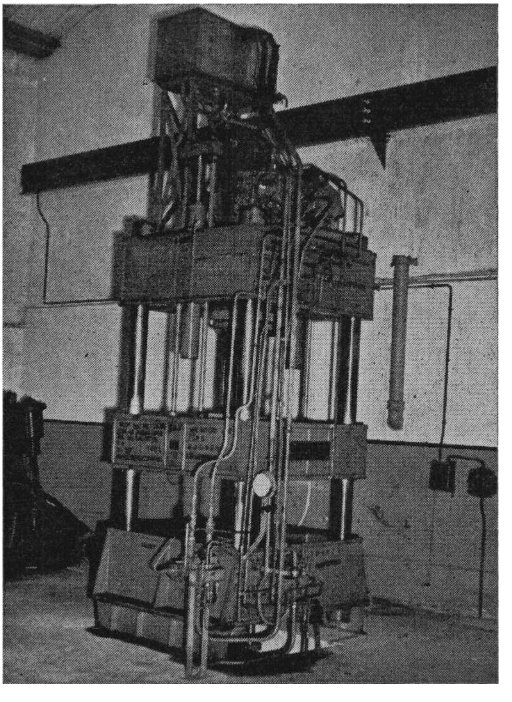
(iii) *Sample from Kumsi, Mysore - A* sample of low-grade manganese ore from Kumsi, Mysore, assayed Mn, 34·8; Fe, 1·1; SiO_2, 28·8; A1203, 3·0; and P, 0·016 per cent. Magnetic separation of -100 mesh deslimed sample yielded a manganese concentrate assaying Mn, 46·6; Fe, 6·5; SiO_2 and A1203,9·9; and P, 0.017 per cent with a manganese recovery of 73.4 per cent.

(iv) *Sample from Kuttinga, Orissa* - The sample assayed Mn, 38·9; Fe, 10·9; SiO_2 and A1203, 12·7; and P, 0·35 per cent. Magnetic separation of -10 mesh deslimed ore after heating yielded a manganese concentrate assaying Mn, 46.2; Fe, 6·6; SiO and A1203, 8·5; and P, 0·27 per cent with a recovery of 70·8 per cent Mn. Except for high phosphorus content, the concentrate conformed to the required specifications.

(v) Sample from Rairakhol Mines, Orissa - The sample as received assayed Mn, 38·5; Fe, 17.5; SiO_2, 3·8; A1203, 5·0; and P, 0·35 per cent. Low intensity magnetic separation for removal of magnetite at 35 mesh size, followed by high intensity magnetic separation of deslimed and preheated sample yielded a manganese concentrate assaying Mn, 47·6; Fe, 7·0; and P, 0.34 per cent, with a Mn recovery of 53·8 per cent. This concentrate can, however, be used for production of ferro-manganese only after blending with low phosphorus ores or concentrates.

51.0 Hot-dip Aluminizing of Steel Wire and Sheets

The laboratory scale work on hot-dip aluminizing of ferrous materials has given very encouraging results and the quality of the product produced shows good heat and corrosion resistant properties. The work of the Laboratory can be taken up by the industry, if manufacturing conditions similar to industry are standardized on a pilot plant scale. Such a plant is under fabrication for aluminizing of mild steel wire to begin with at the National Metallurgical Laboratory.



A VIEW OF THE HYDRAULIC **PRESS OF** 2 TONS/SQ. IN. CAPACITY **RECEIVED** FROM U.K. **UNDER THE** TECHNICAL CO-OPERATION **SCHEME OF** COLOMBO PLAN

The fabrication of degreasing, pickling and washing tanks has been completed and the melting kettle for aluminium has to be cast, pattern for which is being made. The coiler and the decoiler are now being fabricated. Some industrial work was undertaken for the Premier Automobile Ltd., Bombay, for Fiat car mufflers. The different parts of the mufflers were aluminized and were sent for service trial to the party.

52.0 Refractories Pilot Plant

Based on research carried out in the Laboratory, a number of patents have been obtained on improved manufacturing technique and development of refractories which are not being made in the country so far. As pilot plant trials are very essential before such new products and techniques are exploited commercially, a pilot plant for the production of refractories of different types was planned and during the year under review the tentative layout of the plant, the different machinery and equipment required were worked out and orders were placed for the machinery, some of which have since been received. The final layout of the plant, construction of the pilot plant bay and erection of the equipment are being pursued actively.

During this period with the limited capacity laboratory equipment already available and improvising others, semi-pilot plant trials were carried out on carbon and clay bonded graphite crucibles, dense and insulation refractories from bladed kyanite and magnesite refractories from Almorah magnesite.

LIAISON AND INFORMATION SERVICES

TECHNICAL AID TO INDUSTRIES

The Liaison and Information service to industries and government bodies has been enlarged considerably both in scope and actual service rendered. One of the main activities of the National Metallurgical Laboratory is technical aid to small and medium scale industries. Such technical aid often requires exhaustive examination of technical information available from published sources, compilation of statistical data, practical observations arising out of periodical visits to industrial establishments and *ad hoc* investigations in the respective divisions of this Laboratory in which the Liaison and Information Division is playing an active role. The Laboratory has attached considerable importance to such technical aid to metallurgical industries. During the last few years the Laboratory has conducted a large number of experimental and *ad hoc* investigations on behalf of the industries which relate to the causes and remedial measures of the failure of the equipment, methods of improving the quality of the products, utilization of indigenous raw materials, manufacturing processes of various articles, etc. Such investigations have not only helped the industries to solve their difficulties but have also resulted in efficient production. Besides, this Division correlates the technical problems and enquiries received from outside. As much as 200 technical enquiries were attended in 1958-59 alone and 19 short-term investigations and specification tests were conducted by the Laboratory on behalf of industries.

PUBLICATIONS

Neirly three hundred papers have been published up to date in Indian and foreign journals. The Laboratory has also a technical journal of its own published every quarter for disseminating the scientific knowledge and carrying the results of research to the doors of industry. The details of publication are furnished in Appendix I.

PATENTS

During the year under review, non-technical notes on the following patented processes were prepared and circulated:

1. Refractory compositions comprising graphite and alumino-silicate materials and glasses to render such compositions resistant to oxidation - Patent No. 62352.
2. Improvements in or relating to hot-dip aluminizing of steel - Patent No. 65230.
3. Improvements in or relating to mullite refractories from kyanite - Patent No. 58553.
4. A process for the stabilization of dolomite and a method of making refractory bricks from stabilized dolomite -Patent No. 61981.
5. A process to produce dense carbon aggregates from carbonaceous materials of varied volatile contents - Patent No. 62938.
6. Hot-dip aluminizing of ferrous materials — Patent No. 55289.
7. Improvements in or relating to magnesium silicate refractories and use of the same - Patent No. 57884.

Great interest has been shown by a large number of industries for the commercial exploitation of some of the above processes and concrete offers for the commercial exploitation of the patents have been received which are under consideration.

The following patents have been filed during the period under review:

1. A process for recovering zirconium dioxide from zircon - Patent No. 63904 dated 30 April 1958.
2. Improvements in or relating to hot-dip aluminizing of steel - Patent No. 65230 dated 13 September 1958.
3. An improved method for the production of chromium-manganese alloys by alumino-thermic reaction - Patent No. 65231 dated 13 September 1958.
4. A process for electrolytic production of iron-chromium alloys from chromite ore - Patent No. 65558 dated 24 October 1958.

The following patents were applied for during the period under review :

1. A process for the production of chemically bonded metal clad or unclad basic refractories.
2. A process to produce carbon pastes for **use in** the continuous Soderberg electrodes of electric ferro-alloy furnaces and electric cells used in the manufacture of metals like aluminium.

PRACTICAL DEMONSTRATION

The following patented processes developed in the National Metallurgical Laboratory were released free of royalty for the benefit of the small-scale industries.

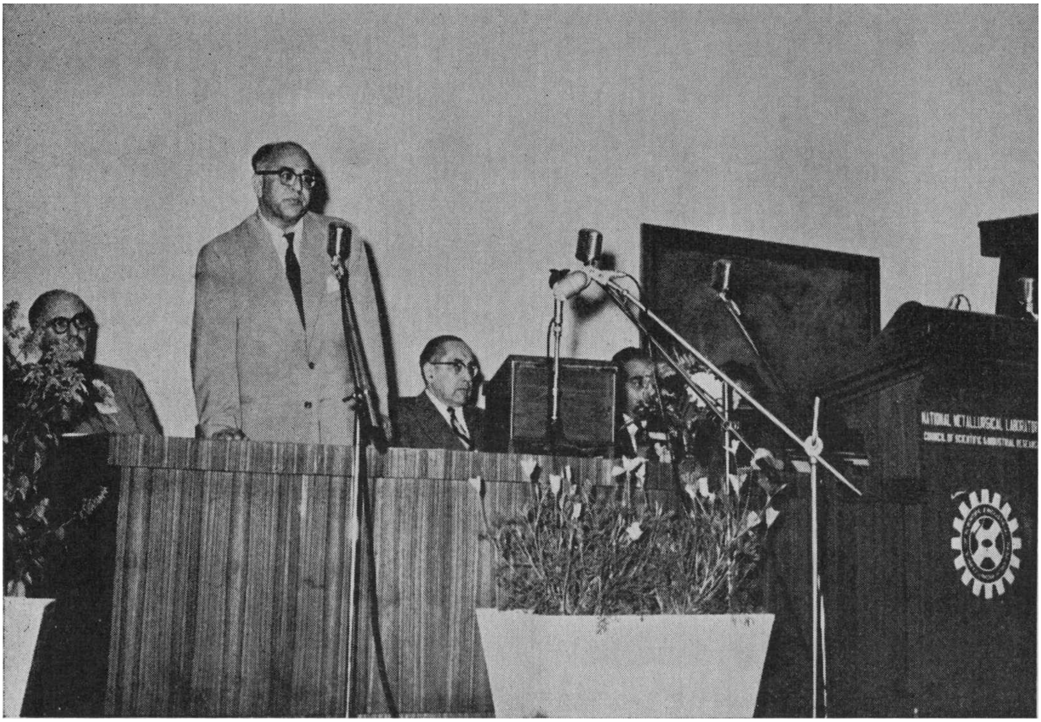
1. Improvement in or relating to electroplating of metals on aluminium - Patent No. 51524.
2. Chemical polishing of aluminium - Patent No. 47401.
3. Improvement in or relating to brass plating from non-cyanide bath - Patent No. 45565.
4. Improvement in or relating to metallization of non-conductors — Patent No. 45579.

To impart the technical ' know-how ' of the processes, one-week demonstration programme was held in the Laboratory which was attended by a large number of representatives of small plating and allied industries also from the Small Industries Service Institute, Government of India. Sir Jehangir Ghandy, Kt., C.I.E., Chairman, Executive Council of National Metallurgical Laboratory, inaugurating the demonstration said that National Metallurgical Laboratory has given very good account of itself in the last few years. Finding practical application and implementing the results of research is no less important than the successful accomplishment of investigations in the Laboratory. He concluded by referring' to the importance of these patented processes released free of royalties and hoped that the small-scale industries from all parts of India will greatly benefit from the dissemination of the technical know-how given freely by the National Metallurgical Laboratory. The decision to release the processes free of royalties, even though substantial payment offers were received, was highly commended.

SYMPOSIUM

A symposium on " Iron and Steel Industry in India " was organized by the National Metallurgical Laboratory from 4th to 7th February 1959, to focus attention on the latest technological and research developments in the iron and steel industry and their rational utilization. The Symposium was inaugurated by Prof. M. S. Thacker, Director-General, Scientific & Industrial Research. Sir J. J. Ghandy, Kt., C.I.E., Director-in-Charge, Tata Industries Ltd. and Chairman, Executive Council of the National Metallurgical Laboratory, presided.

Sir Jehangir Ghandy, in his presidential address, pointed out that the Symposium organized by the National Metallurgical Laboratory should give an impetus to the studies in hand and provide encouragement for further work both in the laboratory and



PROF. M. S. THACKER, DIRECTOR-GENERAL, SCIENTIFIC & INDUSTRIAL RESEARCH, DELIVERING THE INAUGURAL ADDRESS AT THE SYMPOSIUM ON IRON AND STEEL INDUSTRY IN INDIA "

on the shop floor. Sir Jehangir reviewed some of the latest developments in iron and steel technology and suggested their applications in India. He highly commended the research work conducted in this direction in the National Metallurgical Laboratory and extended, on behalf of the Executive Council, their deep appreciation to Dr. Nijhawan and his staff for the very valuable work being done by them in the laboratory.

Prof. M. S. Thacker, in his inaugural address, observed that the Symposium on " Iron and Steel Industry in India " organized by the National Metallurgical Laboratory, was particularly significant in the context of India's Second Five Year Plan. Despite the fact that India had substantial resources of iron ore, Prof. Thacker pointed out, her *per capita* consumption of steel was very low compared to that of other industrially advanced countries of the world. It was, however, a happy augury, he stated, that the new steel plants in the public sector had started production and this Symposium rightly synchronized with the opening of Rourkela and Bhilai Steel Projects. The deliberations of the Symposium in which many foreign and Indian experts are taking part, would, no doubt, be a great contribution to the promotion of the industry in this country. He paid a warm tribute to Dr. Nijhawan and his research workers for the excellent work they were doing in the National Metallurgical Laboratory.

The Symposium drew a large gathering of top-ranking scientists in different branches of iron and steel from all over the world like Prof. Charles Crussard, Director, IRSID, France; Dr. P. Coheur, Mg. Director, National Metallurgical Research Council and Professor of Metallurgy at the University of

Liege, Liege, Belgium; Dr. T. P. Colclough, Technical Adviser, British Iron and Steel Federation, U.K.; Mr. R. H. Collcutt, the British Iron and Steel Research Association, London; Mr. W. S. Hindson, Managing Director, Indian Steel Works Construction Co. Ltd., London; Prof. G. R. Bashforth, UNESCO Expert in Metallurgy; Prof. Dr. Ing. Erich E. Hofmann, Professor and Director, Des Institute for Eisenhuttenkunds der Technischen Universitat Berlin, Demag-Humboldt Niederschachtofen Gmb.H, Germany; Dr. Carl Popp, Specialist in Metallurgical Processes, Duisberg Rhein, Demag A. G., Germany; Dr. S. Maekawa, Muroran Plant, the Japan Steel Works Ltd., Japan; Prof. M. Y. Imai, Tokyo University, Japan; Mr. A. A. Parish, Manager, Australian Iron & Steel Ltd., Australia. Thirty-seven papers covering the various aspects of iron and steel technology were presented and discussed.

DR. B. R. NIJHAWAN, DIRECTOR, EXPLAINING TO PROF. HUMAYUN KABIR, MINISTER FOR SCIENTIFIC RESEARCH & CULTURAL AFFAIRS, THE VARIOUS PRODUCTS EXHIBITED AT THE NATIONAL METALLURGICAL LABORATORY STALL IN THE ' INDIA-1958 ' EXHIBITION HELD AT NEW DELHI

During the Symposium, Low-shaft Furnace Pilot Plant with a production capacity of 15 tons of pig iron per day from low or high-grade iron ore and non-metallurgical coal and fuels, was inaugurated on 5th February 1959 by Hon'ble Sardar Swaran Singh, Union Minister for Steel, Mines & Fuel. In his inaugural address, Hon'ble Minister observed that the country like India where there is great shortage of metallurgical coal and considerable deposits of lignite and other non-metallurgical coals exist, methods are to be developed for using these non-metallurgical fuels for the production of pig iron. With this object in view, he said, the Low-shaft Furnace Pilot Plant Project has been commissioned to investigate the possibilities of producing commercial grades of pig iron from low or high-grade ore and non-coking coals. The results of the investigation to be conducted in this plant, the Minister said, will be watched with great interest all over the country and abroad. The Minister paid a tribute to the valuable work of the National Metallurgical Laboratory in various aspects relating to iron and steel technology and other research and development projects.

COLLOQUIA

Colloquia were held on the following sub; jects during the year:

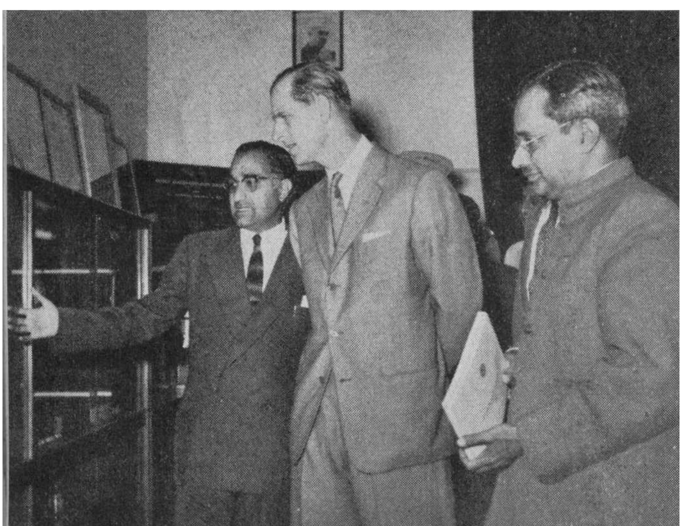
	Subject	*Speaker*
1.	**Iron** & Steel Industry in U.S.S.R.	Dr. B. R. Nijhawan
2.	The Mechanical Properties of Solids by High Frequency Vibrational Excitation-Part I	Dr. E. G. Ramachandran
3.	The Mechanical Properties of Solids by High Frequency Vibrational Excitation-Part II	Shri J. K. Khanna
4.	Low Frequency Dynamic Study of the Mechanical Properties of Cold-rolled Titanium	Shri S. K. Banerjee
5.	**Manufacture** of Porous **Bronze Bearings**	Shri S. Ranganathan

	Subject	*Speaker*
6.	Studies on Atmospheric Corrosion of Metals and Alloys	Shri A. K. Lahiri
7.	Study of Some Fireclays for Firebrick Industry	Shri A. V. Subramanyan
8.	A New Apparatus Developed for Accelerated Fatigue Testing	Shri G. D. Sani
9.	Structure of Ni-Zn Electro-depositions	Shri Y. N. Sadana
10.	Purification of Vermiculite from Mysore and West Bengal	Shri S. K. Banerjee
11.	D. G. Amplifiers	Shri A. P. Chowdhury
12.	Crystal Growth in the Thermal Oxidation of Copper under Reduced pressures	Dr. Y. N. Trehan
13.	Problems of Special Libraries in India with Particular Reference to Council Libraries	Mrs. K. Banerjee
14.	Battery Active Manganese Dioxide from Low-Grade Manganese Ore by Chemical Process	Shri S. R. Srinivasan
15.	Strain Ageing in Mild Steel	Shri B. N. Das
16.	Tinless Bronzes	Shri R. D. Gupta

EXHIBITION

The National Metallurgical Laboratory participated in the 'INDIA-1958' Exhibition organized by the Ministry of Commerce & Industry, Government of India, held at New Delhi from October 1958 to January 1959. The various products developed in the Laboratory, e.g. nickel-free stainless steel, electrolytic manganese metals, graphite crucibles, liquid gold, etc., were exhibited which drew large number of interested people. The demonstration of L.D. process of steel making was a great success and always used to attract a huge gathering.

DR. B. R. NIJHAWAN, DIRECTOR, EXPLAINING TO H.R.H. THE DUKE OF EDINBURGH THE VARIOUS PRODUCTS AND PROCESSES DEVELOPED AT THE NATIONAL METALLURGICAL LABORATORY



DISTINGUISHED VISITORS

During the period under review, distinguished visitors like H.R.H. the Duke of Edinburgh; Sardar Swaran Singh, Cabinet Minister, Government of India; Dr. Zakir Hussain, Governor of Bihar; Shri Y. N. Sukhtankar, Governor of Orissa; Mr. J. R. D. Tata, Chairman, Tata Industries Ltd.; Mr. A. D. Shroff, Financial Director, Tata Industries Ltd.; Sir J. J. Ghandy, Director-in-Charge, Tata Industries Ltd., and Chairman, Executive Council of National Metallurgical Laboratory; Dr. C. D. Deshmukh, Chairman, University Grants Commission; Mr. Yoshiki Ogawa, Professor, Faculty of Engineering, Tokyo University of the Japan Science Council; Mr. Albert Mirles, Chemical Engineer in the Department of Economic Affairs of the Government of France, etc., besides many other renowned Indian and Foreign visitors and press correspondents visited the Laboratory.

AWARDS, DEPUTATIONS AND NOMINATIONS

AWARDS

Dr. T. Banerjee, Dy. Director, was awarded the Dr. K. G. Naik Gold Medal for the year 1958 by the University of Baroda for his contributions to the published research, which have been found or are most likely to find applications in developing Indian industries during the period of five years to the award of the medal.

Shri Y. N. Trehan, Junior Scientific Officer, was awarded the Ph.D. degree from the Punjab University for his thesis entitled " Crystal-growth in Solid-gas Reactions ".

DEPUTATIONS

Dr. B. R. Nijhawan was deputed to U.S.S.R. as one of the Members of the Scientific Delegation of the Government of India invited by the U.S.S.R. Academy of Sciences.

Dr. B. R. Nijhawan was deputed to China and Japan to study the working of the iron and steel industry in those countries as a Member of the Delegation sponsored by the Government of India.

Shri B. N. Das, Assistant Director, who was deputed to undergo training in " Industrial Metallurgy " under the Technical Co-operation Scheme of Colombo Plan in the U.K., has returned.

Shri A. N. Kapoor, Senior Scientific Officer, was deputed to undergo training in the field of " Aluminizing of Ferrous Metals under the Colombo Plan in the U.K.

Shri D. S. Tandon, Senior Scientific Officer, was deputed to undergo training in the field of " Electroplating of Metals under the Colombo Plan in the U.K.

NOMINATIONS

Dr. B. R. Nijhawan has been elected as President of the Institute of Indian Foundrymen for the year 1959-60.

Dr. B. R. Nijhawan has been nominated:

(i) to serve as a Member of the Expert Committee for postgraduate studies in Foundry Technology of the Indian Institute of Technology, Kharagpur;

(ii) to serve as a Member of the Advisory Committee for the Department of Metallurgical Engineering, Indian Institute of Technology, for the session 1958-59;

(iii) to serve as a Member of the reconstituted Metallurgy Advisory Committee of the Department of Atomic Energy, Government of India.

Dr. T. Banerjee, Deputy Director, has been nominated to serve as a Member on the Engineering Hardware and Equipment Sectional Committee, EDC-32 of the Indian Standards Institution.

Dr. E. G. Ramachandran, Assistant Director, has been nominated as an alternate representative of the C.S.I.R. at the meeting of the Alloy & Special Steel Study Group Subcommittee of the Indian Standards Institution held at Bangalore on 19th and 20th May 1958.

Shri P. P. Bhatnagar, Assistant Director, has been nominated to serve as a Member of the Steel Wire Ropes Subcommittee EDC 32: 2 of the Indian Standards Institution.

Shri P. K. Gupte, Assistant Director, has been nominated:

(i) to serve as an official Member on the joint Subcommittee for concrete reinforcement-BSMDC-1 of the Indian Standards Institution;

(ii) to serve as a representative of the C.S.I.R. on the Automotive Vehicles Sectional Committee (EDC: 38) of the Indian Standards Institution.

Shri B. N. Das, Assistant Director, has been nominated:

(i) as a Member of the Development Council for the scheduled industries engaged in the manufacture of bicycles, sewing machines and instruments, for a period of two years ;

(ii) to serve as a Member of the Sewing Machine Sectional Committee, SMDC: 34 of the Indian Standards Institution.

Shri H. V. Bhaskar Rao, Assistant Director, has been nominated to serve as a Member and Convener of the Graphite Crucibles Subcommittee, SMDC: 18: 1 of the Indian Standards Institution.

Shri S. S. Bhatnagar, Senior Scientific Officer, has been nominated to serve as a Member of the Utensils Sectional Committee, EDC: 47 of the Indian Standards Institution.

Shri Jatinder Mohan, Senior Scientific Officer, has been nominated on the Coke for Cupola Subcommittee, CDC: 14:6 of the Indian Standards Institution.

APPENDIX I

PAPERS PUBLISHED

Proceedings of the following symposia organized by the National Metallurgical Laboratory containing all the papers presented, were published during the period under review:

(i) Mineral Beneficiation and Extractive Metallurgical Technique

(ii) Recent Developments in Foundry Technology

The first issue of the NML Technical journal, which is an official organ of the National Metallurgical Laboratory, was published in February 1959 and will be issued quarterly. A monograph on beneficiation of low-grade manganese ores containing results of research done in the National Metallurgical Laboratory has been published.

Besides the above, the following papers and articles were published in leading Indian and foreign journals:

A - Research Publications

1. ARORA, S. M., GUPTE, P. K. & NIJHAWAN, B. R., " Aluminizing of Steel by the Aqueous Flux Process ", *Transactions of the Indian Institute of Metals,* (1958), 57-72.
2. SHARMA, R. A., KAPOOR, A. N. & CHATTERJEA, A. B., " Preparation of Titanium Aluminium Alloys by Alumino-Thermic Reduction, Pt. II ", *Transactions of the Indian Institute of Metals,* (1958), 89-99.
3. RAMAKRISHNA RAO, M., " Phase Relationships in the Stabilization of Dolomite ", *J. sci. industr. Res.,* 17B, (1958), 156-158.
4. MURTHY, H. P. S. & MURTHY, J. R. K., " Improvements of Certain Indian Refractories Clays by pH Control ", J. *sci. industr. Res.,* 17A, (1958), 321-325.
5. KAR, B. C., GUPTA, M. K. & MUTHUKRISHNAN, V., " Simultaneous Determination of Copper, Aluminium and Magnesium in Zinc Alloys for Die-casting by Porous Cup-spark Techniques ", *Transactions of the Indian Institute of Metals,* (1958), 3-11.
6. BANERJEE, S. K. & NARAYANAN, P. I. A., " Beneficiation of a Laminated Iron Ore from Rajharapahar for Bhilai Steel Project ", *Indian Mining Journal,* VI, (1958), 1-11.
7. SOMAYAJULU, B. V., GUPTE, P. K. & KRISHNAN, R. M., " Some Observations on the Recent Development in the CO_2 Process ", *Engineering Times & Foundry News,* 1, (1958), 39-43.
8. SANTOK SINGH, R., SOMAYAJULU, B. V. & NIJHAWAN, B. R., " Moulding Characteristics of Oyaria Sand ", *J. sci. industr. Res.,* 17A, (1958), 458-460.
9. DAS, B. N. & CHOUBEY, R., " Friction and Frictional Wear ", *Transactions of the Indian Institute of Metals,* (1958), 67-77.
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12. **TANDON, D. S. & BANERJEE, T., " Plating on Aluminium Using an Iron Inter-layer, Part III — Use of Iron Inter-layer, Deposited from Ferric Chloride Solution at Temperature Lower than 95°C. and without Flash-plating of Copper or Brass ", *Transactions of the Indian Institute of Metals*, (1959), 55-67.**

B - Review Papers

1. BHASKAR RAO, H. V., " Super-duty Silica Bricks - A Review ", *Research & Industry,* 3, (1958), 173-176.
2. CHATTERJEA, A. B., " Tempering of Steel ", *TISCO Review,* 5, (1958), 129-137.
3. NIJHAWAN, B. R., " The Role of National Metallurgical Laboratory in Research and Development of Indian Foundry Sands and Moulding Materials ", Inaugural issue of *Engineering Times and Foundry News,* 1, (1958), 9-20.
4. NIJHAWAN, B. R., " Institute Stimulates Study of New Techniques " Supplement on the Iron, Steel & Structural Engineering Industries, published along with the issue of the *Hindustan Times,* dated 7 August 1958.
5. NIJHAWAN, B. R., " Ageing of Steel ", *TISCO Review,* 5, (1958), 177-182.
6. RAMACHANDRAN, E. G., " Property Changes on Phase Transformations - Physical Theory ", *TISCO Review,* 5, (1958), 183-191.
7. RAMACHANDRAN, E. G. & VED PRAKASH, " Techniques of Studying Phase Changes ", *TISCO Review, 5,* (1958), 192-197.
8. CHATTERJEA, A. B., " Grain-size Specification and Steel Selection ", *The Eastern Metals Review,* Annual Number, XII, (1959), 89-96.
9. RANGANATHAN, S., " Porous Metal Self-lubricating Bearings ", *The Eastern Metals Review,* Annual Number, XII, (1959), 109-116.
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The following articles were published in the special issue of *Statesman Supplement,* dated 4 February 1959, entitled " Iron & Steel Industry in India ", issued on the occasion of the inauguration of the Symposium on " Iron & Steel Industry in India " organized by the National Metallurgical Laboratory :

11. NIJHAWAN, B. R., " Ferrous Metallurgical Research in India ".
12. MATHUR, G. P. & NARAYANAN, P. I. A., " Beneficiation of Raw Materials for Iron & Steel Production ".
13. CHATTERJEA, A. B. & NIJHAWAN, B. R., " Low Shaft Furnace Smelting of Pig-Iron in India ".
14. KRISHNAN, R. M., SRIVASTAVA, K. N. & BANERJEE, T., " The Iron and Steel Industry in India ".
15. SEN, B. L., " Results of Experiments with L.D. Oxygen Converter

APPENDIX II

RESEARCH AND INVESTIGATION REPORTS PREPARED DURING THE **PERIOD UNDER REVIEW**

1. Moulding Characteristics of Brahmani River Sand from Rourkela, Orissa - R. Santok Singh, B. V. Somayajulu & B. R. Nijhawan (IR.122/58)
2. Moulding Characteristics of Hyderabad Silica Sand - R. Santok Singh & B. V. Somayajulu (IR.123/58)
3. Semi-pilot Plant Studies on the Beneficiation of a Ferruginous Manganese Ore from Joda West Mines of Tata Iron & Steel Co. Ltd.

   and

   Proposals for a Plant of 600 tons/day Capacity Employing the Low Temperature Magnetizing Reduction Process - G. V. Subramanya, S. B. Das Gupta & P. I. A. Narayanan (IR.124/58)
4. Beneficiation of Fluorspar from Bhagatwali Mine, Rajasthan - P. V. Raman, G. V. Subramanya & P. I. A. Narayanan (125/58)
5. Beneficiation of a Low-grade Manganese Dioxide Ore from Amritpura, Chitaldrug Dt., Mysore - S. B. Das Gupta & P. I. A. Narayanan (IR.126/58)
6. Sintering Studies on the Magnetic Concentrate Produced from Low-grade Salem Magnetite Ore - S. K. Banerjee & P. I. A. Narayanan (IR127/58).
7. Beneficiation of Low-grade Manganese Ore from Kumsi, Mysore - B. L. Sen Gupta, G. V. Subramanya & P. I. A. Narayanan (IR.128/58)
8. Beneficiation of Fluorspar from Ramorwali Mine, Rajasthan - P. V. Raman, G. P. Mathur & P. I. A. Narayanan (IR.129/58)
9. Investigation Report on a Sample of Bauxite Supplied by Messrs Orissa Cement Co. Ltd., Rajgangpur - H. V. Bhaskar Rao & A. V. Subramanyam (IR.130/58)
10. Moulding Characteristics of Medium Silica Sand - P. C. Das & J. Mohan (IR.131/58)
11. Investigation on Londha Sands - R. S. Singh, J. Mohan & P. K. Gupte (IR.132/58)
12. Moulding Characteristics of Gidni Sand - P. C. Das, J. Mohan & P. K. Gupte (IR.133/58)
13. Investigation on Vengurla Silica Sand - R. Santok Singh & B. V. Somayajulu (IR.134/58)
14. Moulding Characteristics of Yellow Moulding Sand - P. C. Das & Jatinder Mohan (IR.135/58)
15. Studies on the Beneficiation of a Nickeliferous Ore from Ranakpur Mines, Pali District, Rajasthan - S. K. Banerjee & P. I. A. Narayanan (IR.136/58)
16. Beneficiation of Low-grade Garnet Sample from Nellore, Andhra - G. P. Mathur, B. L. Sen Gupta & P. I. A. Narayanan (IR.137/58)

17. Moulding Characteristics of Snow White Silica Sand - P. C. Das, Jatinder Mohan & P. K. Gupte (IR.138/58)

18. Moulding Characteristics of Adjoy River Sand - R. Santok Singh & B. V. Somayajulu (IR.139/58)

19. Investigation on Bhavnagar Sands - R. Santok Singh, J. Mohan & P. K. Gupte (IR.140/58)

20. Recovery of Ferromanganese from Joda Electric Furnace Slag by Tabling Method - G. P. Mathur, P. V. Raman & P. I. A. Narayanan (IR.141/58)

21. Recovery of Metallics from Gun Metal Ash by Tabling Method - S. K. Banerjee, P. V. Raman & P. I. A. Narayanan (IR.142/58)

22. Pre-concentration of Lead-Zinc Ore from Zawar, Rajasthan - S. B. Das Gupta & P. I. A. Narayanan (IR.143/58)

23. Moulding Characteristics of Durgapur Sand -- P. C. Das, J. Mohan & P. K. Gupte (I R. 144/59)

24. Development of Graphite Crucibles from Indian Raw Materials -- T. V. Prasad & H. P. S. Murthy (IR.145/59)

25. Recovery of Metallics from Low-grade Aluminium Powder from Messrs Devidayal Industries (Private) Ltd. - S. K. Banerjee & P. I. A. Narayanan (IR.146/59)

26. Erosion of Induced Draft Fan at Bokaro Thermal Power Station - K. P. Mukherjee, A. K. Lahiri & T. Banerjee (IR.147/59)

27. Corrosion of Pump Impeller at Tallah Water Tank-A. K. Lahiri & T. Banerjee (IR.148/59)

28. Concentration Studies on a Low-grade Manganese Ore from Jhabua, M.P. - G. V. Subramanya, R. Ganesh & P. I. A. Narayanan (IR.149/59)

29. Beneficiation of Limestone from Toli Village - Garhwal Dist., U.P.-S. K. Banerjee & P. I. A. Narayanan (IR.150/59)

30. Semi-pilot Plant Studies on the Beneficiation of Ferruginous Manganese Ore from Siljora-Kalimati Mines, Keonjhar District, Orissa - B. L. Sen Gupta, G. V. Subramanya & P. I. A. Narayanan (IR.151/59)

31. Brown Spots on Aluminium Circles Developed During Storage - K. P. Mukherjee, A. K. Lahiri & T. Banerjee (IR.152/59)

32. Beneficiation of Limestone from Village Pundras, Dt. Garhwal, U.P. - S. B. Das Gupta & P. I. A. Narayanan (IR.153/59)

33. Proposal for a Beneficiation Plant of 100 tons/day Capacity to Treat the Ferruginous Mangynese Ore from Siljora-Kalimati Area, Orissa - B. L. Sen Gupta, G. V. Subramanya & P. I. A. Narayanan (IR.154/59)

34. Vacuum Determination of Hydrogen in Steels - N. G. Banerjee (RR.95/58)

35. Thermal Beneficiation of Low-grade Chrome Ores - R. N. Misra, M. C. Sen & P. P. Bhatnagar (RR.96/58)

36. The Electrical and Magnetic Properties of Some Low-manganese, Low-aluminium Steels — E. G. Ramachandran & Ved Prakash (RR.97/58)

37. Investigations on the Magnetic Properties of Some Permanent Materials - E. G. Ramachandran & Ved Prakash (RR.98/58)

38. Studies on Indian Refractory Clay, Part II, Clays from Bihar, Bengal & Orissa - T. V. Prasad & H. P. S. Murthy (RR.99/59)

39. A Study of Shevaroy Bauxites for the Development of High Alumina Refractories - H. V. Bhaskar Rao (RR.100/59)

40. Magnesite Crucibles for Use in High Frequency Induction Furnace - M. R. K. Rao, P. C. Sen & H. V. Bhaskar Rao (RR.101/59)

41. Evaluation of Silica Raw Material for the Manufacture of Silica Bricks - Gurbux Singh Minhar & H. V. Bhaskar Rao (RR.102/59)

The following Survey and Literature Reports were also prepared :

1. Property Changes on Phase Transformation - Physical Theory - E. G. Ramachandran (SR.67/58)
2. The Role of National Metallurgical Laboratory in the Development of Ferro-alloy Industry in India - P. P. Bhatnagar & B. R. Nijhawan (SR.68/58)
3. Recent Trends in Steel Plant Refractory Practice - H. V. Bhaskar Rao & B. R. Nijhawan (SR.69/59)
4. The Role of National Metallurgical Laboratory in Ferrous Metallurgical Research and Development in India — B. R. Nijhawan (SR.70/59)
5. Iron & Steel Industry in India - B. R. Nijhawan (SR.71/59)
6. The Development of Iron & Steel Industry in India's Five Year Plans - R. M. Krishnan, K. N. Srivastava & T. Banerjee (SR.72/59)
7. Recent Trends in Iron & Steel Technology - B. R. Nijhawan (SR.73/59)
8. Grain-size Specification of Steel Selection - A. B. Chatterjea (LR.52/58)