

1922.

NEW ZEALAND.

PIG IRON AND STEEL

(REPORT ON THE PRODUCTION OF) FROM NEW ZEALAND TITANIFEROUS IRONSANDS.

Laid on the Table of the House of Representatives by Leave.

16 Victoria Street, Westminster, London S.W. 1, 24th October, 1921.

ACTING on your instructions, I have supervised the experiments at Messrs. Summerson's works at Darlington, on the production of pig iron and steel from New Zealand titaniferous ironsands, and in an appendix are given details of the experimental runs.

I went down to Darlington on Friday night, 19th August, and on Saturday visited the works to examine the furnace, electrical equipment, &c. It had been arranged to have a run on the following day in the presence of the Right Hon. W. F. Massey, P.C., as a demonstration, but not to form part of the experimental run; this demonstration took place on Sunday, 21st August, and the metal was cast into pigs.

On examining the furnace after this heat the bottom was found to be in a bad condition, and it was decided to repair the hearth before starting the experimental run. This was done, and the furnace charged; but before the heat was ready to tap, the metal cut through the bottom by the side of the steel electrode into the water-jacket used for cooling the electrode, and the furnace had to be stopped. This accident caused considerable delay, and three days were occupied in removing the old steel electrode and thoroughly relining and repairing the hearth of the furnace; and it was not till Friday, the 26th August, that we were able to start again. It was then decided that we should work continuously night and day so long as the furnace-lining lasted; and we had four heats, during which we made 22 cwt. of pig and 4 cwt. 12 lb. of steel, when it became necessary to stop the furnace again for repairs.

For many years pig iron and steel have been made in the electric furnace, and there was no doubt that these products could be produced from the titaniferous ironsands of New Zealand. The special questions which had to be solved were—(1) To what extent the titanium present in the sands passed into the pig iron or steel; (2) in the event of any appreciable quantity passing into the finished products, did they seriously affect the physical properties, and, if so, to what extent? In addition, there was the general economic question whether pig iron and steel could be economically produced in the electric furnace, and more particularly in the Snyder furnace, and whether this furnace was suitable, or the most suitable, for the purpose.

With regard to the special questions of titanium, the results of the experiments show that, as regards both the pig iron and steel, very little titanium passed into the pig iron or steel, and the small quantity present did not have any injurious effects on the physical properties of either the pig iron or steel.

In the production of pig iron in the electric furnace there is always considerable difficulty in ensuring that the carbon shall not be less than 3·5 per cent., the tendency being to produce a material with about 3 per cent. or less which does not possess the identical properties of ordinary pig iron containing 3·5 per cent. or more of carbon produced in the blast furnaces.

For some purposes this low carbon product gives better results than ordinary pig iron, but for other purposes not so good; and I considered it important to demonstrate that pig iron could be produced so that it could be sold as such in the open market. In the first heat made it will be seen that the pig iron contained 3·34 of carbon, and this was obtained by adding, on my suggestion, to the molten metal in the furnace about 40 lb. of "carburite," a special material containing 50 per cent. of carbon, made by coking a mixture of ground-up electrodes and iron swarf, which I have found by experience is more effective in carburizing the metal than ground coke. In the next heat only 10 lb., or three-quarters the quantity of carburite used in the previous heat, was added, as the

works considered it unnecessary, and the carbon fell below 3 per cent. On increasing the carburite to 23 lb., or double the quantity used in the last heat, the carbon was increased to over 3 per cent., but was still below that obtained when 40 lb. was used. It will be noted that the carbon was considerably higher in the furnace sample than in the metal as cast in each case; and this is somewhat difficult to explain, as one would not expect any appreciable loss of carbon between the period of sampling the bath and tapping. It is probably explained by the bath sample being taken from the surface of the metal bath in contact with the coke floating on the surface, as this top layer would probably be somewhat higher in carbon than the sample representing the average composition of the bath. This emphasizes the importance of adding a large excess of heavy carburizing-material like carburite, which will sink below the slag, if pig iron containing the normal percentage of carbon is to be produced.

Experience has shown that, although it is somewhat difficult, pig iron containing 3·5 per cent. of carbon can be produced, and the fact that in the first experiment the bath sample gave 4 per cent. showed clearly it can be done in the Snyder furnace.

To test the working-properties of the pig iron casts Nos. 9 and 10 were melted in an ordinary foundry cupola, and a number of castings made, and the ordinary test bars cast for mechanical testing. The metal ran well, and the castings were quite satisfactory, being sharp and clear. A test bar cast to test fluidity gave satisfactory results.

The mechanical tests were fairly satisfactory, although the tensile strength is slightly below the better grades of cast iron, which give a tensile of from 10 to 12 tons per square inch, compared with 9·1 tons per square inch given by this iron.

The analysis of the metal from the cupola was as follows :—

Total carbon	..	..	3·480	Sulphur	..	..	0·061
Graphitic carbon	..	..	2·886	Phosphorus	..	..	0·223
Combined carbon	..	..	0·594	Manganese	..	..	0·615
Silicon	..	..	2·279	Titanium	..	..	0·050

It will be noted that the total carbon and the sulphur are both higher than the mean of the two heats 9 and 10, and the silicon lower. This is what was to be expected, as some sulphur is always taken up by the metal from the coke during melting and some silicon oxidized. The phosphorus is lower and carbon higher, and is probably due to a little of the hæmatite pig iron from the previous charge being left in the cupola.

The conditions of the furnace at the end of No. 11 heat, the third run, was very bad, and it was doubtful how long it would stand, and it was decided therefore to make a steel heat instead of another of cast iron. Partly owing to the bad condition of the furnace, and partly owing to the large amount of slag formed by cutting-away of the hearth, this heat was not very satisfactory, although the quality of the steel produced was good. The yield was exceptionally low, the volume of slag exceptionally high, and consequently the energy consumed per ton of steel made was 11,219 units (K.W.H.), whereas the consumption should not have exceeded 3,700 to 4,000 as a maximum.

The bad results obtained in this particular heat may, however, be regarded as largely accidental, and had the furnace been in good condition far better results would have been obtained. The analysis of the finished steel was as follows :—

Carbon	..	..	0·532	Manganese	..	..	0·582
Silicon	..	..	0·143	Arsenic	..	..	0·016
Sulphur	..	..	0·035	Titanium	..	..	Trace
Phosphorus	..	..	0·034				

Very little titanium remained in the steel, and the physical properties were quite satisfactory. It forged and welded well, and the tensile strength and bending tests were satisfactory.

In my opinion the production of steel direct from the ore or sand *in one furnace* is not commercial, and two furnaces are essential—one to reduce the ore and the other to refine the metal produced and convert it into steel. When the operation is done in one furnace the process is greatly delayed by the presence of the slag produced from the ore; and, although this may be largely removed, the conditions for the rapid and effective production of varying classes of steel are difficult to obtain, and lead to delays involving increased consumption of current and increased labour charges, &c. The capital cost per ton of steel for a given output when two furnaces are used would be no greater than if the operation was carried out in one furnace, as while the metal is being converted into steel in a second furnace the first furnace can be reducing another charge of ore, and the output from the two furnaces working together would be greater than if the whole operation of steelmaking were done separately in one furnace.

The economic production of pig iron and steel on a commercial scale in New Zealand will largely depend upon the design of the furnace. In my opinion the Snyder furnace, although quite suitable for producing steel from scrap steel in the usual way, is not suitable for the production of either pig iron or steel direct from ironsands. The fact that fused oxides are in contact with the hearth for a considerable time while the reduction is taking place causes excessive wear, and I do not think it will be possible to run the furnace for a reasonable period without constant stoppages for repairs, which increases the power-consumption by cooling down the furnace, which has to be reheated after each stoppage, thus greatly reducing output and increasing wages-cost per ton, apart from the increased cost of labour and materials for repairs, &c. In this particular run only four heats were possible before the furnace-hearth gave out, and, although with further experience this result might be improved upon, the conditions are such that very frequent stoppages will be inevitable. The electrode consumption was also high, considering that graphite electrodes were used, and the power consumed

was also very high. In heat No. 9 the units (K.W.H.) consumed per ton of pig were 5,715; in heat 10, 4,151; and in heat 11, 5,111: or an average of 4,949 K.W.H. per ton of pig iron: whereas with a furnace designed for the work the consumption should not exceed 3,500 K.W.H. per ton of pig iron, and under good working-conditions should be less.

It is impossible to form any accurate opinion as to labour-costs on a short run of this description on such a small furnace. Two furnaces per shift were employed on the furnace, with the assistance of one ladleman when required. Owing to the extremely small output—only just over a ton per twenty-four hours—the labour-costs were extremely high—approximately £4 10s. to £5 per ton of pig iron; whereas with a furnace properly designed for the work an output of 15 tons should be obtained with labour-costs of about £1 1s. per ton, exclusive of repair labour, such as bricklayers and fitters, &c. In such a furnace the charging could be done by labourers, with one skilled foreman per shift to supervise and be responsible for the working of the two furnaces.

The following may be taken as the approximate costs of producing pig iron in two furnaces producing each 15 tons per twenty-four hours, based on eight-hour shifts:—

COST OF PRODUCING 30 TONS OF PIG IRON PER TWENTY-FOUR HOURS IN TWO FURNACES OF 15 TONS CAPACITY.

	Cost of 30 Tons.	Cost per Ton of Pig Iron produced.
Materials:—	£ s. d.	£ s. d.
61 tons of sands @ 3s. per ton	9 3 0	0 6 1·2
4 tons of lime @ £2 12s. 6d. per ton	10 10 0	0 7 0·0
12 tons of coke-breeze and coal @ £1 10s. per ton	18 0 0	0 12 0·0
Total materials	37 13 0	1 5 1·2
Labour:—		
Furnace labour—		
3 foremen @ £1 per day	3 0 0	0 2 0·0
24 labourers @ 14s. per day	16 16 0	0 11 2·4
6 pitmen @ 14s. per day	4 4 0	0 2 9·6
3 electricians @ 16s. per day	2 8 0	0 1 7·2
9 labourers @ 14s. per day (yard work)	6 6 0	0 4 2·4
Total labour	32 14 0	1 1 9·6
Ferro-silicon (50 per cent.), 750 lb. @ £13 per ton	4 7 0	0 2 10·8
3,000 lb. electrodes (Soldenburg), (100 lb. per ton), @ 2d.	25 0 0	0 16 8·0
Power (3,500 K.W.H. per ton), 52,500 K.W.H. @ 0·1d.	43 15 0	1 9 1·9
Repairs, including labour and refractories, @ 5s. per ton	7 10 0	0 5 0·0
Incidentals (rent, light, water, &c.) @ 2s. per ton	3 0 0	0 2 0·0
Management, @ 4s. per ton	6 0 0	0 4 0·0
Contingencies, @ 2s. per ton	3 0 0	0 2 0·0
Depreciation, 7½ per cent. on £50,000 = 7s. 6d. per ton	11 5 0	0 7 6·0
Grand totals	174 4 0	5 16 1·5

I have assumed that the Soldenburg electrode will be used in above estimates. If the ordinary carbon electrodes are used the price would be at least 4d. per pound, and costs per ton of pig iron would be increased by 16s. 8d. If coke-breeze cannot be obtained and coke at £4 per ton has to be used, the cost would be increased by £1, and the total cost would then be £6 16s. 2d. per ton.

It will be noted that the chief items of cost, apart from labour and power, are lime, coke-breeze, and electrodes. The lime I have taken at £2 12s. 6d., the price given by Mr. E. Parry in his pamphlet on "The Manufacture of Carbide of Calcium in New Zealand," published in 1918 in the *New Zealand Journal of Science and Technology*.

The price of coke delivered in New Zealand, obtained by the High Commissioner's Office by cable, is £4; but in this country small coke or breeze which is useless for most purposes can be obtained for a few shillings per ton, and can probably be bought in sufficient quantity in New Zealand at considerably less than half the price of coke, and, mixed with some local coal, will give quite satisfactory results. I have taken this mixture of coke-breeze and coal at £1 10s. per ton; and preferably a hard anthracite coal should be used. If coke-breeze is unobtainable and coke at £4 per ton has to be used, this will increase the cost of pig iron £1 per ton; and if the actual cost as the result of investigation is found to be somewhere between £4, and the figure of £1 10s. taken, the correct figure will have to be substituted. In any case it will be highly desirable to use at least 30 per cent. of coal in admixture with the coke, and this would probably appreciably reduce the average price of the fuel below £4 per ton, as some local coal could probably be obtained at a lower figure than coke.

Recently in Sweden a new electrode called the Soldenburg electrode has been introduced for ferro-silicon and similar furnaces, and the latest reports are that it is giving very satisfactory results, one furnace having been working continuously for over twelve months. This electrode is made by feeding in the coke paste or mixture into a steel tube on the top of the furnace, where it is tamped and

burnt by the waste heat while being fed into the furnace. I see no reason why this should not be used in the furnace making pig iron, and it would very greatly reduce the costs of the electrodes compared with ordinary carbon electrodes. If the Swedish type of high furnace were adopted the Soldenburg electrode could not be used, but the consumption of ordinary electrodes would only be about 20 lb. per ton, and a considerable saving would be effected. Great difficulty, however, has been found in using coke in this furnace, charcoal being necessary to obtain good results, which I assume is not available in New Zealand.

Carbon electrodes are costing at present in this country nearly 5d. per pound, but prices are falling, and in a year or two electrodes should be obtained at 4d. per pound in New Zealand. This is the price taken by Mr. Parry in estimating his costs for calcium-carbide manufacture. If these carbon electrodes had to be used the cost per ton of pig iron would be increased by 16s. 8d. per ton over the estimates given.

I understand that power can be produced in New Zealand at a very low figure—about £3 per horse-power per year—which is approximately equivalent to 1s. 10d. per unit; and to enable electric smelting of pig iron to have a reasonable chance of commercial success it will be necessary that it should be supplied at about this figure.

I have taken power at $\frac{1}{10}$ d. per K.W.H., which is a very low figure, and possibly slightly lower than it can be produced at; but in starting a new industry of the kind in which power is such an important item of the total costs, unless it can be supplied at an extremely low figure there is little chance of commercial success.

The actual cost of a plant would depend very much on the site, and what had to be expended upon levelling, foundations, water-supply, the cost of building-materials, &c.; and until these are known and actual tenders obtained it is impossible to give more than a very approximate estimate, especially at the present time when prices are varying from week to week. On the assumption that the above general costs were normal, a two-furnace plant of the ferro-silicon type to produce about 10,000 tons of pig iron per annum, including furnaces, buildings, and all accessories, would cost about £50,000, and allowing £20,000 for working-capital a total capitalization of £70,000 would be necessary. The above would only cover actual cost of works plant ready for connecting up to power plant, but would not include cost of cables from the power plant to the works. If Swedish furnaces of the high type were adopted the cost would be somewhat increased for the same output—probably to the extent of £10,000.

In September the price of pig iron delivered at New Zealand ports was £11 9s. per ton, and on the lower estimated cost of £5 16s. 2d. per ton would show a profit of £5 12s. 10d. per ton of pig iron produced; but prices are at present abnormal, and during the next few years a very appreciable fall in prices may be expected. Pre-war the cost of pig iron delivered in New Zealand was about £4 15s. per ton, which is about £1 1s. per ton less than the estimated cost of production; and, although prices are not likely to fall to those ruling in 1914, pig iron in Europe can be bought at present at about £5 per ton, and it is probable it will be obtainable shortly at about £4 10s. Allowing for freight of about £2, this would mean that European pig iron could be delivered in New Zealand at about £6 10s. to £7 per ton, and consequently pig iron would have to be produced at about £5 10s. per ton to enable it to be sold at £6 10s. and a profit of £1 per ton to be made, assuming there was no protective duty. The costs of production should therefore not exceed £5 10s. per ton, which would give a profit of £10,000 on a total capitalization of £70,000, and be equivalent to a return of 14·3 per cent.

On the actual estimated cost of production—viz., £5 16s. 2d.—assuming selling-price were £6 10s., the profit would only be 13s. 10d. per ton, equivalent to £6,916 per annum on 10,000 tons of pig iron, which would yield 9·8 per cent. on £70,000.

Although pig iron in the near future may be purchasable at £4 10s. in Europe, the price is little if any above the cost of production, and consequently it is not likely to continue to be sold at this figure. So far as can be judged at present, pig iron will not be produced under £4 10s. per ton for a long time, and consequently cannot be sold at a reasonable profit under £5; and therefore the price delivered in New Zealand is more likely to approximate to £7 than £6 10s., which would leave a profit on the estimated costs of production of about £1 3s. 10d. per ton—equivalent to 17 per cent. on the total capital.

If it were decided to make steel, a special furnace would have to be used to which the molten metal from the pig-iron furnace could be transferred, and this might also be used for making steel direct from such scrap steel as is obtainable.

The production of steel would involve considerably more capital expenditure, as, apart from the cost of the furnace, either a steel-foundry, hammers, or a forging-press or small mill would have to be provided. Whether a small mill or forging-press, or hammers, should be installed would depend upon the class of finished steel for which there was the greatest demand, and would have to be decided after careful investigation.

Considerable quantities of small bars, bolts, and rods are imported into New Zealand, and a small bar and rod mill to roll these might be desirable.

Provided a market could be found for the pig iron, either in form of pig iron for sale to foundries or in the form of finished castings, I should strongly advise that no steel plant be erected, but the whole of the productions be confined to pig iron, at all events for the first year or so.

BLAST FURNACE v. ELECTRIC FURNACE.

Although it may be possible to make small quantities of pig iron and certain classes of finished steel products commercially in New Zealand in the electric furnace, the establishment of a large iron and steel industry will only be possible when either the home demand has greatly increased or it is possible to produce pig iron or finished steel at such a price that these can be exported at a profit. To justify the erection of modern furnaces and steel plant it would be necessary to have a market for not less than 150,000 tons of pig iron and steel a year.

Provided cheap raw materials can be obtained, pig iron can be produced in a blast furnace much cheaper than in an electric furnace; but to produce economically the blast furnace must be of modern design and produce not less than 250 tons of pig iron per day, and should under the best conditions produce as much as 500 tons per day. The efficiency and economy of the blast furnace depends upon its large output, and can only be commercially successful when a market for a large output is available.

For the success of such a plant, cheap ore, cheap coke, and cheap limestone in large quantities are essential. As regards cheap ore suitable for blast-furnace purposes, the Parapara deposits should be able to supply this, but at present there seems no probability of obtaining large supplies of good coking coal at a price which would enable pig iron to be produced for export in competition with Australia or other iron-producing countries. With coke even at £2 10s. per ton, assuming it could be obtained for this, the cost of producing pig iron would be such that when the cost of freight to destination was added it could not compete with other pig iron in the Eastern markets.

The total demand in New Zealand for pig iron before the war was approximately 10,000 tons per annum, and for finished steel about 140,000 tons. Of this 140,000 tons about 25,000 tons were rails, about 20,000 tons galvanized and black sheets and plates, about 14,000 wire, and about 25,000 tons bars, bolts, and rods, and the remainder miscellaneous products, many of them manufactured articles such as pipes, tanks, &c.

If it were possible to roll rails, plates, and sheets, and bars and rods, in one mill, the possibility of starting a works to supply the colony might be seriously considered; but one mill would be required for rails, another for plates and sheets, another for bars and rods, and another for wire; and it would be necessary to start three or four works, each practically a separate industry, to convert the steel produced at the original works into the final finished products.

The electric furnace can, on the other hand, be worked economically with small units; and, although it is very doubtful if it can ever compete with a modern blast furnace and steel plant in the production of steel rails and other classes of cheap finished steel products on a large scale, in cases where the blast furnace is not possible it may be able to produce cheaper than pig iron or steel can be imported.

CONCLUSIONS AND RECOMMENDATIONS.

The conditions in New Zealand are such that a blast furnace and modern steel plant are not at present feasible; but if power, coke, coal, and limestone are obtainable at reasonable prices, small quantities of pig iron and steel may be produced to partially meet the local requirements, and this will form the basis for building up a larger industry when the demand has increased sufficiently to justify expansion on a larger scale, should further investigation show that suitable raw materials are available.

Both pig iron and steel of satisfactory quality, containing little titanium, can be produced from titaniferous ironsands in the electric furnace, but the Snyder furnace is not suitable for the production of pig iron.

In my opinion you will be justified in starting the manufacture of pig iron in the electric furnaces, provided power, coke, coal, and lime can be obtained at a price which will enable pig iron to be produced at about £5 10s. to £5 15s. per ton as the basis of costs given in this report.

Subject to the above, I recommend—

- (1.) The erection of an electric-furnace plant, specially designed for the production of pig iron, to produce 10,000 tons of pig iron per annum, and that a foundry be attached for the manufacture of castings to meet local requirements.
- (2.) That later on, but not at first, a steel furnace be erected to produce steel either entirely from scrap or partially from scrap and partially from pig iron produced from the iron-sands.
- (3.) That when the steel furnace is erected a small mill to roll rods and small bars, and possibly small steel sections, be installed, or alternatively hammers or a forging-press, whichever is considered most likely to meet the special conditions.

Yours faithfully,

p.p. EDWARD RILEY AND HARBORD:

F. W. HARBORD.

The High Commissioner for New Zealand, 413-416 Strand, W.C. 2.

APPENDIX.

THE smelting experiments were carried out at Messrs. Thomas Summerson and Sons (Limited) Works at Darlington, in a 400 K.V.A. Snyder single-phase furnace. The power input to the furnace was 350/370 kilowatts, and was supplied at 140/150 volts and 2,500 amps. A tracing of the furnace is attached hereto [not printed].

The electrical measurements were made by means of two Board of Trade unit-meters, and checked by means of voltmeter, ammeter, and wattmeter, placed across the leads to the furnace. The readings of the two unit-meters were added together and multiplied by 1.25, the latter being the factor of the instruments. The instruments were read as nearly as possible every quarter of an hour throughout the run, and the average taken to check the Board of Trade meters. Graphite electrodes were used, and these were weighted at the commencement of the tests and again after the fourth heat at the end of the run. The consumption of electrodes was averaged over the whole run, and worked out at 51 lb. per ton of metal produced.

A sample was taken out of each bag of ore and each charge of lime and coke-dust. The samples were mixed together and analysed. The results of the analyses are as follows :—

	<i>Ironsand.</i>				Per Cent.
Ferric oxide	..	..	..	..	50.85
Ferrous oxide	..	..	..	..	25.39
Silica	..	..	..	..	5.07
Titanic acid	..	..	..	..	7.88
Alumina	..	..	..	..	3.43
Oxide of manganese	..	..	..	..	0.77
Lime	..	..	..	..	1.87
Magnesia	..	..	..	..	3.48
Phosphoric acid	..	..	..	..	0.586
Arsenic acid	..	..	..	..	Nil.
Sulphur	..	..	..	..	0.046
Oxide of copper	..	..	..	..	Trace.
Oxides of nickel and cobalt	..	..	..	..	0.045
Carbon dioxide	..	..	..	..	Nil.
Combined water	..	..	..	..	0.68
Moisture	..	..	..	..	0.08

100.177

Equivalent to—Metallic iron, 55.34 per cent. ; phosphorus, 0.256 per cent.

	<i>Lime.</i>				Per Cent.
Silica	..	..	..	..	1.18
Lime	..	..	..	..	78.00
Loss on ignition	..	..	..	..	19.21

	<i>Coke-dust.</i>				Per Cent.
Moisture	..	..	..	..	0.25
Ash	..	..	..	..	14.11
Volatile matter	..	..	..	..	0.93
Fixed carbon	..	..	..	..	84.96

100.00

Sulphur	..	..	..	..	0.83
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DETAILS OF SEPARATE HEATS.

As a result of two preliminary heats carried out in my presence it was found that the fluxing effect of the oxide of iron was very severe, and great care would be necessary in lining the furnace and thoroughly fritting the hearth.

During the first run the metal leaked down the side of the steel electrode and got into the water-jacket and caused a complete stoppage. The furnace was then carefully relined, and was ready on Friday, the 26th August. As this experiment was the ninth carried out altogether on New Zealand ironsands it was called heat 9. The furnace after relining was burnt in with coke for three hours, and the lining glazed by means of a wash heat of metal from a previous run.

In each heat 1,200 lb. of ironsands were treated, and were charged into the furnace in two portions at intervals of about one hour.

HEAT 9.

In this heat the composition of the two charges was as follows : Ironsand, 600 lb. ; coke-dust to pass $\frac{1}{2}$ in. mesh, 70 lb. ; coke-breeze, 40 lb. ; lime, 50 lb. The sand and coke-dust were mixed four times, the coke and lime then added and mixed again twice more.

A second similar charge was put in about an hour later. The reduction was completed in 3 hours 40 minutes, at which point the slag was run off, during which process 6 lb. of lime was added.

To recarburize the metal 40 lb. carburite (50 per cent. C.), and at periods 40 lb. coke-dust, were added, and recarburization was completed in $1\frac{1}{2}$ hours, during which period the furnace was on half-tap—i.e., only half the usual quantity of current was used.

At this point 77 lb. of ferro-silicon (24.8 per cent. silicon) was added, together with three shovels of slag-forming mixture consisting of 2 parts lime and 1 part silver sand. Later 3 shovels of slag-forming mixture and 4 lb. fluorspar was added, and the metal teemed after 6 hours total run.

Electrical Measurements.—Heat 9.

Date : 26th August, 1921.

Time.	Volts.	Amps.	Watts.	Units.		Remarks.
				No. 1.	No. 2.	
11:33	140	2,650	375	493,405	503,544	Commence.
11:45	150	2,200	375	..	..	
12:00	160	2,350	375	..	..	
12:15	148	2,400	375	..	..	
12:30	164	2,300	375	..	..	
12:45	162	2,450	390	..	..	
12:50	..	..	..	493,598	503,747	Off for 10 minutes.
1:00	160	2,500	370	..	..	
1:15	150	2,650	405	..	..	
1:30	156	2,550	370	..	..	
1:45	155	2,500	360	..	..	
2:00	174	2,200	350	..	..	
2:15	150	2,500	360	493,819	503,976	
2:30	156	2,500	364	..	..	
2:45	160	2,300	358	493,914	504,070	
2:55	102	2,000	210	..	..	
3:05	104	2,000	210	..	..	
3:15	Off	..	..	493,944	504,104	Off 20 minutes for slagging.
3:33	105	2,000	180	493,948	504,119	
3:46	100	2,100	205	..	..	Off for 19 minutes.
4:06	96	2,100	200	..	..	
4:22	98	2,200	200	..	..	Off for 7 minutes.
4:46	90	2,500	210	..	..	Off for 10 minutes.
5:00	115	2,000	190	..	..	Off for 4 minutes.
5:30	98	1,800	180	..	..	
5:40	..	..	..	494,053	504,227	Off for 15 minutes.
5:47	..	..	..	..	..	Run terminated.

Total length of run ..	..	..	..	..	..	6 hr. 14 min.
Effective length of run	..	..	..	..	..	4 hr. 49 min.
Mean volts on furnace	..	..	..	..	..	.. 136
Mean amperes	..	..	..	..	..	.. 2,316
Mean watts	..	..	..	..	..	.. 309
Watts (= volts × amps)	..	..	..	..	..	.. 315
K.V.A. (= watts × time)	..	..	..	..	..	.. 1,496
Total units (K.W.H.) consumed × 1.25	..	..	..	..	..	.. 1,664
Pig iron produced ..	..	..	..	..	..	(lb.) 651
Units (K.W.H.) per ton of pig	..	..	..	..	..	.. 5,715
Slag made ..	..	..	..	..	..	(lb.) 541

$$\text{Ratio } \frac{\text{Slag}}{\text{Iron}} = \frac{541}{651} = 0.831.$$

Metallic iron charged in form of sands	..	..	..	..	..	(lb.) 743
Metallic iron as ferro-silicon, &c.	..	..	..	..	..	(lb.) 61
Lime charged	..	..	..	..	..	(lb.) 126
Coke-breeze charged	..	..	..	..	..	(lb.) 260
Lime per ton of iron produced	..	..	..	..	..	(lb.) 433
Coke per ton of iron produced	..	..	..	..	..	(lb.) 894
Yield of pig iron per cent. of iron charged	..	..	..	..	..	.. 80.97

The analyses of the products obtained were as follows :—

<i>Pig Iron (before addition of Ferro-silicon).</i>					Per Cent.
Total carbon	..	..	..	..	4.137
Silicon	..	..	..	..	0.255
Sulphur	..	..	..	..	0.011

<i>Pig Iron (as Cast).</i>					
Graphitic carbon	..	..	..	..	2.937
Combined carbon	..	..	..	..	0.404
Silicon	..	..	..	..	2.763
Sulphur	..	..	..	..	0.010
Phosphorus	..	..	..	..	0.313
Manganese	..	..	..	..	0.345
Titanium	..	..	..	..	0.078

Total carbon, 3.341.

	Slag.			Per Cent.
Silica	..	..	..	20.24
Titanic oxide	..	..	..	13.20
Alumina	..	..	..	8.63
Ferrous oxide	..	..	..	7.72
Oxide of manganese..	..	..	..	0.97
Lime	..	..	..	32.40
Magnesia	..	..	..	16.42
Phosphoric anhydride ..	..	..	..	0.11

HEAT 10.

After the metal from heat 9 had been teemed the furnace was immediately charged again with a similar charge to that used in heat 9, except that the coke used was ground to pass an $\frac{1}{8}$ -in.-mesh sieve. The composition of the two charges was as follows: Ironsand, 600 lb.; coke-dust to pass $\frac{1}{8}$ in. mesh, 70 lb.; coke-breeze, 40 lb.; lime, 50 lb.

The materials were again intimately mixed as in the previous heat. A second charge was put in after an hour's run. The reduction was completed and the slag tapped after 3 hours 36 minutes.

For carburization 40 lb. of coke-dust was used, and later 10 lb. carburite was added, and was complete in 1 hour 33 minutes, at which point 88 lb. of ferro-silicon was added, and the metal teemed after a total run of 5 hours 51 minutes.

Electrical Measurements.—Heat 10.

Date: 26th August, 1921.

Time.	Volts.	Amps.	Watts.	Units.		Remarks.
				No. 1.	No. 2.	
5.49	..	..	..	..	..	First charge.
5.52	..	..	..	..	..	Full tap.
6.00	150	2,500	360	494,055	504,232	
6.15	158	2,500	370	..	..	
6.30	154	2,350	370	..	..	
6.45	175	2,250	372	..	..	
6.50	..	..	..	494,216	504,400	Second charge.
7.15	160	2,500	373	..	..	Off for 17 minutes.
7.30	160	2,500	370	..	..	
7.45	170	2,500	375	..	..	
8.00	164	2,400	376	..	..	
8.15	170	2,600	377	..	..	
8.30	175	2,250	367	..	..	Off for 4 minutes; slag over-flowing.
9.00	160	2,500	380	..	..	Off for 7 minutes; slag over-flowing.
9.15	104	2,000	210	494,580	504,781	Off 25 minutes for additions and slagging.
9.50	120	2,800	230	..	..	Off for 15 minutes.
10.19	109	1,900	190	..	..	Off for 9 minutes.
10.37	100	2,250	210	..	..	Off for 5 minutes.
11.00	110	1,650	185	..	..	Off for 6 minutes.
11.15	109	1,900	180	..	..	
11.32	Off	..	..	494,657	504,862	Run terminated.

Total length of run	..	..	..	..	5 hr. 40 min.
Effective length of run	..	..	..	..	4 hr. 12 min.
Mean volts.. ..	..	..	..	..	144
Mean amps	..	..	..	..	2,315
Mean watts	..	..	..	..	311
Watts (= volts × amps)	..	..	..	..	323
K.V.A. (= watts × time)	..	..	..	..	1,388
Total units (K.W.H.) consumed × 1.25	..	..	..	..	1,540
Pig iron produced	..	..	..	..	(lb.) 831
Units (K.W.H.) per ton of pig	..	..	..	..	4,151
Slag made	..	..	..	..	(lb.) 836

Ratio $\frac{\text{Slag}}{\text{Iron}} = \frac{836}{831} = 1.006.$

Metallic iron charged in form of sands	..	..	..	(lb.) 743
Metallic iron as ferro-silicon	..	..	..	(lb.) 69
Lime charged	..	..	..	(lb.) 110
Coke and breeze charged	..	..	..	(lb.) 260
Lime per ton of iron produced	..	..	..	(lb.) 297
Coke-breeze per ton of iron produced	..	..	..	(lb.) 702
Yield of pig iron per cent. of iron charged	..	..	..	102.34

The analyses of the products obtained were as follows:—

<i>Pig Iron (before addition of Ferro-silicon).</i>					Per Cent.
Carbon by combustion	..	..	..	..	3.155
Silicon	..	..	..	..	0.070
Sulphur	..	..	..	..	0.017
<i>Pig Iron (as Cast).</i>					
Graphitic carbon	..	..	..	..	2.419
Combined carbon	..	..	..	..	0.380
Silicon	..	..	..	..	2.308
Sulphur	..	..	..	..	0.010
Phosphorus	..	..	..	..	0.279
Manganese	..	..	..	..	0.237
Titanium	..	..	..	..	0.093
Total carbon, 2.799.					
<i>Slag.</i>					
Silica	..	..	..	..	20.62
Titanic oxide	..	..	..	..	13.34
Alumina	..	..	..	..	8.50
Ferrous oxide	..	..	..	..	3.54
Oxide of manganese	..	..	..	..	1.10
Lime	..	..	..	..	35.47
Magnesia	..	..	..	..	16.57
Phosphoric anhydride	..	..	..	..	0.11

HEAT 11.

This heat followed on immediately after the last heat had been teemed. The composition of the charges was similar to that used in heat 10 and was as follows: Ironsands, 600 lb.; coke-dust, 70 lb.; coke-breeze, 40 lb.; lime, 50 lb.

The materials were intimately mixed as before. In this heat, however, three charges as above were put in with intervals of approximately an hour between each. The reduction of the total charge of 1,800 lb. of ore was complete, and the slag tapped after 5 hours 20 minutes.

For carburization 23 lb. of carburite and 42 lb. of coke-dust was used, and later 10 lb. coke-dust was added, and was completed in 2 hours 5 minutes; 99 lb. ferro-silicon was then added, and the metal tapped after a total run of 8 hours 12 minutes.

Electrical Measurements.—Heat 11.

Date: 26th August, 1921.

Time.	Volts.	Amps.	Watts.	Units.		Remarks.
				No. 1.	No. 2.	
11.45	..	..	..	494,657	504,862	First charge.
11.55	..	..	..	..	..	Full tap.
12.00	..	160	2,600	360	..	..
12.15	..	154	2,500	360	..	..
12.30	..	160	2,500	360	..	..
12.45	..	164	2,450	360	..	..
12.57	..	..	..	494,828	505,050	Second charge; off for 7 minutes.
1.15	..	154	2,500	365	..	..
1.30	..	164	2,350	370	..	..
1.45	..	162	2,500	365	..	..
2.00	..	162	2,400	365	..	..
2.01	..	..	..	494,981	505,207	Third charge; off for 15 minutes.
2.30	..	156	2,500	360	..	Off for 2 minutes.
2.45	..	166	2,350	370	..	..
3.00	..	150	2,600	375	..	..
3.15	..	155	2,500	365	..	..
3.20	..	..	..	..	..	Off for 15 minutes; boil-over.
3.45	..	160	2,500	355	..	..
4.15	..	160	2,400	365	..	..
4.30	..	168	2,300	375	..	..
4.45	..	150	2,550	375	..	Off for 6 minutes.
5.00	..	..	..	495,374	405,621	Off for 33 minutes, slagging.
5.45	..	100	1,800	185	..	..
6.15	..	94	2,300	205	..	Off for 13 minutes.
6.50	..	100	2,050	200	..	..
7.15	..	100	2,050	195	..	Off for 14 minutes.
7.52	..	Off	..	495,525	505,790	..

Total length of run	8 hr. 7 min.
Effective length of run	6 hr. 12 min.
Mean volts	147
Mean amps	2,235
Mean watts	331
Watts (= volts × amps)	328
K.V.A. (= watts × time)	2,050
Total units (K.W.H.) consumed × 1.25	2,245
Pig iron produced	(lb.) 984
Units (K.W.H.) per ton of pig	5,111
Slag made	(lb.) 1,666

$$\text{Ratio } \frac{\text{Slag}}{\text{Iron}} = \frac{1666}{984} = 1.693.$$

Metallic iron charged as sands	(lb.) 996
Metallic iron charged as ferro-silicon	(lb.) 79
Lime charged of iron produced	(lb.) 150
Coke and breeze charged	(lb.) 382
Lime per ton	(lb.) 341
Coke per ton of iron produced	(lb.) 825
Yield of pig iron per cent. of iron charged	91.53

The analyses of the products obtained were as follows:—

Pig Iron (before addition of Ferro-silicon.)

	Per Cent.
Carbon by combustion	3.538
Silicon	0.068
Sulphur	0.012

Pig Iron (as Cast).

Graphitic carbon	2.490	} Total carbon 3.019.
Combined carbon	0.529	
Silicon	2.055	
Sulphur	0.006	
Phosphorus	0.329	
Manganese	0.237	
Titanium	0.051	

Slag.

Silica	18.64
Titanic oxide	9.95
Alumina	7.24
Ferrous oxide	5.50
Oxide of manganese	1.18
Lime	31.74
Magnesia	24.85
Phosphoric anhydride	0.11

The average yield, taking all three pig-iron heats together, was 91.64 per cent., and the consumption of lime 347 lb., coke 812 lb., and ferro-silicon 237 lb. per ton of iron produced. The average current-consumption was 4,949 K.W.H. per ton of iron produced.

HEAT 12.

After heat No. 11 was completed the lining of the furnace was examined and it was found that the slag had worked through between the magnesia brickwork and the basic material forming the hearth, and also a large portion of the hearth had been eroded away. However, the bad places were patched, and it was decided to run one more heat and to make steel direct. The same charge as before was put in, as follows: Ironsands, 600 lb.; coke-dust, 70 lb.; coke-breeze, 40 lb.; lime, 50 lb.

The second portion was charged into the furnace after 1½ hours' run, and the reduction was complete after 4 hours 39 minutes; the first slag was then poured.

56 lb. hæmatite ore and 50 lb. lime were then added, and later 9 lb. fluorspar, 28 lb. hæmatite ore, and the second slag poured an hour after the first. There were then further additions of 23 lb. lime, 98 lb. hæmatite ore, and the final slag poured off an hour later.

The metal was then carburized with coke-dust and 14 lb. ferro-silicon, 3 lb. ferro-manganese, and a small piece of aluminium added, and the steel poured into ingots after a total run of 8 hours 32 minutes.

Electrical Measurements.—Heat 12.

Date : 27th August, 1921.

Time.	Volts.	Amps.	Watts.	Units.		Remarks.
				No. 1.	No. 2.	
8.15	..	..	..	495,525	505,790	Lining temporarily patched.
9.50	..	..	..	495,572	505,855	First charge.
10.00	144	2,500	373	..	..	
10.15	160	2,750	375	..	..	
10.30	160	2,500	375	..	..	
10.45	178	2,200	380	..	..	
11.00	150	2,600	386	..	..	
11.15	166	2,300	370	..	..	
11.20	..	..	..	495,781	506,074	Second charge ; off for 7 minutes.
11.32	148	2,650	375	..	..	
11.45	168	2,100	364	..	..	
12.00	170	2,100	358	..	..	
12.15	180	2,000	370	..	..	
12.30	154	2,500	365	..	..	Off 1 minute for electrode.
12.45	136	2,700	375	..	..	
1.00	150	2,400	375	..	..	
1.03	..	..	..	..	..	Half tap.
1.05	100	2,200	225	..	..	
1.30	97	2,100	200	..	..	
1.48	100	2,000	200	..	..	
2.00	100	2,000	200	..	..	
2.20	95	2,200	220	..	..	
2.29	..	..	..	496,175	506,493	Off for 23 minutes, first slag.
3.00	146	2,300	320	..	..	
3.19	140	2,600	337	..	..	
3.25	..	..	..	..	..	Off for 17 minutes, second slag.
3.47	150	2,300	320	..	..	
3.58	160	2,100	320	..	..	
4.08	..	..	..	496,301	506,619	Half tap.
4.20	89	2,300	215	..	..	
4.33	..	..	..	496,345	506,664	Off for 15 minutes, third slag.
5.00	128	2,600	340	..	..	Off for 1 minute.
5.20	90	2,300	215	..	..	Off for 1 minute.
5.30	92	2,400	215	..	..	
5.45	104	2,000	200	..	..	
6.00	Off	..	..	..	..	
6.22	..	Metal teemed	..	496,416	506,742	Off for 22 minutes.

Total length of run ..	..	..	..	..	8 hr. 32 min.
Effective length of run ..	..	..	..	..	7 hr. 5 min.
Mean volts ..	..	..	..	..	135
Mean amps ..	..	..	..	..	2,322
Mean watts ..	..	..	..	..	309
Watts (= volts × amps) ..	..	..	..	..	313
K.V.A. (= watts × time) ..	..	..	..	..	2,215
Total units (K.W.H.) consumed × 1.25 ..	..	..	..	..	2,304
Steel produced ..	..	..	..	..	(lb.) 460
Units (K.W.H.) per ton of steel ..	..	..	..	..	11,219
Slag made (mostly lining and dolomite used in patching) ..	..	..	..	..	(lb.) 2,471
Ratio $\frac{\text{Slag}}{\text{Iron}} = \frac{2471}{460} = 5.4.$					
Iron charged in form of sands ..	..	..	..	..	(lb.) 743
Iron charged as ferro-silicon, ferro-manganese, and hematite ore ..	..	..	..	..	(lb.) 100
Yield of iron in form of steel (per cent.) ..	..	..	..	..	54.6

The analysis of the steel was as follows :—

	Per Cent.
Carbon by combustion ..	0.532
Silicon ..	0.143
Sulphur ..	0.035
Phosphorus ..	0.034
Manganese ..	0.582
Arsenic ..	0.016
Titanium ..	Trace

Slags.					
First slag—					Per Cent.
Iron	..	..	..	..	4.22
Second slag—					
Iron	..	..	..	..	7.59
Third slag—					
Iron	..	..	..	..	2.26
Lime	..	..	..	..	42.10

STEEL INGOTS.

The steel ingots were forged down to square bars, and cold and forging tests carried out on them at an adjacent works, and other bars were forwarded to London for further tests.

The forging tests made in Darlington were satisfactory; the material forged under the hammer without any signs of red shortness, and welded fairly well. A cold-bend test was made by bending under the steam-hammer a $1\frac{1}{4}$ in. square bar, and this bent through an angle of 155° before fracture.

The results of mechanical tests made in London were as follows:—

Tensile Tests.

Laboratory No. 3271.

Ultimate strength, 49.6 tons per square inch. Yield-point, 35.4 tons per square inch. Reduction of area, 23 per cent. Elongation in $4\sqrt{\text{area}}$, 15.2 per cent. Fracture, two-thirds crystalline, one-third silky.

Cold-bending Tests.

Dimensions, 1.40 in. $\times$ 1.00 in. (planed). Bent over 3-in.-diameter bearing. Broke after passing through 65° . Crystalline.

These results were quite satisfactory, and about what would be expected from steel of this grade.

CASTINGS.

The pigs from heats 9 and 10 were mixed together and melted in the cupola, the metal then being cast into test bars and different castings.

One of the 2 in. $\times$ 1 in. test bars tested at the works for transverse strength gave the following results: Breaking-strain, 24.75 cwt.; deflection, $\frac{1}{16}$ in.

Other bars were brought to London for further mechanical tests. The results of these tests were as follows:—

Tensile Test.

Laboratory No. 3270.

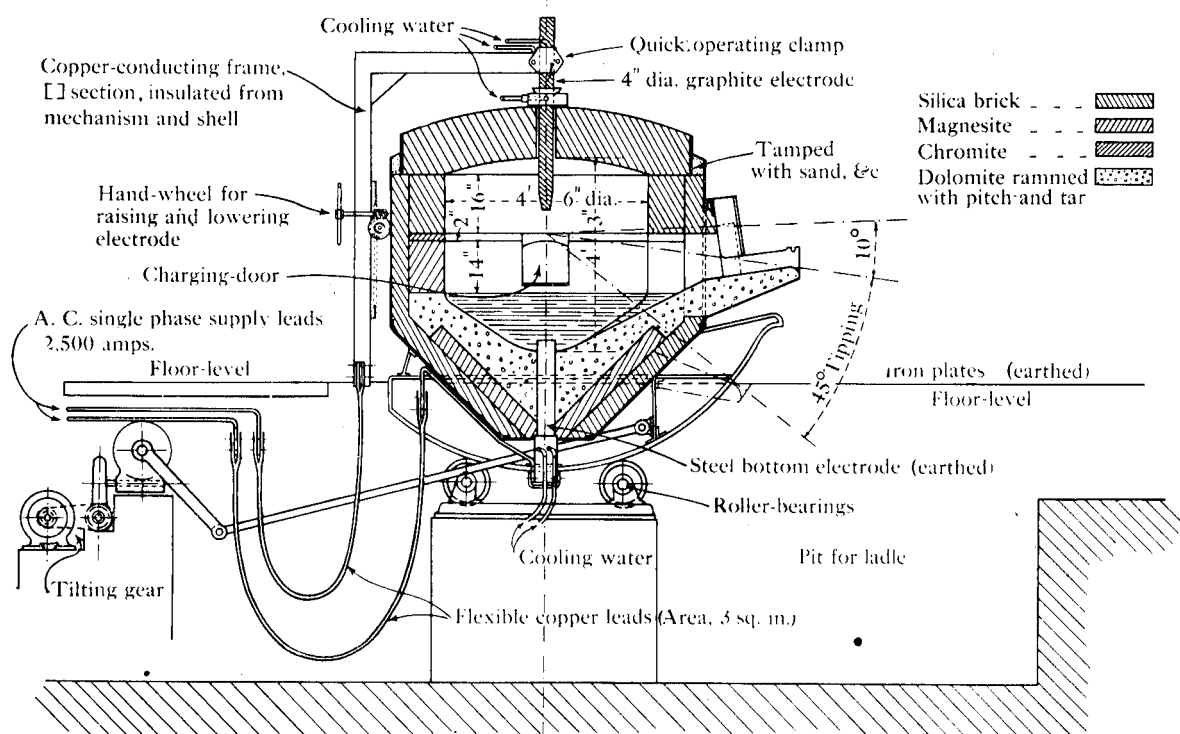
Dimensions: Diameter, 0.565 in.; area, 0.251 sq. in. Tensile strength, 9.1 tons per square inch. Appearance of fracture, sound.

Transverse Test.

Laboratory No. 3269.

Dimensions, 1.01 in. $\times$ 2.04 in. Breaking-strain, 27.5 cwt. Final deflection, 0.51 in. Appearance of fracture, sound.

400 K.W. SNYDER ELECTRIC FURNACE.



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