APPENDIX JJ

REPORT ON HUNTSMAN'S CAST STEEL

Reproduction of a Testimonial issued by Fourness and Ashworth, Engineers to their Royal Highnesses the Prince of Wales and the Duke of Clarence, 28th March 1792, printed in booklet form in both English and French versions

TO THE PUBLIC

In justice to Mr. Huntsman, who makes the best Cast Steel, in this, or perhaps any other country, we wish to present Society at large with the following brief character of it, which, as persons who have for several years been in the practice of using it, we shall at all times be ready to confirm. We have made trial of different kinds of Cast Steel, but never met with any that would abide the same execution as Huntsman's.

The efficient properties of Mr. Huntsman's Cast Steel are simply two, namely extreme hardness combined with great toughness and ductility. A point may be made that will cut glass, and at the same time, endure arduous work, as a Turning Tool for any kind of metal, without undergoing those frequent repairs necessary to tools made of other steel. It is calculated also to take the highest polish; therefore for Burnishing Tools, and Plates to beat or roll any kind of metal to a fine surface upon, it possesses a decided superiority; and, as to Dies, there is perhaps no Steel that can be made into a face of equal hardness and durability. For Buckles, Buttons, and other articles of the steel kind, to which great superficial brilliancy is requisite, there is, we believe, not another fabric of steel so completely adequate. Indeed, as a hint to Opticians it is probable this Steel would admit of a polish sufficient for Speculums; for Mirrors it is particularly suitable. By a judicious workman, a plate of this Steel can be laid to, and united firmly with any malleable Iron or Steel, of even an ordinary kind.

There are many Smiths, within the compass of our knowledge, who have not been able to find out the real qualities of this Steel, on account of having had no previous instruction relative to the working of it. It has often been said, and amongst other incorrect statements it has been asserted that the Huntsman Cast Steel could not be united or welded to any other Steel or Iron; but the opinion is a mistaken one, because we can satisfactorily prove to any person that Mr. Huntsman's Cast Steel may be securely united or welded to any other Steel or forged Iron. To elucidate this fact is one part of the design of this testimonial.

When Smiths use Cast Steel, they frequently imagine that it requires the same heat commonly given to other Steel before it comes under the hammer; nay, some indeed think it necessary to give the same heat to it as they would give to Iron; whereas, if instead of this erroneous method, Huntsman's Cast Steel were treated with care in the fire by the smith who works it, it might be brought into any required congenial state. It might, as already observed, be laid to any piece of wrought Iron or Steel. In fine, two pieces of the same Steel, at a proper welding heat, will firmly unite under the hammer together. Steel of so fine a texture as it is, cannot bear excessive heat, since excessive heat undoubtedly destroys one of the two of its virtual properties, we mean its toughness.

For the facing of Anvils and Hammers, and the making of cold Chissels, no other Steel we have been able to select can bear any competition with it. It may be tempered to any degree of hardness, and again meliorated to any degree of mildness or ductility. Needles of all denominations, Fish-hooks of every kind, we are enabled to certify, may be much relied on, when made of this Steel. Likewise (to be concise) Edged Tools of every description made of the same; Screw Taps and Plates, Drills and Boring Bits, Points of Tools for the digging of ores, coal, &c., most of which we have some acquaintance with, are more to be confided in than any other we have tried.

It may not be unnecessary to observe (since the idea of interestedness generally produces bias) that we have no connection whatever with Mr. Huntsman, nor is it at all at his request or instance, we lay before the public this sketch of the qualities of his Steel; for, we ingenuously believe, were the nature and properties of it better and more universally understood, mechanics in general would be benefitted (since to all mechanical workmen, safe and durable tools are of great importance) and the ingenuity and industry of the man who prepares it, by an extension of his sale, might be better rewarded. We are still the more induced to present to the public this impartial, but imperfect character of Huntsman's Steel, as we understand that during the course of more than thirty years of time devoted to the manufacturing of it, he has so much neglected his own interest and credit, as never to give the public, thro' any general or circular medium, any account whatever of his Steel. It was by accident that we learnt there was such Steel, after being much put about to get such as would make Tools to perform services which we could get no other Steel to stand. All the orders we have since given Mr. Huntsman by pattern, have been executed according to pattern.

Springs of all sorts, scroll as well as others, may in general be depended on when made of this Steel and suitably tempered; Huntsman, however, has suffered much by some manufacturers, or perhaps agents unfairly making use of his stamp, therefore it would be prudent for those who wish to make trial of the genuine article, to purchase it from traders of known integrity, and such as do business with Huntsman himself, as there will probably always be some who would not scruple to deal surreptitiously in an article of high character.

The whole of this information we offer to the public, as friends of a man who we think ought in an advanced stage of life, as well as for his own gratification, as his family's prosperity and comfort, to be repaid by an increase in trade, for his expenditure of time, and his sedulity in contributing to the convenience of the mechanical part of society.

APPENDIX KK

CAST STEEL MANUFACTURE IN FRANCE IN 1793

Extracts from a Report by Hassenfratz on the Manufacture of Cast Steel by the Citizen le Normand at Graville, dated 15th May 1793. Manuscript in the French National Archives. Reference F^{14}.4485. Translation by the author.

The iron cemented by the Citizen le Normand is Swedish. The furnace used has two chests within one structure. Each chest, judged by eye, is about 120" long, 32" wide and 40" deep.* The chests are made with bricks of ordinary thickness; they are heated by coal. The hearth is between the two chests; the fire circulates around in a space of 8"; the two chests are separated from each other by a similar space so that the fire may pass between them. The space around the chest is interrupted every 12" by transverse bricks which separate the chests from one another and from the walls of the furnace. The space is closed by a vault and the smoke escapes through a chimney placed at the middle of the furnace. Two openings made in the side wall of the furnace along the length of the chests allow the charging of the chests; these are closed up when the furnace is fired. In the walls at the ends of the chests are the openings for the trial bars.

The firing ordinarily lasts three, four or five days, according to the size of the bars. I do not know the consumption of fuel or what is used to cement the iron; I believe that only charcoal is used as cement.

Blister steel of good quality is drawn down under the large hammer. That drawn down in my presence had a good uniformly fine grain and appeared suitable for a number of applications. Up to now it has almost entirely been used for the manufacture of files.

(There follows a description of file making, which has not been translated)

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* With the normal packing of iron and charcoal, this would give around 6 tons of iron per chest or 12 tons per furnace.

The blister steel is also melted in crucibles and this is the source of the Graville cast steel.* A secret has been made of the flux used. I was told by the person who allowed me to see the works that they did not use glass, whilst those who directed operations told me in Paris on my return that they used white glass. The small amount of flux which I saw on the shell of steel left from a melt spoiled by the fusion of the crucible persuaded me that they had used a very fusible glass.

It is clearly an essential condition that, whatsoever flux is used, it must not contain any metal other than iron nor any other substance such as sulphur or phosphorus which might give to the steel the bad properties of being either hot or cold short.

I did not see the details of the melting of steel, firstly, because they were not melting when I visited the works and, secondly, because the operation is secret. I did, however, see the furnaces in which the small amount of cast steel made at this works has been produced. These furnaces are of three kinds :

1 A forced draught furnace similar to those used in the copper foundries in Paris. This furnace is rectangular and the crucible full of steel is placed on a stand on the furnace bars. The coal is packed between the crucible and the furnace walls. A blower placed below the furnace bars gives the oxygen needed for combustion. The furnace opening is above. Trials I made at the Brezin foundry in Paris proved to me that steel can be melted in two hours in this type of furnace.

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* Graville was between Le Havre and Harfleur, on the banks of the Vauban Canal.

2 A small reverberatory furnace, similar to those in which cast iron is melted, and not differing from them apart from its size. That which I saw was 20" along the firebars at the bottom of the furnace plus 12" of hearth; its width was 12" and its height 16". A side opening allowed entry and withdrawal of the crucible. I do not know whether such a small furnace is capable of producing sufficient heat to melt steel, but I was assured that it had been melted thus at Graville.

3 A furnace exactly similar to that of Mocque. There is no doubt that steel could very well be melted in such kinds of furnaces because they had succeeded in melting a small portion of manganese, which requires a much higher temperature than either iron or cast steel. Using blister steel to provide cast steel, the temperature necessary is much lower than that to melt iron or natural steel.*

It seems they have only melted small quantities of steel at Graville and these only for their own use. I am not aware that it has been offered for sale.

Citizen le Normand complained, as all persons who have melted or wished to melt steel, of the difficulty of obtaining crucibles which would stand up to the melt; he talked of having tried, without success, those of clay and those of plumbago but had always had the disappointment of only succeeding with a small proportion of his operations.

The crucible is the heart of the manufacture of cast steel. It appears that it is in this part of the work that we are behind. Everyone involved in the manufacture of cast steel has focussed his researches into the

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* The reasoning here is somewhat obscure. Manganese melts at 1260°C when pure; at lower temperatures when impure. Wrought iron would melt at about 1500°C. Both natural steel and cast steel would melt at somewhat lower temperatures, dependent on carbon content; there would be no difference in melting point for natural steel and cast steel if the carbon contents were the same.

proper flux for fusion and all have neglected to investigate the crucibles. All substances suitable for melting with steel and to cover it when molten and prevent extraneous reaction with the steel are satisfactory as steel fluxes, provided they do not impart to it any foreign matter which might render it defective or take from it the carbon which is necessary to constitute the steel. The fluxes only differ in their fusibility, but since the temperature at which they work is always lower than that of liquid steel, such small differences are of little account. The fluxes are always earthy substances, vitrified either before or during the operation, and, since the crucibles themselves are composed of earthy substances, the fluxing materials have an action on the crucible and may cause it to melt. Glassworks experience has made it known that crucibles can, without any marked alteration, be used to melt vitriable materials and that the reaction of glass on the crucible is more or less slight because of the composition of the latter. But the glassworkers have also learned that there is a more detrimental material to the crucibles than the glass and that this material is iron; where there is iron mixed in the crucible material, it burns a hole at this particular place and the molten material runs out. Thus, if during the working of the glass, some pieces of iron fall into the crucibles, they melt, corrode the bottom of the crucible where they touch, liquefy the crucible material around it and perforate it. Iron, as one sees, is more corrodible to the crucible than the glass itself. The major glassworks have, therefore, sought out the best clays, those which are most advantageous in making durable crucibles; among existing clays there are only five or six such in France. The glassworks procure these at elevated prices; they work them with a third or even a half weight of the same clay which has been fired. The best clay for the making of crucibles is that which contains only alumina and silica; all calcareous or magnesiated earth is pernicious and accelerates fusion.

Not having made as yet a single research into crucibles for melting steel, they have been content to use those in clay or in plumbago such as are used by the copper foundries. These crucibles have defects; firstly, by being made from a fusible composition, more fusible than those of the glassworks, and secondly, by being too thin and not being able to resist the melting and subsequent action of the liquid steel. The temperature of the molten steel is very high and, even if it does not melt the crucible material, it will soften it and the force exerted by the steel on the walls will deform them and burst them.

Four qualities are needed for steelmaking crucibles; firstly, to be highly infusible; secondly, to have sufficient thickness to resist the weight of the steel; thirdly, to withstand the initial degree of fire without breaking; fourthly, to be able to be returned to the fire after having poured out the steel contained in them, so as to serve for several successive heats.

The composition of the crucibles in the glassworks fulfils in part the first condition; they can also be given sufficient thickness to allow them to meet the second. But it is necessary, on heating up, to take particular care; the least lack of attention and a fire pushed too quickly or applied unevenly often suffices to crack them; the copper founders' crucibles have the same defective tendencies and, since it is possible to warm them up without breaking them and then make them serve a great number of operations,it makes one think the same could come about with steelmaking crucibles made to the composition of those in glassworks, except that there will have to be greater care because of the greater thickness.

Those with experience of the melting of steel in France, being more occupied with fluxes and high temperatures than with crucibles and the cost of operations, have made use of furnaces in which only one crucible may be placed; such furnaces will work well but will render the operation costly; everything leads to the belief that it should be possible to melt in furnaces containing several crucibles but the proof of this will only be obtained with trials and assessments not yet made.

The cast steel which I saw in bar form at Graville appeared to me to be of excellent quality and quite in accordance with the sample forwarded to the Council of Mines. But had this steel been melted in the works of the Citizen le Normand? This was a question which I had been charged by the Council of Mines to resolve and on which I found it impossible to have all the assurances I desired, firstly because the person who showed me the bar was not the director of operations; he was away, in the direction of Rouen. Secondly, because, in order to preserve their advantage in this manufacture, the entrepreneurs wished to make a mystery of their procedure. The only evidence I could obtain was to see the three furnaces in which they assured me they had made their trials and had then carried out the operation which had produced the steel which was in their shops; I also made the examination of a shell surrounded by vitreous flux which was said to have come from an operation in which the crucible had melted and the greater part of the steel which it had contained had been lost. It appeared that in each operation some 12 to 20 kilograms of steel was melted.*

After my return to Paris, I took steps to see the Citizen le Normand, who was still in the capital. I talked with him on the means of assuring that, without making known the procedure of which he wished to make a mystery, there could be a certitude that he had melted the steel of which he had sent a sample to the Council of Mines and of which I had seen worked bars in his shops. We had the hope that we might repeat the trials in Paris and that the Citizen le Normand, in response, would send the person who had already made the trials at Graville. After having talked over the means of carrying out such operations, however, in the spirit of what was acceptable both to the Citizen le Normand and the Council, it was obvious that the trials could only be made at Graville and that the Citizen would cast the molten material before the commissioners charged to certify the melt had been carried out in their presence and that trials would subsequently be made on the ingot cast before the commissioners and on which they had stamped their mark.

The works of the Citizen le Normand at Graville appeared to us to be well designed, the furnaces and machines constructed with much care and exactitude, the operations well planned and carried out with intelligence. The iron and steel obtained from the works were of good quality.

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* This is equivalent to 26 lb. to 44 lb. per crucible; if this indeed was the case, then the trials were on quite an ambitious scale, exceeding those known in Sheffield at this date.

The cast steel appeared superior to English steel.

The works merit encouragement from the Government through all the means within its power. It is time our industry broke out from the narrow limits in which it has been confined up to the present and that it should develop an outlook which is appropriate to the genius of a great nation.

A P P E N D I X LL

THE MINING OF CLAY AT STOURBRIDGE

Extracts from R. Angerstein, Resa genom England, 1753-55, Vol.1, Folios 372-373. Manuscript in Jernkontorets Bibliotek, Stockholm. Translation by courtesy of the late Torsten Berg, Esq.

The Stourbridge clay is dug up half a mile from the town and looks bluish as long as it is wet but whitens to a light grey as soon as it has had time to dry. Immediately above the seam there is another one producing ordinary clay used for making bricks and above that is a seam of coal which in turn is covered by hard rock. However, in some places where the coal outcrops, the rock is not to be seen. The fireclay feels very smooth and slippery between the fingers but nevertheless has to be ground and sieved before it can be used for bricks or other fire-resistant products. In the making of crucibles or pots for glass, the ground clay is mixed with some finely ground bricks or old used pots. The latter material must first be very carefully separated from the glassy pieces which stick to it; they would give the vessel, which ordinarily stands up well to the fire, a lower melting point and poorer lasting qualities. Bricks made of this fireclay are sold for 25/0d. per thousand and the common ordinary bricks for 11/0d. per thousand. The wages are 4/0d. per thousand. A special brick, thicker at one end, is made for furnace arches and sold at 2/6d. per hundred. In addition to bricks, crucibles and the like, great quantities of the clay are sent by wagon to Bewdley, the carriage amounting to 5/0d. or 6/0d. per ton. From Bewdley it is shipped to Bristol and other places in England by water. The cost of freight to Bristol is 5/0d. per ton and the clay is sold there for 27/0d. to 28/0d. per ton. Half a mile down the valley a new clay mine, 48 feet deep, was being opened. During the sinking of the winding shaft two new coal seams have been found, one a foot thick and the other 18 inches. The coal seam now being worked is below the latter. During the removal of the earth at the surface a third seam was found above the clay and in the rocky hill lying above the valley there is said to be a fourth.

A P P E N D I X MM

CRUCIBLE MAKING

Extracts from F. le Play,
'Mémoire sur la Fabrication de l'Acier en Yorkshire',
Annales des Mines, 4me Serie, Tome III (1843),
pp.643-650 and 661-663.
Translation by the author

The Crucibles for Steelmelting

The crucibles in which the steel is submitted to the melting operation constitute a most important part of the equipment. It has required a long series of trials to (644) determine the size and shape of crucible which gives rise to the least consumption of fuel and the minimum loss of raw material. That all the works have arrived at almost complete agreement proves that today the questions are well resolved.

The crucibles are essentially composed of a refractory clay found in the neighbourhood of Stourbridge (Worcestershire) which plays the same part in the metallurgical shops in Great Britain as the clay from Forges in the north of France and that of Ardenne in Belgium. In all cases, since this material, by virtue of the considerable distance which it has to come, costs so high a price in Sheffield, it is generally mixed with its own bulk of a lower quality clay from Stannington near to Sheffield. One adds to the mixture a small quantity of coke dust and powdered fragments selected from old crucibles after their use and one prepared from the whole a homogeneous and very compact dough.

Properties of Refractory Clays used for the Making of Crucibles

Comparative trials made by a capable Sheffield manufacturer, who has had the good will to communicate the results to me, have shown that the Stourbridge clay is much better suited to the making of crucibles than all other refractory clays of Great Britain and the Continent. He has not found another which has been able to resist three successive melts whilst the crucibles of pure Stourbridge clay can often resist six melts. It has seemed to me to be of interest to

seek the cause of this superiority. The Stourbridge clay, kept in a dry place, presents itself in firm (645)
lumps which are difficult to break by pressure of the hand and which even resist light blows with a hammer. It is grooved by the nail and takes on some polish when cut with a knife. Its colour is dark brown. Its fracture offers two distinct appearances; certain parts are matt and earthy; others are perfectly smooth and shiny and recall the brilliant surfaces given by certain brown haematites. It pulverises easily under the pestle and the powder passed through a silk sieve is composed to a large degree of particles which are virtually impalpable. The material is completely homogeneous; the small fragments obtained by washing the powder in a small trough are readily reduced by grinding to an impalpable powder completely identical with that which was separated by washing. The dry clay absorbs very promptly any water with which it comes into contact. It then moves easily under pressure but it does not form a dough like the fat clays used for the making of glassworking crucibles.

Stourbridge clay does not contain other fixed principles* excepting silica and alumina. I have not found in it the least traces of alkaline earths or metallic oxides. It is distinguished above all from most other refractory clays by the high proportion of alumina which it contains. The earthy matter which forms the essential constituent of the clay is intimately mixed with a combustible substance which, on calcination in a closed vessel, leaves a (646)
residue of carbon; this colours each of the particles of the earthy matter a dark grey and is not completely gassified except under a very prolonged heating. This very intimate mixture of carbon appears to contribute considerably to the increase in the refractory properties of the clay.

I have found in Stourbridge clay the following composition :

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* Oxides.

Silica	46.1%
Alumina	38.8%
Combined water and combustible matter	12.8%
Carbon produced by heating in a closed vessel	1.5%
TOTAL	99.2%

Stannington clay offers almost the same external characteristics as that from Stourbridge, except that it is not so dark; it is not so homogeneous, for one can easily separate by washing several brilliant plates of mica; it is also more prone than Stourbridge clay to give a dough with water. Calcined within a closed vessel, it gives a rather dark grey residue but heating cannot disperse this colour and it gives no loss in weight. I have found in it

Silica	42.0%
Alumina	40.9%
Magnesia	0.1%
Lime	1.3%
Oxide of Iron	trace
Combined Water	14.7%
TOTAL	99.0%

The mixture which is used to make each crucible is made up as follows : (647)

Stourbridge clay, dry and powdered	11 lb. 8 oz.
Stannington clay, dry and powdered	11 lb. 8 oz.
Fragments of old pots, powdered*	14 oz.
Powdered coke	2 oz.
TOTAL	24 lb. 0 oz.

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* This is normally termed "grog".

One moistens the material with a sufficient quantity of water so that the dough that results agglomerates under pressure and keeps the shape given to it. But it is very necessary that the dough has the homogeneity and consistency of that used for making glassworks crucibles.* When the crucible has been made by the procedure which will be described and when it has been submitted to a dull red heat, one notices that the fracture shows a veritable breccia composed of earthy fragments with a fine coke debris jointed by a small amount of a greyish argillaceous cement. These elements are only feebly agglomerated and are easily broken with a blow from a hammer. I have found that the weight of the preheated crucible was on average 20½ lb.

But this texture is completely modified when the crucibles have been used for melting steel. The dough is converted into a vitreous enamel of extreme hardness which cannot be scratched by a file. It shows a deep black colour which can only be distinguished from the coke fragments embedded into it by their lesser brilliance. The vitreous texture becomes more pronounced and the pores more numerous dependent on
the crucible remaining for a longer period at the (648)
fusion temperature of the steel. In the case of a crucible which has been experimentally used for five melts, under the influence of temperature the earthy matter has been transformed into a black, very vitrified and perfectly homogeneous enamel which, on taking out from the furnace, shows itself to be as malleable as a semi-frozen glass.

Method of Manufacture of Crucibles

The manufacture of steel crucibles requires comparatively less labour than for the crucibles used in the

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* It seems strange that le Play should not have described the treading operation applied to the clay; it is just conceivable that it was still considered to be the essential secret in the process and was kept from him.

glass works or the zinc works. It always takes place by a moulding method, using the equipment shown in Fig.5. This equipment comprises :

1 A cylindrical mould in cast iron (aa), carefully honed inside, slightly conical towards the top, open at both ends, having the height and the external form which has to be given to the crucible;

2 A thick pedestal in cast iron (bb), solidly fitted into a block of wood and furnished with a circular surround on to which the conical cylinder fits by its smaller end; in the centre of the pedestal, corresponding to the axis of the cylinder, is to be found a small hollow mortice in the body of the cast iron, designed to receive the end of the core, of which more below;

3 A core (cc) made from a hard and very heavy wood coming from the tropical regions, run through with an axle tree of iron (d), whose more narrow extremity fits into the mortice in the cast iron pedestal, whilst the other forms a rounded head designed to take the blows of a heavy hammer. Above this wooden core is a circular plate of cast iron (ee) having the same diameter as the larger end of the cast iron mould. (649)

Following the detail in Fig.5, one can easily understand that when the axle tree of the core is held vertical and is engaged in the mortice in the base by its bottom end, there remains between the core and the exterior mould a gap which has precisely the shape which one wishes to give to the crucible.

To mould a crucible, the worker begins by smearing a layer of oil over the two parts of the mould and placing the cylinder on the pedestal in the position shown in Fig.5. Next he places in the cylinder the quantity of clayey dough indicated above (24 lb.) and introduces by force the central core into the middle of the clay, keeping it in such a position

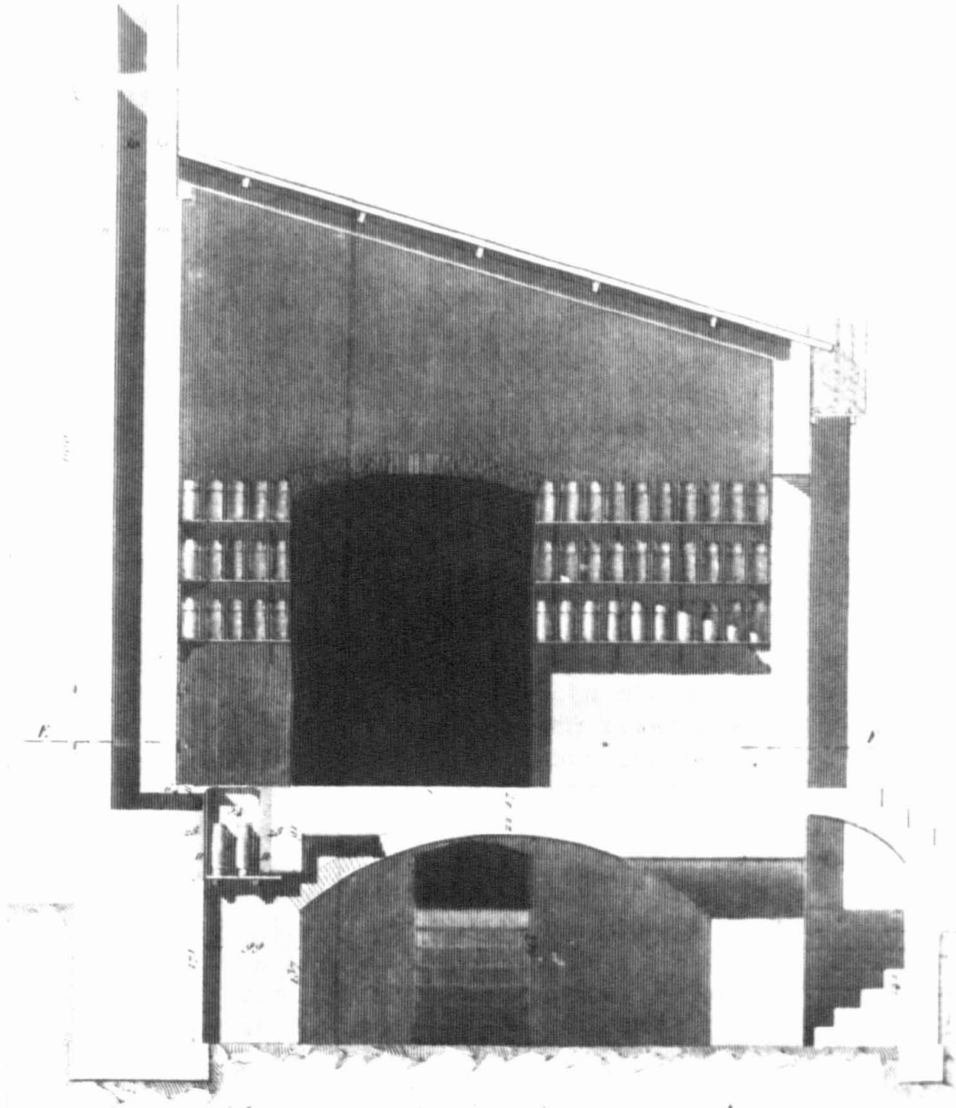

Fig. 3. Coupe verticale suivant les Plans A A' B'B ...

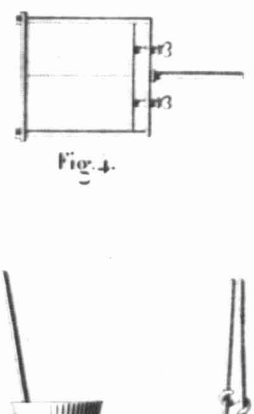

Fig. 4.

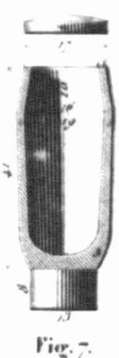

Fig. 7.

Fig. 6.

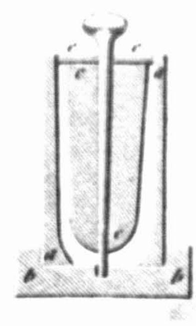

Fig. 5.

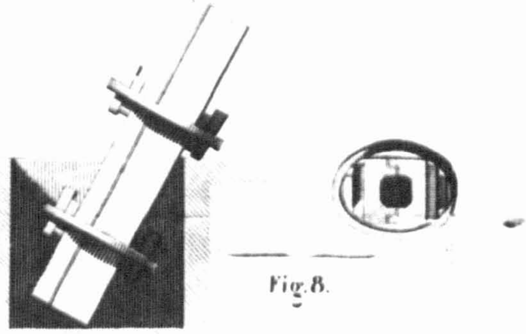

Fig. 8.

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Fig. 9.

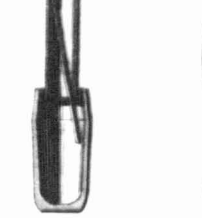

Fig. 11.

Fig. 10.

Échelles p.r les Fig. 4, 9, 10 et 11 0.m 05 p.r 1 m ... 10 décimètres ... 15 pieds anglais

Échelles pour les Fig. 5, 6, 7 et 8 0.m 05 pour 1 met ... 10 décimet ... 3 pieds angl.

F. Le Play del.

that the axle tree remains vertical and corresponds with the axis of the cylinder. Since the resistance developed by the clay does not allow the core to penetrate very far by the effect of simple pressure, the worker then operates, as has been said, by means of hammer blows using two hands, until the bottom end of the iron axle tree has penetrated into the mortice and the iron disc has come level with the upper rim of the cylinder.

To remove the moulded crucible, it only remains to take out the central core, to close the hole made by the end of the axle tree, to raise the cylinder still containing the crucible above the pedestal, which is invariably fixed to its support, and to place the bottom of the crucible thus uncovered on a circular ring of wood of a diameter slightly less than its base and itself supported on a column of iron (figure 6). The exterior mould held with care and allowed to slip under its own weight is lowered to the floor and leaves the crucible free on the ring. The workman (650)
gives the final shape to the crucible by shaping the top portion inwards under light pressure and thus giving it the form shown exactly in Figure 7.

The greatest girth of the crucible thus is found some 4" below the level of the opening. The greatest external diameter is 7½", the corresponding internal diameter is 6¼"; the external diameter at the opening is 6¾". The thickness varies progressively from 1 3/16" at the base to 9/16" at the top wall.

The cheeses on which the crucibles stand are small cylinders of clay of 5⅛" diameter and 3 3/16" high. The covers, slightly domed in the centre, have a maximum thickness of 1⅝".

It is essential that the crucibles lose their moisture only slowly after moulding; for this reason, one leaves them several days in the moulding shop: then one puts them on several rows of shelves (Figures 2* and 3) fixed along the walls of the melting shop where the proximity of the furnaces keeps the temperature sufficiently high.

* Figure 2 is not reproduced here; it shows a similar feature to that given in Figure 3.

The making of the crucible is very laborious work; a good workman gives up at least six days to make the 108 crucibles needed each week in a shop with ten furnaces run at full output. I find a difficulty in explaining, in a region where labour is of high cost, one has not yet simplified this work by means of a machine whose arrangement presents itself readily to the mind; in which the core would be pressed by a screw travelling through a nut in a system fixed firmly to its base.*

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Life of Crucibles

The crucibles are not absolutely past being used after the third melt and most of them could be used once or twice more. But in so prolonging their use, one increases the steel losses which take place through accidents which happen unexpectedly to the crucibles; all things considered, it has been proved by experience that the losses of raw material involved more than balance the economies. (661)

In spite of the care taken in the manufacture of the crucibles, these sometimes crack or are pierced during working; it can so happen in these cases that the whole of the charge runs out and falls into the ashpit, completely altered in character under the influence of the oxidising medium which it has transversed. More usually, nevertheless, the melters, alerted by the boy, who notices bright sparks falling below the grate, can remedy the fault before the whole charge is lost; to this end, they apply a pad of refractory clay to the exterior of the damaged part and slightly incline the crucible in such a way that it is made to carry more of the pressure on the sound part of the wall. If the leak persists in spite of (662)

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* It is not known when such a system was first introduced but the translator has in his possession a photograph of machine moulding by this method as practised at Wm. Jessop's works around 1900 and there are references to the use of moulding machines at River Don Works as early as 1867 (see p.275).

these endeavours they have to take out the crucible and save what remains of the contents. These leaks are almost the only cause of the small loss which takes place in steel melting shops.

Another cause contributes to the restriction of the number of melts carried out in the same crucible; this is the gradual shrinking of volume which brings about a corresponding diminution in the weights of the charges. The interior volume of the air dried crucible is 540 cub. ins. and I have found that the volume of a well-preserved crucible which has given three melts has been reduced to 390 cub.ins. The workers in many shops are agreed in affirming this diminution; it continues to show itself in further melts. This remarkable fact appears to me to be attributable to a double cause. The shrinking which occurs with clay on heating under ordinary circumstances is due to the commencement of vitrification which leads to a bringing together of the divers elements; one knows very well that, under the influence of the high temperature of the melting furnace, the clay does not reach the upper limit of vitrification forthwith, as in the other metallurgical hearths; the variations in structure present in the crucibles which have served for one melt, two melts or three melts confirm this explanation well; their texture, looked at under a magnifying glass, is at once more vitrified and less porous when it has been exposed for a longer time to the action of the fire. In the second place, the crucibles, at the high temperature at which they are held, acquire in part the softness of glass and in the same way do not break under sudden shocks; one can understand, therefore, that the pressure exerted by blows and the pressure of the tongs continually has the effect of reducing the volume. (663)

Finally, the volume of the charge, when molten, scarcely exceeding 110 cub.ins., it is clear that the shrinking of the clay does not influence the weights of the charges except in increasing the difficulty in placing in the crucibles, in a short time, the solid pieces and clippings which make up the charge. This influence is sufficiently marked to make it necessary to reduce the weights of the three charges made in the same crucible successively from 32 lb. to 30 lb. to 28 lb.*

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* This explanation given by le Play differs from the more usual one which implies a cutting of the crucible wall at the slag-metal interface so that it is dangerous to fill the crucible again to such a level; a smaller charge thus fills most of the pot but avoids the danger level. This certainly is given as the explanation why, with the larger pot from some thirty years later, the successive charges were 60 lb., 54 lb. and 48 lb.

A P P E N D I X NN

CRUCIBLE MAKING

Extracts from the Specification published by R. F. Mushet in British Patent No. 213, 20th July 1861

My Invention consists in manufacturing melting pots or crucibles from the mixture of certain clays hereinafter described, the said mixture of clays being combined with the usual admixture of old pot or burnt clay and coke dust. Melting pots or crucibles made according to my Invention are especially intended to be employed for the purpose of melting steel or homogeneous iron, metal, or any mixture of steel-producing materials, or of homogeneous iron-producing materials into cast steel or into cast homogeneous iron, commonly called homometal, respectively. The said crucibles are also, however, well suited for use when the melting of other substances besides steel and homogeneous iron has to be effected at an intense heat or high temperature.

The clays which I prefer to employ for my process are the kaolin or china clay of Cornwall or Devon, and the best black or grey fire-clay of Staffordshire. The kaolin clay which I find best suited for my process is that raised by the Leemoor China Clay Company at Leemoor near Plymouth, and the kind of black or grey fire-clay which I prefer to employ is that raised at the Freehold Clay Works or at the Amblecote Clay Works near Stourbridge. But I do not confine myself to the use of these particular varieties of kaolin or china clay and black or grey fire-clay, for other varieties of these clays, or clays having the same or nearly the same composition may be employed without departing from the nature of my Invention. I prepare the kaolin or Leemoor china clay for my purpose by passing it through a riddle of from 64 to 100 meshes per square inch. I prepare the black or grey fire-clay for my purpose either by slaking the lumps or pieces of the said clay into a fine powder by sprinkling water over the said lumps of clay, or I grind the said lumps of clay under edge runners, or I pass the said lumps of clay through rollers, and pulverize the clay so as to pass through a riddle of from 64 to 100 meshes per square inch. When thus prepared the black or grey fire-clay is ready for my process. I do not, however, confine myself to the use of riddles of the exact degree of fineness herein set down, for finer or coarser riddles may be employed for passing the clays through; but I have found that when riddles of the degree of fineness I have herein set down are made use of, the clay is well prepared for my purpose, and the melting pots manufactured from the said clay are of excellent quality. I further break up and free from the adhering slag and sand a quantity of melting pots or crucibles which have been used for melting steel in, or have been otherwise calcined at an intense heat, and I grind or crush this old pot, called also "cement", so as to pass through a riddle of from 64 to 100 meshes per square inch. I also grind or crush a quantity of clean hard coke, manufactured by preference from bituminous or anthracite pit coal, and pass the said ground or crushed coke through a riddle such as I have herein-before described. The old pot or cement and the coke thus prepared are ready for my purpose. I do not, however, confine myself to the use of old pot or cement or of pit coal coke for my process, for other materials, such as burnt fire-clay and the carbonaceous matter found encrusting the insides of gas retorts, or plumbago, may be employed in addition to or in place of old pot and pit coal coke respectively. But I find that old pot or cement and ground coke are economical, and answer very well for my purpose; but I do not claim the use of either old pot, burnt clay, pit coal coke, or gas retort carbon as ingredients to be employed in the manufacture of melting pots or crucibles for the said ingredients are employed in the manufacture of other melting pots or crucibles.

When I am about to manufacture melting pots from the materials I have herein-before described I proceed as follows : - To five bushels of the prepared black or grey fire-clay I add five bushels of the prepared kaolin or Leemoor china clay, one bushel of prepared old pot or cement, and one bushel and a half of the prepared coke. I mix these pulverized substances carefully and thoroughly, and I then add as much water as will convert the mixture of the said substances into a plastic mass, which is the pot clay I employ out of which to manufacture my melting pots or crucibles. But I do not confine myself to the relative proportions of kaolin clay to fire-clay herein set down, as these proportions may be varied without departing from the nature of my Invention, but I find in practice that the pots manufactured from these proportions of the respective ingredients are excellent in quality; nor do I confine myself to the proportions of prepared old pot and coke dust herein set down, for they may be varied, but I have found that these proportions answer well.

I next proceed to temper or knead the mass of pot clay obtained as I have described, so as to render the said pot clay very tough and plastic, and of uniform texture throughout the mass; I then divide the tempered pot clay into lumps of the weight required to form the melting pots intended to be made, and I roll and ball up these lumps of clay in the ordinary manner ready for placing in the pot, flask, or mould wherein the manufacture of the melting pots is completed. The pot, flasks or moulds I employ are similar to those ordinarily employed in the manufacture of melting pots or crucibles. The pots are then moulded and finished in the usual manner, and are afterwards stored on shelves to dry; and when dried are annealed for use in an ordinary annealing grate, and in the manner usually practised by steel manufacturers and others.

The pot clay may be kneaded or tempered in any convenient manner, either by workmen treading it with their feet in the usual manner, the clay being placed upon a clean smooth floor or stage, made preferably of iron plates, or the pot clay may be tempered in an ordinary clay pug mill.

Melting pots manufactured from the materials I have described possess the advantage of being exceedingly strong when intensely heated, and they are so close and dense in their texture that the metal melted in the said pots rarely escapes, which when inferior pots are employed frequently occurs. My melting pots also do not soften or yield when exposed to the most intense heat which can be produced in a cast steel melting furnace, so that even when the pots are of very large size they will carry the great weight of metal with which they are charged without risk of the weight of the said metal when melted rending the pot and the metal escaping.

Other kaolin clays similar to the Leemoor clay and other fire-clays of a nature similar to the black or grey fire-clay of Staffordshire may be employed, but I have found that the clays herein named make most excellent melting pots capable of withstanding the utmost heat of a steel melting furnace.

APPENDIX OO

THE MAKING OF AN INGOT FOR A GUN FORGING

Extracts from an Article published in the
Sheffield and Rotherham Independent,
28th April 1874

The first step towards the production of the 81-ton gun has just been taken. All the built up guns made at the Royal Arsenal, Woolwich, are lined with a steel tube. This tube is derived from a solid cylinder or ingot, supplied from the works of Messrs. Firth and Sons, of Sheffield. The casting of the tube for the enormous gun now designed was carried out at these works on Friday last in the most successful manner. The ingot is made of crucible steel and required for its construction 628 crucibles, each containing 70 lb. of metal, the total weight being thus nearly 20 tons. The casting occupied 42 minutes and occupied 194 men. The ingot thus produced measures 42 inches in diameter and 13 feet in length.* This will have to be reheated and hammered out, by Messrs. Firth, to the proper dimensions for the tube in the rough, after which it will be bored, turned and tempered in the Royal Gun Factories at Woolwich. The above named firm, in addition to supplying all the tubes for the large guns at Woolwich, are extensively employed by the French Government. After being cast, the ingot is covered with hot ashes and other non-conducting substances, under which conditions it is allowed to cool very slowly. When cold a portion is cut off the top (the ingot being cast in an upright mould) and the lower end, being the denser, is marked for the breech. The block thus formed is drawn out by a series of heatings and hammerings which occupy several days, until it forms a cylinder of sufficient length. The forging or drawing out of the cast block under the hammer imparts to it the desired properties of great solidity and density. In order to provide for forging ingots of such size as 15 tons and upwards, the Messrs. Firth have erected in their works two of Nasmyth's steam hammers of 25 tons weight each, at a cost of £33,000. After the ingot has been roughly bored out at Woolwich, it undergoes a process of

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* There is some error here. These dimensions give an ingot weighing about 27 tons; a length of 130" rather than 13 feet would be nearer the mark.

"toughening", which consists of heating the tube in a vertical furnace and then plunging it bodily into a bath of rape oil, in which it is allowed to cool or soak until the next day, generally for twelve hours or more. The tank contains several hundred gallons of oil and has an enclosed space around it, in which circulates a supply of cold water for the purpose of keeping the oil below a certain temperature. The necessity for this process, whereby the steel is tempered, will be seen from the fact that steel, in its natural state after casting and forging, is nearly as soft and inelastic as malleable iron. If heated and plunged into cold water the steel becomes hard, but is at the same time brittle. But oil, being a very bad conductor of heat, and having a high boiling point, operates differently. The hot steel that is plunged into it parts with heat much more slowly than when water is used and the metal subsequently becomes toughened as well as hardened.* Cast steel is the most expensive of all cannon metals.** It is used by the authorities of the Royal Gun Factories, not for the sake of imparting strength to the gun, but in order to give smoothness and hardness to the bore.

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* This is not a complete explanation, as reference to the detail given in Chapter 1 will show.

** As Professor Landes wryly remarks :

> "The one area in which there was little or no stinting was the manufacture of arms; man has rarely quibbled about the cost of instruments of death".
>
> (The Unbound Prometheus, p.252)

APPENDIX PP

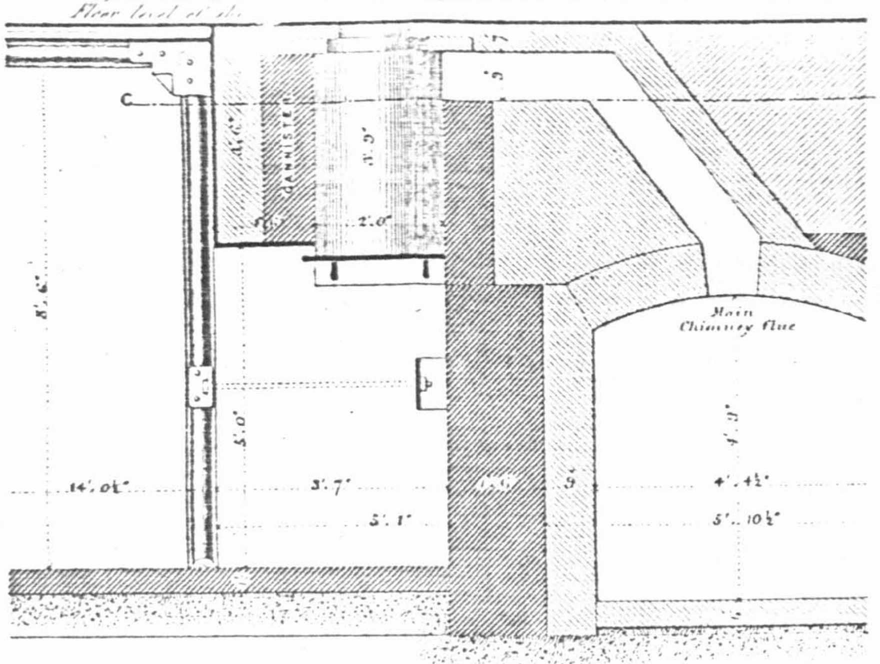
STEELMAKING AT THE RIVER DON WORKS IN 1874

Extracts from W. Hackney, 'The Manufacture of Steel', Minutes of Proceedings of the Institution of Civil Engineers, Vol.xlii (1874-75), Part iv, pp.10-14 and 61-62

Two examples of the furnaces now used for melting steel in crucibles are shown in Plate 1.

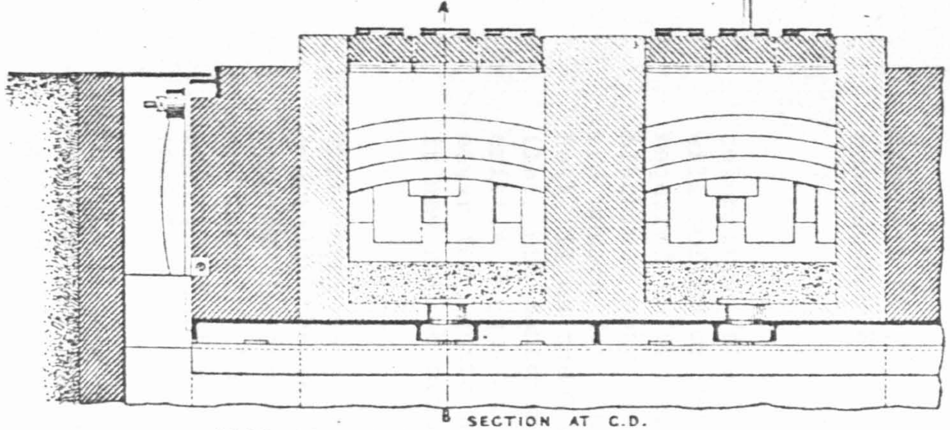
Figs.1 and 2, prepared from working drawings kindly furnished by Messrs. Vickers of Sheffield, represent the ordinary pot-hole, in which coke is the fuel used. Each hole or furnace is a simple rectangular chamber, communicating, near the top, with a large main flue, which is common to a row of furnaces. The tops of the furnaces are on a level with the floor of the melting-shop, and the grates are accessible from the cave below. Each furnace is covered by a square fire-tile, or quarry, fixed in a wrought-iron frame, from which a handle projects in front. The furnaces are lined with ground gannister, a variety of millstone grit that is found near Sheffield, and is of great value as a fire-resisting material. When the furnace is to be relined, a wooden mould is put into it, and the ground material rammed round.

The pots almost universally used are of fire-clay, mixed with a little coke-dust, and sometimes also with a little burnt clay (old ground pots) to make the mass more porous, and thus diminish the risk of cracking. The mode of making and annealing the pots, the furnace tools used, and the other details of working, are described fully by Dr. Percy. The pots vary much in size: thus Percy mentions some as holding a charge of only 28 lbs.; and others from 40 lbs. to 45 lbs. The present tendency is towards the use of large pots, holding 55 lbs. to 70 lbs. for the first charge, and 5 lbs. to 10 lbs. less each time they are refilled; in order that the 'flux line' - the level of the surface of the liquid steel, where the chief corrosion of the pot takes place - may not come twice at the same height. When pots of plumbago or blacklead ware are used, they are frequently made to hold 75 lbs. Clay pots stand from two to four rounds, depending on the fusibility of the steel melted, and blacklead pots about twice as many. Blacklead pots are, however, seldom used except in melting the very mildest qualities of steel, such as the boiler-plate metal, for which Pittsburg has acquired a deserved



SECTION AT B.B.

Fig: 4.

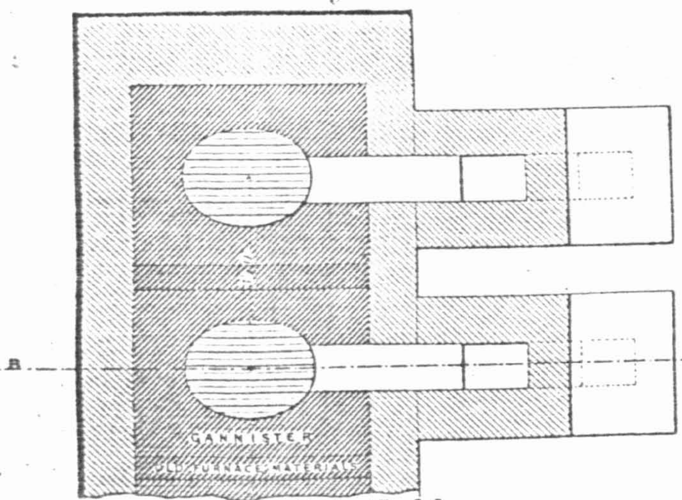


SECTION AT C.D.

REGENERATIVE GAS POT-STEEL MELTING FURNACE.

Scale for Figs 1, 2, 3 & 4.

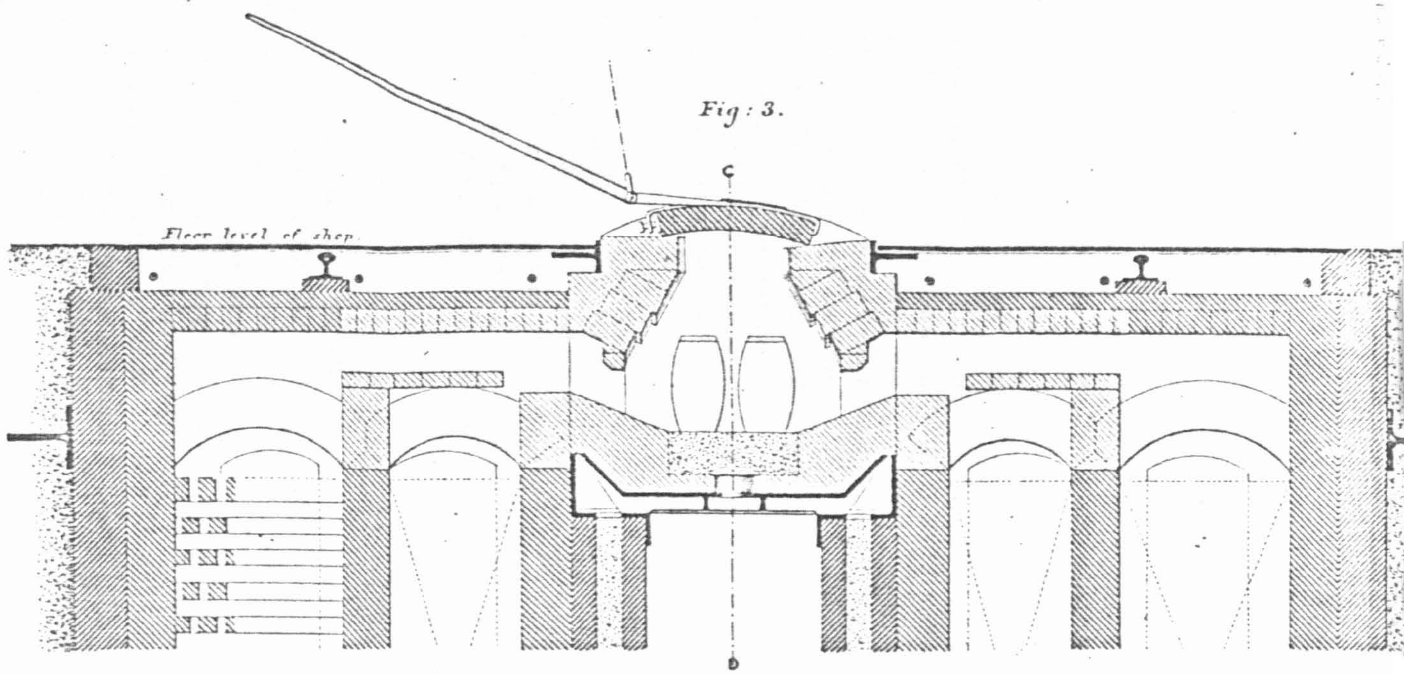
Fig: 2.



PLAN AT C.C.

ORDINARY POT-STEEL MELTING HOLE.

Fig: 3.



SECTION AT A.B.

celebrity; steel so refractory that the best clay pots will soften or burst at a heat little greater than that required to render the steel liquid. An objection to blacklead pots, independent of their cost, is that they are unsafe for the workmen. A clay pot, at steel-melting heat, is as tough almost as leather; it may be beaten flat, but cannot be broken: while a blacklead pot remains brittle at any heat, and the puller-out or the teamer can never feel quite sure, in handling a partly-worn pot, that it may not be crushed under the pinch of the tongs.

Three charges or rounds are melted in twelve hours, and generally the melting is carried on by day only, as the wear of the furnaces is much increased by working them day and night. The consumption of coke is from 2¼ to 3½ tons per ton of steel melted, equivalent to from 4 to 5 tons of coal.[1]

The application of the regenerative gas furnace to the melting of steel in crucibles is shown by Plate 1, Figs. 3 and 4. The furnace illustrated is of the same design as that lately started at the works of Messrs. Sanderson Bros., Sheffield, and represents Dr. Siemens' most recent practice. The melting-chamber is a long trench divided by cross walls into two, three, or four sections, each holding six pots arranged in two rows. The regenerators are placed at each side, and flues lead up from them to the melting-chamber, opposite to each pair of pots. The gas and air meet about 22 inches back from the entrance into the melting-chamber, and flow into it very slightly mixed, the air being above the gas. The mixture takes place in the melting-chamber itself, so that the strongest heat is obtained exactly where it is required. The spent flame passes down to the chimney through the two regenerators that are not at the time employed in heating the entering gas and air, and heats them up in readiness for the next reversal of the currents.

The pots are the same as those used in the ordinary coke furnaces, except that they are shorter and wider, in order that they may stand firmly, and they are without the usual

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1 "Appendix C", which occupies pp.61-62 of the original, is copied in full below.

hole in the bottom, which in the case of pots for coke melting is made by the guide-pin of the moulding-plug, and is filled up, before charging, by a handful of sand. The pots stand on a bed of coke-dust. This forms an excellent soft support for them, in which they may be bedded so as to stand firmly, and to which they do not stick; coke, or coke-dust, not being wetted, as sand or crushed quartz would be, by melted slag.

The coke-dust burns away very slowly, partly because the slag formed by the melting of the ash of the upper part protects the dust below, and partly because the under side of the flame, that sweeps over it, contains an excess of gas. Any slag or spilled steel is dropped out, between the heats, through a hole in the bottom of each division of the melting-chamber, into the cave below.

The sides of the chamber, above the pots, are arched vertically and horizontally, that they may stand firmly though the pillars between the ports should give way. Over each pair of pots is a fire-brick cover, that may be drawn more or less off, or moved as required, by the lever shown in Fig.3, which is hung from a runner on an overhead bar extending the whole length of the furnace at about 9 feet above the floor. All parts exposed to strong heat are of the most refractory quality of Dinas or silica brick; the covers and the regenerators are of Stourbridge, or other good fire-clay brick. The floor-plates are carried a few inches clear of the furnace brickwork, and are kept cool by a current of air.

The saving of fuel effected by the use of gas furnaces instead of ordinary melting-holes is very remarkable. From 22 cwt. to 30 cwt. of common small coal[1] does the work that takes in the old way 3 or 3½ tons of coke; and the purity of the flame, its perfect freedom from dust, has the further advantage that, as the outsides of the pots are not worn away, they may be made, by carefully moderating the heat, as has been done in France, to last for twice as many rounds as in the old

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1 "Appendix C".

furnaces; or, on the other hand, if blacklead pots are used, as in melting the mild Pittsburg boiler-plate steel, the furnaces may be worked at a higher heat than can be relied upon in coke furnaces, so that a still milder, less fusible steel may be melted.

The casting of large ingots, or of heavy castings, in crucible steel, is an operation requiring great skill and system. Several hundred pots are frequently required to make one casting. A small ladle is fixed over the mould, and a number of pots of molten metal are emptied into it sufficient to fill it. The stopper-hole in the bottom is then opened, and a stream of steel allowed to run into the mould. Meantime, a constant succession of pots is being emptied into the ladle, until the mould is filled; the metal from the pots being poured in as the steel runs out into the mould, so as to keep the ladle always full.

Pot steel is looked on as the highest quality of steel for all purposes, and is employed in those cases in which quality is of more importance than price, as in making tool steel, the highest priced springs, tires, and axles, and in America, as already mentioned, an extremely soft steel for the boiler and fire-box plates of locomotives. To some extent this preference is the result of habit; pot steel is the oldest and best known variety, and it is "safer" to continue using it than to try cheaper steel.

One important advantage, however, that pot steel has over Bessemer steel, and over some kinds of open-hearth or "Siemens" steel, is that it is, or may be, made from much more pure materials. The production of soft, malleable iron, either by puddling or in any other way from pig iron, or directly from iron ore, is as will be illustrated further on, a process of purification; the greater part and often nearly the whole of the most deleterious impurities, sulphur and phosphorus, is left in the slag; and the iron, if freed from slag, is nearly pure. Thus, if Bessemer steel and crucible steel are made from the same pig iron, the material for the crucible steel being first brought to the state of soft, malleable iron, the crucible steel will be much the purer of the two. This advantage is however shared by the open-hearth process, as soft malleable iron may also be converted into steel on the open hearth by dissolving it in a small quantity of pure cast iron.

A second advantage of crucible steel is that, so far as is yet clearly established, the metal may be more completely and more certainly 'dead melted' than steel produced in other ways. When a charge of puddled or cemented bar iron is melted in a crucible, the metal when it first becomes liquid is in a state of effervescence or apparent ebullition, and the slag covering it is full of bubbles. If it is now poured into a mould, the ingot is so honeycombed as to be useless. After some time the boiling ceases, the metal becomes tranquil, and the slag is clear and glassy; the steel is then 'dead melted' and if it is poured carefully into a mould, the ingot will be free or nearly free from bubbles, and the top of it, instead of swelling up, or boiling over, at the moment of setting, will sink in, becoming as it is termed 'piped'.

This liability of the metal to become honeycombed is one of the greatest difficulties with which the steel-maker has to contend, the more so as its cause, and the conditions that induce or prevent it, are very imperfectly understood. What is known of it will be considered further on.

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APPENDIX C

CRUCIBLE STEEL MELTING

1 Extract from a letter from Mr. E. Reynolds, Messrs. Vickers, Sons, and Co. (Limited), Sheffield, inclosing the tracing of steel melting holes for coke fuel (Plate 1, Figs.1 and 2).

"I inclose herewith a tracing of our melting holes for coke fuel. I have failed to find either here or amongst our neighbours any drawing of the conventional furnace. It differs from ours chiefly in the following particulars, viz., whereas it is customary to carry the products of combustion of each furnace direct into a flue, forming a chimney 14 inches square and about 40 feet high, we, having to combine the contents of many crucibles into one large casting, and wishing to avoid the obstruction of these chimney stacks, have connected many melting holes into one common flue, with a chimney outside the building. Next, whereas common practice covers the 'cellar' by a brick arch of from 10 to 15 feet span, beneath which the pots are made, we have made iron floors, and make the pots in a separate building.

"In England, I believe universally, the practice is to use two pots in each melting hole, and the ordinary charge for each pot is 50 lbs. for the first round, but we, having succeeded in producing very good pots, commonly use 70-lb. pots, and on special occasions have used pots containing 100 lbs. The ordinary day's work (in Sheffield) is three rounds, the charges being about 48 lbs. in the first round, 44 lbs. in the second round, and 30 lbs. in the third round; whereas we get about 66 lbs., 60 lbs. and 50 lbs. respectively. The diminished charges in the second and third rounds are due to the corrosion of the inside of the pot, at the level of the melted metal, from the action of the slag, technically called 'flux', which lies on the surface of the metal, and which so far reduces the thickness of the pot that it would not be safe to fill it so full a second time.

"The first round takes about four hours to melt, the second three hours, and the third from two to three hours, according to the temper of the steel melted; easy work being preferred for the third rounds.

"Abroad, at any rate in the large German works I have seen, the practice is to use four pots in each melting hole, these being of inferior quality and thrown away after each round. This, however, sacrifices the heat due to getting the pot hot and ready for work, which makes an hour difference between the first and second rounds.

"The consumption of fuel may be taken at about 3½ tons of coke to the ton of mild steel, and from 2¾ to 3 tons for other qualities; the general average being about 3 tons per ton of steel.

"Before altering some of our melting holes to the Siemens system, we had three hundred and thirty-six ordinary melting holes, and when very busy we used about one-half night and day; so that we used more than one thousand crucibles daily, each turning out about 1½ cwt. of steel, so that the daily production was about 75 tons. In altering to the Siemens system we get the same melting power in the same space; i.e. Siemens furnaces for ninety-six pots occupy the same space as forty-eight old melting holes, which number was our set for one chimney: but as a matter of course the Siemens furnaces ordinarily work night and day, so that the turn-out, if fully employed, would now be greater; the continuous work being found so destructive to the ordinary furnaces that it could only be used exceptionally".

2 Particulars, supplied by Dr. Siemens, of the working of regenerative gas furnaces for crucible steel melting (Plate 1, Figs. 3 and 4).

At Messrs. Vickers, Sons, and Co.'s works, the consumption of and saving in fuel, &c., are as under : -

In the regenerative gas furnaces -

	s. d.
1½ ton of coal per ton of steel melted, at 9s.	13. 6.
Repairs of furnace ditto	3. 0.
	16. 6.
Royalty	5. 0.
	21. 6.

In ordinary furnaces -

	s. d.
2½ tons of coke per ton of steel melted, at 18s.	45. 0.
Repairs of furnace ditto	12. 0.
	57. 0.

Feb. 29, 1872

The Monkbridge Iron Company report that their consumption of coal per ton of steel melted amounts to 29 cwt., which includes the gas necessary for annealing the pots.

Jan. 26, 1875

Messrs. Sanderson Brothers report that their men make 66½ hours each set per week, work being commenced at 1 a.m. on Monday morning, and ceasing at from 1 to 3.30 p.m. on Saturday. The men change shifts every 12 hours, viz. 6 a.m. and 6 p.m., those coming at 1 a.m. on Monday leaving at 6 a.m. the same day. Three founds of tool steel are made per 12 hours, and sometimes 7 per 24 hours, according to the temper of steel melted.

Feb. 22, 1866

Messrs. Verdié et Cie. (Firminy, Loire) report to M. Boistel that they make a found in 3½ to 4 hours, say 6 in 24 hours. The pots last six founds, instead of three as in the coke holes. The consumption of coal is about 3 tons per 24 hours, and the steel melted 2.7 tons, equal to 1.11 ton of coal per ton of steel melted.

Statement of the working of a regenerative gas steel-melting furnace at the works of Messrs. Anderson, Cook* and Co., Pittsburg, Pa., from Nov. 7th to 14th, 1869 -

Twenty-four heats, averaging 3¼ hours each, produced 43,013 lbs. of steel, and consumed 26,448 lbs. of coal, or 348 bushels (of 76 lbs. each). Total cost of fuel, 348 bushels at 3 cents = $10.44.

In the old furnaces at the same establishment it takes to melt the same weight of steel, 5,160 bushels of selected coke at 10 cents, making the total cost for fuel = $516. Thus, the saving effected by the gas furnace, in fuel alone, amounts to $505.56 on 43,013 lbs., or 19 tons English, or $26.50 per ton.

The melting is done in plumbago pots.

* Presumably Anderson, Woods and Co. (see p.626 and Table XII).

APPENDIX QQ

CRUCIBLE MELTERS' WAGES *

Reproduction of a Document setting out wage scales for the operation of the newly commissioned gas fired crucible furnaces at the works of William Jessop and Sons, 7th April 1902.
From a private collection

On and after April 9th 1902, the following Wages and Premium will be paid at the 80-Pot Gas Melting Furnace : -

WAGES

MELTERS	12/6 per turn
PULLERS OUT	6/- " "
MOULDERS	4/9 " "
ODD MEN	4/7 " "
LEVER MEN	4/3 " "
LEVER LADS	3/- " "

SCALE OF PREMIUM

MELTERS	-/6 per cwt.
PULLERS OUT	-/6 " "
MOULDERS	-/3 " "
ODD MEN	-/3 " "
LEVER MEN	-/3 " "

PREMIUM will be paid at the rate of 26 Heats for 11 Turns, as follows : -

17½% of "380" pressed and topped Ingots) Total weight
20% of "265" Hand and Pit Saw topped Ingots) passed.

Any EXTRA Heats, HALF the weight got out to be paid as premium.

In case of FEWER Heats, Half the Minus Heats to be deducted from the premium.

WILLIAM JESSOP & SONS, Limited

(Signed) ... J. Barsham

To W. Liversidge

April 7th 1902

* A further document of a similar nature may be found attached to Appendix JJJ.

A P P E N D I X RR

CHENOT'S PROCESS FOR THE PRODUCTION OF SPONGE IRON

A Summary of Information derived from the Various British Patents (Nos. 11515/1846, No. 246/1854, No. 658/1854 and Nos. 1587-1590/1856) and from E. Grateau, 'Mémoire sur la Fabrication de l'Acier Fondu par le Procédé Chenot' Revue Universelle, Vol.6 (1859), pp.1-62.

This summary is a slightly edited version of information which originally appeared in a paper prepared by the author for a conference on 'Alternative Routes to Steel' sponsored by the Iron and Steel Institute at the London Hilton on 5th-6th May 1971, and can be found in its original form in the Proceedings of the Conference, pp.3-6.

1 The selection of 'suitable' iron ores; Those preferred appear to have been the carbonate ores, containing some manganese.

2 The roasting of the ores.

3 The crushing of the roasted product. In general this was taken to the stage of giving pieces 1 to 1¼ cm. across.

4 The separation of the earthy matter from the 'ferriferous' substances; originally this was carried out by gravity methods, but later electromagnetic separators were used. These were highly developed units for their time, employing either permanent magnets or electro-magnets. Both types are described in the patents, but Chenot preferred the latter as being more powerful and giving a cleaner separation.

5 Subsequently, if the mineral was powdery, as was the case with oolitic ores, it was compressed into small blocks with the appropriate amount of charcoal and 3% of resin as a binder; otherwise it was simply mixed with the charcoal. The amount of charcoal was carefully calculated;

with a mineral containing at this stage some 55% of iron, the charcoal is stated to be 1.4 times the volume of the mineral or 290 kg. charcoal to 1000 kg. of enriched mineral.

6 At this stage it was charged to the retort. In one particular form the total height above ground level was around 40 feet. The central firebrick retort was surrounded by a gallery of flues down each side, the retort being some 20 inches wide and 60 to 80 inches long internally. At Haumont in France, a double furnace was used, with a central flue and two outer rows of flues, served by three fire-grates. The exhaust gases were in one case used in a waste heat boiler; in another example they were used to roast the ore. Below the retort was a cooling chamber, it being necessary to cool the sponge before allowing it to come into contact with the air, to prevent its spontaneous oxidation. This was a double walled water cooled box running the whole length of the retort. Its base was closed by a series of iron stopper rods pushed through holes in the supporting frame. A bogie ran below, with a movable base and the charge was allowed to fall out by removing a number of the push rods. It is not clear how the process was first started up, but in its normal semi-continuous process the new charge would be put in on top of the previous charge, now reduced (and therefore shrunk in volume) and allowed to cool somewhat. Having in this manner sealed the top, the reduced charge would be let into the cooling chamber. Meanwhile, the fires would be relit to reduce the new charge. Three days later they would be allowed to go out; the previous charge, now fully cooled, would be let out through the bottom, allowing the newly reduced charge to enter the cooling chamber and a new charge put in at the top; three days later the process would be repeated in all stages. Thus in six days, the single furnace would produce 1100 kg. of sponge from 1500 kg. of enriched ore and 400 kg. of charcoal, with a similar production every three days thereafter until the campaign was stopped. Some 1300 kg. of coal would be required for the above quantities for the external heating.

7 The sponge was then broken up and then magnetically separated to remove the excess charcoal, which could then be reused.

8 It was then available for use in a variety of ways :

(i) It could be added to the iron charged to the puddling furnace for the manufacture of steel; in this way it was claimed that the process was speeded up and the product made more uniform.

(ii) It could be melted down in crucibles with cast iron to give steel, the sponge being compressed into small blocks prior to use.

(iii) The preferred method, however, was to mix the sponge with carbonaceous matter and, if necessary, a resin binder, having incorporated with the mixture a certain quantity of manganese, to compress this into suitable blocks and to remelt it direct in crucibles.

(iv) It was also considered possible to compress the same mixture into blocks resembling short lengths of rectangular bars, to bundle these together and to heat them up in a smoky furnace atmosphere and then to forge weld them together.

APPENDIX SS

THE DIRECT PROCESS OF PRODUCING STEEL FROM IRON ORE

Extracts from the Specification published by C. W. Siemens in British Patent No. 1892, 10th June 1868.

Instead of reducing the ore in vertical hoppers descending into the metallic bath, I effect its reduction in a revolving cylinder, drum or muffle of refractory material which is placed horizontally, or nearly so, above the furnace, within an outer casing forming part of the rotating drum or cylinder, through which flame is made to circulate. The ore to be reduced, which is mixed by preference with a certain proportion of solid carbonaceous material and with fluxing materials, is fed in at one end of the rotating cylinder and is worked gradually forward by its rotation, the interior cylinder at the same time being heated to redness by the external heat. Reducing gas previously purified and heated is made to enter the same cylinder at the charging end through an opening in or near its axis, which gas, in being brought extensively into contact with the heated and moving ore, effects its uniform and entire reduction into spongy or pulverulent malleable iron, which later falls in due course through a vertical hopper or channel into the metallic bath of the melting furnace, where it is readily dissolved and incorporated with the bath of fluid cast iron previously prepared, or with an excess of solid carbon charged upon the hearth of the furnace to form the commencement of a liquid bath, while the earthy constituents of the reduced ore form a slag on the surface of the metal. The reducing gases employed also escape from the further end of the rotating cylinder into the surrounding casing, where atmospheric air is admitted to burn them, the products of combustion being made to escape from the casing near the feeding end towards a chimney, and the draught being regulated by dampers. The air employed for burning these gases should be made to enter the casing under a certain pressure in order to prevent the hot fumes of the melting furnace from rising into the casing in large quantities to the exclusion of the air necessary for burning the reducing gases emanating from the interior of the drum; for this purpose a fan or other means of propelling the air may be employed; or the same effect may be obtained by creating a relative vacuum by virtue of the chimney in throttling the exit passage leading from the interior of the cylinder into the outer casing or combustion channels, and thus causing atmospheric air to enter by its natural pressure to effect the combustion. The air should also be heated moderately before entering the casing, which can be effected by conducting it under the bed or over the roof of the melting furnace, or by leading it through channels in the rotating cylinder exterior to the combustion casing or channels. Instead of effecting the reduction of the ore within the rotating cylinder entirely or even partially by means of reducing gases, solid reducing agents such as anthracite, coke, charcoal, sawdust or peat may be employed, with or without the addition of pitch, tar, oil or resinous substances. Oxides of manganese may be charged with advantage to the iron ore, to be likewise reduced, and lime or other fluxing material may be added to combine in the melting furnace with the silica or gangue contained in the ore; or ores containing silica may be mixed in due proportion with other containing lime, alumina, magnesia or other basic constituents. The rotation of the drum may be conveniently effected by imparting motion to anti-friction rollers, upon which the drum is made to rest, and its rotating velocity should be capable of being regulated at will, as upon it depends the rate at which the reduced ore is fed into the metallic bath. When the bath is complete the rotation of the drum is stopped until after the bath has been tapped, and another bath of cast metal has been formed. In the meantime the communication between the casing surrounding the drum and the melting furnace may be entirely stopped by introducing a solid lump of fire clay into the communicating channel or hopper, but the work of reducing the ore may be nevertheless carried on by maintaining the supply of reducing and heating gas.

APPENDIX TT

COLLATED TECHNICAL DETAILS RELEVANT TO THE STEEL PUDDLING PROCESS

Information collected from a number of sources, originally appearing in the author's paper 'Puddled Steel: The Technology', J.I.S.I., December 1971, pp.954-956.

In addition to the procedural detail given by Ansiaux and Masion (see Appendix UU), a German text of slightly later date by Professor Kerl appears to give confirmatory evidence; the original has not been found but there exists what is described as an adaptation of the text[1] which gives the requirements for good puddled steel as :

(i) a pure, thinly liquid pig iron, preferably rich in manganese

(ii) a high temperature for the melting down period, with adequate control of the furnace to allow a cool reducing atmosphere for the finishing operations

(iii) a slag rich in manganese and basic but fluid; the use of 'brownstone' (braunite or manganese peroxide) and salt is recommended for iron low in manganese; here, more specifically the addition of 40-60 lb of cinder from the same process together with 4-8 lb of brownstone admixed with salt is quoted during the rabbling period, a second addition of the manganese oxide-salt mixture being used later if necessary.

(iv) rapid making up of the balls (or 'loupes') and their shingling is again stressed.

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1 W. Crookes and E. Rohrig, 'A practical treatise on metallurgy, vol.III - steel and fuel', Longmans Green, 1870 (adapted from the last German edition of Professor Kerl's Metallurgy), pp.70-81.

The same source quotes that the melting down and fining period are longer than for wrought iron due to the care necessary to avoid excessive decarburization; thus a day's production (12 h) is stated to be about 1600-1900 lb of steel bars as against 2500-2700 lb of wrought iron. The higher consumption of fuel (1.4-1.6 tons per ton of steel as against 1.0-1.2 tons per ton of wrought iron) is confirmed. On the other hand the loss of metal in the actual puddling operation is given as only 6-9% as against 10-15% in the production of wrought iron (although there were obviously losses in the further forging down to bars from the shingled blooms which could build the overall loss from cast iron to finished bar up to the 15% quoted in the French text, since there is usually quoted a 20-22% loss to finished bar in wrought iron production).

Of greater interest, however, is the furnace description given in the German text; the puddling furnace used for steel production in Germany had a larger ratio of grate area to hearth area than the normal furnace, to give more rapid heating. The bridge also was higher and the hearth deeper to keep the metal under a better slag cover. This meant that the side walls had to be given extra cooling; one reason for the higher fuel consumption. In addition, the roofs were higher to keep the oxidizing air further from the metal; thus the flue had to be larger. Figures 1 and 2 show the furnace arrangements used at Lohe in Siegen; this should be compared with the normal puddling furnace given in the earlier paper.[1]

Surprisingly, two sets of analytical results on samples taken at various stages through steel puddling heats have come to light. The first series is due to Schilling, but no direct reference has been found to the original work. The figures are quoted by

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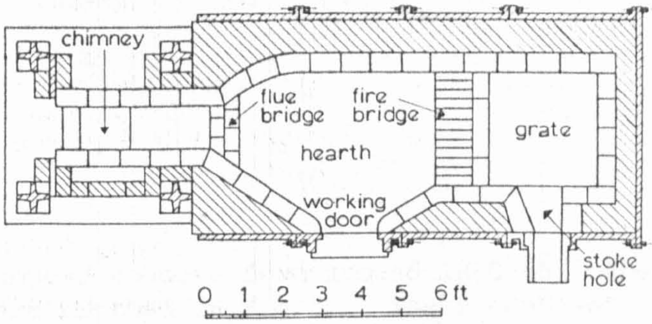
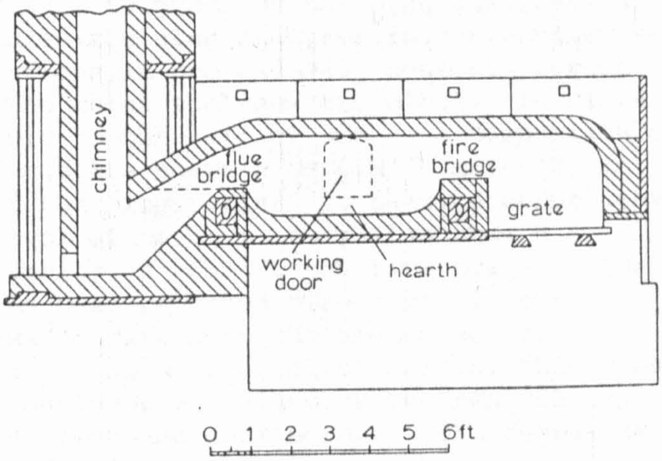
1 It should be noted that a very similar furnace to that at Lohe was described by James Spence in <u>British Patent No. 2134</u> (1858). Two drawings are attached to the patent. See Fig.29 for a reproduction of the normal puddling furnace.



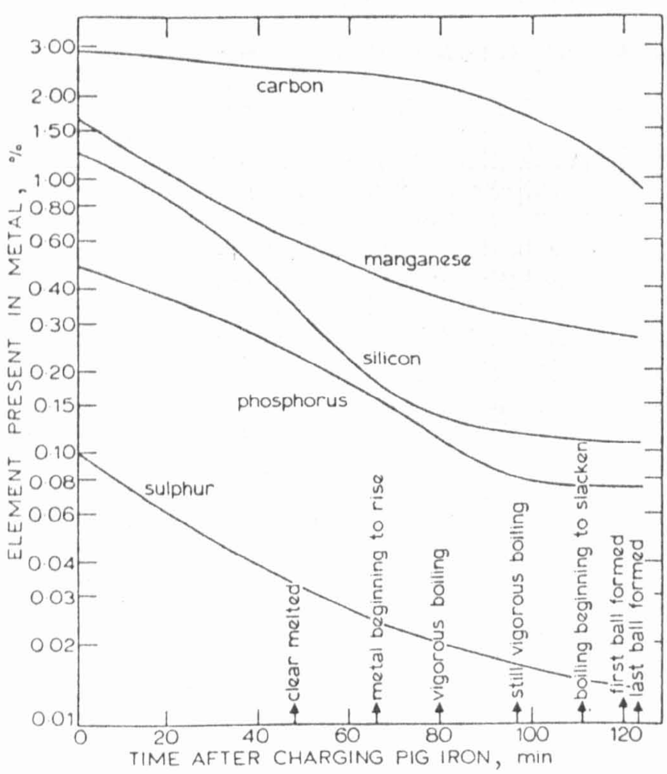
from W. Crookes and E. Rohrig: 'A practical treatise on metallurgy', vol.III, p.79

1 Plan of steel puddling furnace at Lohe in Siegen

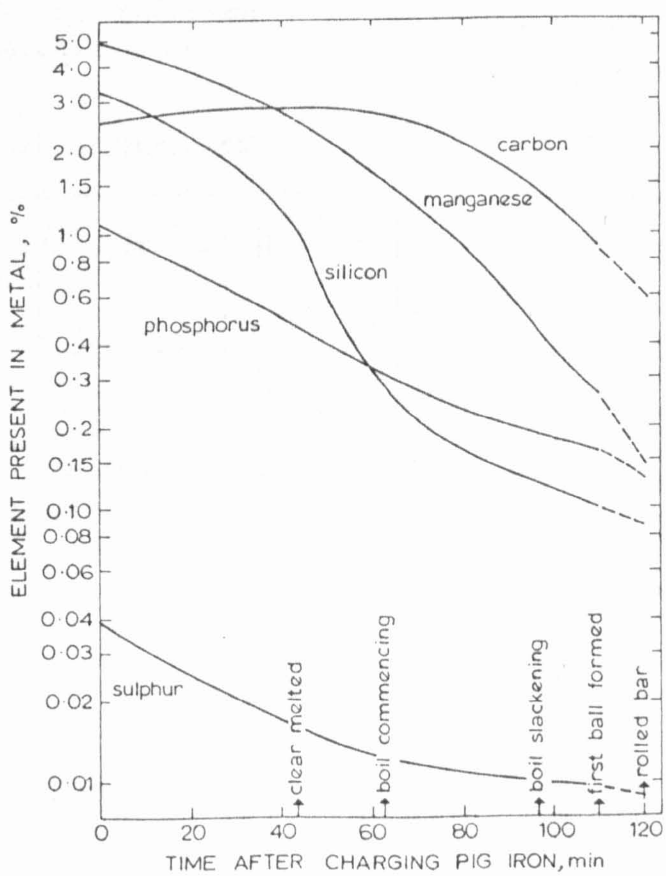


note water cooling on furnace bridge and flue bridge

2 Section through furnace shown in Fig.1



3 Progress of a puddling heat to produce steel (after Schilling)



4 Progress of a puddling heat to produce steel (Dr Kollmann of Oberhausen, 1875)

Bauermann[1] but appear to date from around 1860-65; the metal analyses are plotted in Fig.3. The second set is also from a German source: the samples were taken from operations at the Königshütte works in Upper Silesia and the examination was by Dr. Kollmann of Oberhausen. The report was apparently translated into French for 'Annales industrielles' and the British publication 'Iron' translated from the French.[2] The details here are much fuller and, to judge by the slag analyses, are much more reliable (the slag analyses in the earlier set contain no variations in MnO and P_2O_5 contents across the series). The metal analyses are plotted in Fig.4 on a similar basis to the earlier set. A comparison of the two sets of results shows a general similarity in that the bulk of the 'impurities' is removed before any substantial removal of carbon; they also show a remarkable similarity as regards the time scale. One feature which has been reported elsewhere[3] is the apparent increase in carbon in the second set of figures; even assuming no removal of carbon, this rise is greater than could be explained by the removal of the manganese, silicon and phosphorus. The degree of phosphorus removal is to be noted; to obtain a reasonable phosphorus content in the final steel, however, it does seem that the original cast iron should contain under 0.5% of this element. Even so, in the period 1860-1880, puddled steel would be an attractive proposition, particularly on the Continent where hematite ores were decidedly scarce.

The slag analyses quoted by Kollmann are of interest.

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1 H. Bauermann, '<u>The metallurgy of iron</u>' (5th ed.), 414-417, 1882, London, Crosby Lockwood.

2 'The chemistry of puddling', <u>Iron</u>, 1 Jan. 1876, p.3 and 8 Jan. 1876, p.35.

3 C. Calvert et R. Johnson, 'Sur les changements chimiques que subit la fonte durant sa conversion en fer', <u>Annales de Physique et de Chimie</u>, 1858, Tome Lii, p.485.

APPENDIX TT
continued - 4

The furnace had apparently been used before the experimental melt for the production of wrought iron and the initial analysis is of the slag remaining in the furnace; other analyses are given for various stages through the melt, and also for the hammer slag during the shingling of the first loupe. The figures are as follows :

	SiO_2	FeO	Fe_2O_3	P_2O_5	MnO	Al_2O_3	CaO
Initial slag in furnace	15.32	52.18	22.31	2.30	6.56	0.33	0.70
After fusion of charge	17.13	59.06	9.81	3.40	9.35	0.35	0.69
11 min later	23.18	52.43	6.94	4.22	12.51	0.49	0.83
At commencement of boil	19.95	51.68	11.45	4.26	11.69	0.27	0.50
At coming to nature	19.45	48.04	13.48	4.17	14.40	0.34	0.62
Final slag after removal of all metal	17.39	51.32	17.54	3.93	9.34	0.42	0.58
Hammer slag from first shingling	16.29	51.62	19.32	3.78	8.46	0.38	0.61

From these figures it appears that the early removel of major proportions of silicon, manganese and phosphorus during the melting and rabbling periods is largely brought about by the presence of higher oxides of iron, and that the phosphorus is held in the slag on account of its basic oxidizing character; it is also during this period that the bulk of the sulphur is removed. From the high manganese oxide figure at 'coming to nature', it would appear that an addition of manganese dioxide could well have been made, although there is no reference to this in the text; certainly a high manganese oxide content at the end of the process is an advantage in that it depresses the freezing point of the FeO-SiO_2 slag system, and thus the point made in the French paper is valid.* It will be noted that the Fe_2O_3 content falls initially and then tends to build back; in the absence of the manganese oxide this would indicate a steep rise in the oxidizing power of the slag; on the other hand, it should be remembered that a fair proportion of the

* See Appendix UU.

slag has been expelled from the furnace, and thus the available oxygen is being picked up by a smaller amount of slag and the ferric oxide content will rise more steeply on this account under oxidizing conditions.

Comparing these analyses with those quoted for wrought-iron puddling slags, it appears that the major difference is indeed the manganese content, the MnO replacing FeO; this will be seen from the following examples selected from the literature :

	SiO_2	FeO	Fe_2O_3	P_2O_5	MnO	Al_2O_3	CaO
Final cinder (hand puddling)[1]	16.53	--66.23 ---		3.80	4.90	1.04	0.70
Final cinder (Dank's furnace)[1]	14.17	59.14	20.94	1.20	1.21	1.76	0.25
Final cinder[2]	15.79	69.52	9.21	1.66	2.81	1.76	0.25
Tap cinder[3]	11.76	58.67	17.00	4.27	0.57	2.86	2.88

On the other hand, Schafhautl's powder (the mixture of manganese dioxide and salt) was used in the production of wrought iron and one such operation gave a slag which was essentially similar to those discussed above in the preparation of puddled steel:[4]

SiO_2	FeO	Fe_2O_3	P_2O_5	MnO	Al_2O_3	CaO MgO	FeS
22.30	55.09	9.11	3.71	8.46	nil	traces	1.97

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1 I. Lowthian Bell, '<u>Principles of the manufacture of iron and steel</u>', 395, 1884, Routledge and Sons. (It appears that the analysis of the cinder from the Dank's furnace is taken from the paper by G. Snelus, J.I.S.I., 1872, vol.1, 267).

2 H. Louis, J.I.S.I., 1879, vol.1, 222.

3 J. Percy, 'Metallurgy; iron and steel', 668, 1864, London.

4 T. Tscheuschner, paper in Chemiker Zeitung, vol.x, pp. 617-8 and 645-6 (abstracted in J.I.S.I., 1886, vol.1, p.325).

The pig iron in this case was very low in manganese; the phosphorus content was reduced from 0.31% to 0.08% in the final bar; there is no comment on the carbon content.

The rise of bulk steelmaking, perhaps not fortuitously, coincided with the growing appreciation of the part which could be played by the chemist and two of the analytical surveys quoted[1,2] which date from around 1860, must be among the earliest of such valuable aids to a greater process efficiency. In truth, metallurgy had progressed a long way since the day of the alchemist. On the other hand, certainly until relatively recent times, has not all steelmaking relied on the trained eye and the practised hand: the look of the furnace, the colour and sheen of the slag, the manner of solidification of a spoonful of metal, the feel of a bar thrust into the bath? Thus, although the production of puddled steel seems at this date to have been a most complicated matter, it was probably no more difficult to produce good and reliable steel by this means than by the Bessemer-Mushet or the Siemens-Martin process.

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1 H. Bauermann, '_The metallurgy of iron_' (5th ed.), 414-417, 1882, London, Crosby Lockwood.

2 C. Calvert et R. Johnson, 'Sur les changements chimiques que subit la fonte durant sa conversion en fer', _Annales de Physique et de Chimie_, 1858, Tome Lii, p.485.

A P P E N D I X   UU

THE MANUFACTURE OF PUDDLED STEEL

Extracts from L. Ansiaux and L. Masion, Traité Pratique de la Fabrication du Fer et de l'Acier Puddlé (Liege 1861), pp.64-76. Translation by the author.

A number of relatively brief references to the details of the steel puddling process itself exist in the older textbooks but nowhere yet has such a full account been found as in this French work published in 1861 in Liege: a full translation of its title would be 'A practical treatise on the manufacture of iron and puddled steel'. It is a notably comprehensive work, in the first place giving full details of puddling for the production of wrought iron, with a subsequent description of two processes for making 'a steely-iron' (which by inference is more suited for the subsequent conversion to blister steel or cast steel in place of the more usual Swedish iron) and 'a true steel, more homogeneous and harder'. This latter is the process relevant to our study; the French authors, however, present this method with several back-references to passages in the earlier text. It has been thought fit, therefore, to present here a translation from the French incorporating such earlier material where necessary for a complete appreciation of the process.

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Principles of Refining to Steel

Refining to steel consists in removing from cast iron the total of its foreign materials while at the same time retaining a notable proportion of its carbon. The iron must be made to retain, without being a cast iron, from 0.5% to 2.5% of carbon*; from this, it follows that, by the careful attention of the puddler, it is possible from the same cast iron to obtain steels which are more carburized or less carburized.

Steel is produced in much the same manner as iron, but it is necessary to interrupt the refining much sooner and

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* Elsewhere it is stated that steel is iron with 0.2-1.5% carbon, the latter being the upper limit for successful forging; these limits seem more reasonable.

before it brings about an almost complete decarburization. One of the principal agents in this decarburization is the oxygen contained in the air which is drawn through the furnace; it is essential, therefore, to prevent the ingress of air to the furnace when the cast iron has been decarburized to the point of giving steel, and this necessitates furnace doors and dampers which close tightly. In puddling for steel everything depends on the very uniform working of the process; during the melting down and the coming to nature, the furnace must be operated in a standard manner and, subsequent to their formation, the loupes of steel must be lifted from the furnace as rapidly as possible.

The Additions

When it is desired to obtain a hard and homogeneous steel, it is necessary to add certain substances to the slag on the hearth to render it fluid, to raise the temperature of the liquid metal suitably for the refining to take place and to neutralize by chemical action the highly decarburizing effects which the slag normally possesses. An important condition for the success of the operation is that it must be practicable to work constantly under a layer of slag which is only moderately oxidising but which keeps its fluidity at a relatively low temperature. Besides the crude slag, therefore, it is necessary to introduce other substances. Very good results are obtained by the use of peroxide of manganese, particularly if the cast irons used are deficient in this element. The peroxide is used either alone or mixed with sea salt in the proportion of one part of oxide to two or three of salt, according to the nature of the cast iron.

First Period: Preparation of the Hearth and Charging

The hearth, having been repaired or newly made, and the furnace having been raised to a white heat, some 15-35 kg of mill scale or hammer scale are spread uniformly over the hearth and its surroundings. Should the hearth have been softened too much by the previous operations it is strengthened by throwing over it several ladles of water prior to the addition of the scale. The amount of scale used varies with the type of pig iron; white irons, which themselves produce large quantities of slag, do not need more than 15-20 kg of these materials, but grey irons require a much larger addition, up to 30-35 kg.

The charge of pig iron is then introduced; a normal addition would be 180 kg. The pieces should be spread around the walls so as to present as large a surface as possible to the flame and to melt as rapidly and uniformly as possible. To obtain this uniform melting, it is necessary to charge pieces of cast iron of essentially the same thickness and not to treat at one time more than one grade of iron; otherwise the melting will be uneven and one part of the charge may even be thickening and coming to nature while another, more highly carburized and thus more fluid, is still liquid on the hearth.

As soon as the charge is added, coal is put on the grate and the fire is blown to great activity.

Second Period: Melting

The iron has to be made fluid in the shortest possible time. The grate must therefore have been thoroughly cleaned. The bed of coal is made thicker or thinner according to whether the draught is strong or weak or whether the fuel is good or bad; a furnace in bad condition with poor coal will not make good steel. Subsequently, the door is carefully closed and the damper fully opened. The fire remains in this state for some time until it becomes necessary to recharge the grate; it is a good thing to liven the fire from time to time. After about 15 min the iron begins to soften and the slag introduced is molten. The damper is left fully open; under these conditions the iron melts and at the end of 40-45 min, according to the speed of the furnace and the quality of the fuel, the whole mass should be molten. At this stage of the working, the whole of the interior of the furnace is at a startling white heat; the puddler makes sure with his bar that there are no remaining solid pieces of iron and he stirs the bath in all directions to render it homogeneous. There can be seen from time to time on the surface of the bath some small bubbles, which then burst, making blue flames and helping to stir the molten mass. The puddler is able, by probing with his prong, to judge the degree of crudity of the molten iron, by the greater or lesser production of sparks and the greater or less adherence of the slag to his tool.

Third Period: Rabbling

Rabbling is always done subsequent to the complete fusion of the charge, in the relative absence of air and with the presence of a large quantity of smoke in the furnace. The damper is therefore almost completely closed at this stage; the furnace is so choked that smoke begins to come out of the working door. Cinder, more or less raw, in small pieces, is introduced into the bath and then, somewhat later, the mixture of manganese oxide and salt is added, increasing the fluidity of the slag and reducing its oxidizing capacity.

The manner in which the slag is added is very important and depends on the circumstances; account must be kept of the quantity of slag which was in the furnace before charging the iron, the degree of heat in the system, the quality of the coal, the degree of draught, the quality of the iron and the nature of the metal bath. It is essential in deciding the procedure and in looking attentively to the draught, to keep a medium fluidity in the bath; this has to be maintained throughout the whole of the rabbling period without having to raise the damper too much, so as not to draw external air through the furnace in any quantity during the whole of this period of the working. A slow decarburization is obtained by means of these additions and this permits the removal of the unwanted impurities while still retaining a high content of carbon.

Rabbling is continued in the normal manner but with greater energy and more actively; soon the bath thickens on account of the cooling brought about by the feeble draught. At this stage a new addition is made and the bath is constantly stirred; the temperature within the furnace (or rather the actual degree of heat within the bath) and the fluidity of the metal are of great importance in the progress of the operations. If the bath is found to be too much cooled by the additions it may be necessary to open the damper a little to prevent the metal coming too prematurely to nature; on the other hand, if the metal is too little cooled, it remains fluid and may reach too high a temperature which will prevent it from refining.

Fourth Period: Boiling

The process continues by a partial opening of the damper in such a manner as to clear the smoke but without admitting excess of air. This causes a slow rise of temperature which will initiate a boil which grows in vigour; the metallic mass rises on the hearth, the slag comes up to the height of the door and the bridge of the flue and then runs off on both sides. Small flames illuminate its surface. The mass rises most when it is most fluid and the longer the rising lasts the more the cast iron slowly decarburizes and the more pure and grainy will be the steel which is obtained. Rabbling is continued briskly and the grate is re-charged in such a manner as to raise the temperature rapidly until the mass takes on a stiffer consistency given by its tendency to weld together.

At the beginning of the operation very fluid slag is produced which has only the slightest adherence to the puddler's bar but which tends to adhere more strongly as a measure of the progress of the refining. At first reddish, it becomes whiter as time goes on and begins to carry at its surface small steely grains, which grow little by little and unite into small clots; these are more red and less yellow and more brilliant than the slag. The slag, which up to now has covered the metal, sinks as an indication that it is losing less carbon monoxide. The appearance of grains at the surface of the bath is a sign that the rising is going to cease and the end of the puddling operation is characterized quite distinctly by the abundance of clots, of a white shiny brilliance, and by the resistance of the mass to the puddler's tool. At this instant, coal is charged on to the grate, so as not to have to open the door again before taking out the loupes.

Fifth Period: Formation of the Loupes

It is always essential during puddling for steel to prevent as far as possible the ingress of air into the furnace and from the time of the appearance of the clotted grains in the middle of the slag which is then sinking on to the hearth it is more than ever necessary to exclude air by letting fall the damper, while not cooling the slag too much, since at this time the slag ceases to protect a large part of the metal which is thus likely to be submitted to a strong decarburizing action. The damper is thus gradually closed, to give a furnace flame full of smoke.

The master puddler raises the mass of steel, turns it over, moves it to right and to left, so as to obtain uniform decarburization and then he separates enough to form one loupe. The detached metal is pressed with force between his hook and the forepart of the furnace, taking care to avoid any folding of the steel upon itself. As soon as the loupe is made up it is quickly carried to the hammer; during the shingling of the first one, the puddler makes up a second and so on. The loupe must never be allowed to remain long in the furnace; on the contrary, it must be shingled quickly, to prevent its decarburization by the slag retained by capillarity in the pores of the spongy mass. It is here that the manganiferous slag renders its major service on account of the low temperature at which it is necessary to shingle the steel loupes (compared with those of wrought iron). Simple ferruginous slags quickly congeal when they are somewhat lean and strongly decarburize when they are rich. Thus, without oxide of manganese, there is always a risk of producing a dirty steel, full of slag, or, alternatively, a more or less steely iron, too low in carbon for true steel.

Observations

Working to produce steel requires cast irons (preferably grey irons) which are pure and manganese-rich and the use of additions of crude cinder mixed with manganese dioxide and sea salt when it is desired it shall be hard, homogeneous and shall combine all the properties of steel. In working to produce steel the losses from grey cast iron will be 14-15%, the use of coal will be 1500-1700 kg to the tonne, and 4 or 5 charges will be obtained in 12 h.

A P P E N D I X   VV

THE PRODUCTION OF METEOR STEEL

Extracts from the Specification published by
John Martineau, as agent for Johann Conrad Fischer,
in British Patent No. 5259, 6th October 1825

To produce steel of improved quality, and presenting the wavy appearance of Damascus swords there may be melted, in a covered blacklead or other crucible in a steel-melting furnace, a mixture of 24 parts of zinc, 4 of purified nickel and one of silver, covered with charcoal powder. The molten mass is poured into water to make it brittle, and pounded small. Then 8 oz. of the powder obtained are mixed with about 6 of chromate of iron, 2 of quicklime, 2 of porcelain clay and one of charcoal powder; and the whole is heated in a crucible in admixture with about 24 lb. of blister steel, or other steel used in making cast steel. The molten steel so obtained may be cast and tilted as usual. To produce the wavy appearance, an acid is applied to its surface when polished; one part of nitric acid mixed with 19 of distilled vinegar being preferably employed.

APPENDIX WW

STEELMAKING AT SANDERSON'S WORKS IN WEST STREET, SHEFFIELD, IN 1845

Extracts from W. O. Henderson, J. C. Fischer and His Diary (London, 1966), pp.157-158. This is a translation of Fischer's diary entry for 31st July 1845

.... After lunch I went to my old friend Mr. Sanderson. Sandersons are the biggest manufacturers of cast steel in Sheffield for they have 36 melting furnaces and 6 cementation furnaces in which they make steel from Swedish iron. As I anticipated, I received a warm welcome from old Mr. Sanderson whom I first met twenty years ago on the coach from Chesterfield to Sheffield and he showed me right through his plant which he is not prepared to do for everybody.

We first went to the cementation furnaces. One had just been fired while the other was in full swing. In each of these furnaces there are two receptacles - each containing about 160 hundredweights of Dannemora iron - and three fires. What happens is this. One flame heats the front of the first receptacle, one flame heats the back of the second receptacle, and a third flame heats the space between the two receptacles. There are holes which create a draught of air through the furnace. Mr. Sanderson gave instructions for an 'eye' to be opened for me. This is a little peep hole in the front of the furnace that is covered by a piece of fireproof clay. When the slab of clay is removed I could see the play of the flames and I could estimate the heat inside the furnace. I thought that the maximum temperature had not yet been attained but this is far from easy to determine as things look very different on a sunny day and on a cloudy day.

From here we went to the plant in which cast steel is made. For the last twenty years - indeed I might say for the last fifty years since Huntsman's works first got into full swing - absolutely no change has occurred in the process of making cast steel. One sees the very same furnaces and the very same crucibles. And - cold or warm - the same methods of filling and emptying the crucibles are employed though funnels are now used for the emptying process.*

The casting was very carefully done. Every furnace contains two crucibles each holding between 30 lb. and 35 lb. of steel. One of the first two crucibles to be tapped** had a little hole in it and over half the steel had leaked out. The caster very sensibly poured the steel that still remained in the crucible

* He presumably meant the use of funnels for the filling process.

** "tapped" is inappropriate: "pulled" would be more correct.

into the second crucible. This was possible because no crucible is quite full when it comes out of the furnace owing to the fact that the crucibles are covered by flat heavy lids. The caster then poured out the steel from the second full crucible in a very careful manner. The next furnace was opened shortly afterwards. This time both crucibles were in good order and they were cast in the same way (as the other). Three men perform the casting process. The first lifts the crucible and carries it to a receptacle which is partly buried in the ground. The second worker holds the crucible with a pair of tongs. The third worker removes the crucible lid with a pointed iron bar and then uses a small rake to remove the few pieces of slag that are floating on top of the liquid steel.

A P P E N D I X XX

NOTES ON THE PRODUCTION OF CRUCIBLE STEEL IN SHEFFIELD PRIOR TO 1914

A private communication from J. O. Vessey, Esq.

Overhead charges were static. Purchase and sales prices were never queried. My first job was to open the letters - today they would be called "the mail". I opened the letters in the presence of my father. The contents were not my business. My job was to save the good side of the foolscap envelopes and on them write the mixes for the next day's melts - three melting shops, six rounds. The envelopes were used so that mixes could be written in large figures to enable the melter easily to read them.

MIXES : Swedish iron, cemented Swedish bar iron, our own scrap (returned from customers) and our own ingot tops. The result? Well, it is quite true of the crucible process - "What you put in, you got out". I remember that Austrian Styrian iron was also regarded among our "very best" irons. A typical mix would be :

15 lb.	Ingot Tops and Scrap
15 lb.	SL Swedish Bar Steel
15 lb.	(L) Swedish Bar Steel
11 lb.	SL Swedish Bar Cut Iron
x oz.	Charcoal, according to Temper required (1 oz. charcoal represented 0.08% carbon)
2 oz.	FerroManganese (added 10 to 15 minutes before teeming).

If the steel made included chromium to the extent of, say, 0.50%, then 6¾ oz. ferrochromium was put in with the original charge, and so on. I suppose today it would necessitate specially printed forms, typed in triplicate, copies duly filed in expensive cabinets by teenage blondes at £x per week, a record for posterity! The mixes were then given to each melter who did the weighing up. The carbon content, as mentioned, was adjusted by adding charcoal; we never used white iron. Packets of ferrochrome, ferrovanadium, tungsten (nearly pure tungsten powder, say 99.5% - never ferrotungsten) were made up in the alloy stores as necessary and placed in the now weighed up pans as a last addition before the "weighs" were carried into the melting shop. We never did any advertising - our customers were Sheffield, Birmingham, Solingen and Renscheid. The only magazine to which we subscribed was "The Ironmonger" - this journal produced just the right sized paper to cut up into "screws". The making of screws was one of the skilled jobs one soon learned - screws were the little packets into which were weighed the ferromanganese and the ferrochrome. Aluminium bits of $^{1}/16$ oz. were added at the time of teeming. My father or myself always threw the bits in - it was a good excuse for one of us to be present during teeming time.

POT MAKING: Very often journeymen pot makers were employed and this was a very skilled and important job. Each individual man had his own secret mixture of white China Clay, "Derby" clay, common clay and coke dust and the only secret which they possessed was that one included probably a quarter of a bag more of one type of material and a quarter less of another in the making up of them. All the clays were in ground powdered form, but if any small lumps were found amongst it these had to be knocked through a sieve. The clays were then mixed dry into a pyramid on the Pot House floor. Sufficient clay was mixed to make enough pots for a day's melting in one Melting Shop, for example, 24 pots for a 12-hole furnace. After this process, a hole was made in the centre of the pyramid and water poured in until the whole of the clay was made into a saturated mixture. This was then kneaded with the bare feet for several hours until the pot maker felt the temper of the material coming up to what was desired by him. This was then left for a short time until he had washed his feet and put on a pair of old shoes. The Pot House floor was sacred; no dirty feet or shoes allowed which might contaminate the clay mixture. There was a mat at the door to wipe one's feet on; I never remember that mat being removed for cleaning.

The clay was then cut up and weighed very accurately into pieces of 32 lb. The next process was the balling of these pieces on a steel bench in all directions so that no air pockets would remain within the lump of clay. When this was completed the clay was again left until the man had his meal and then the actual process of making the pot was carried out.

The ball of clay was then thrown into the flask and the plug, with a spindle on the bottom, was forced down, first by hand, until the spindle hole in the bottom had been found and the plug began to tighten. Before this was done, incidentally, the flask inside and the outer surface of the plug were both thoroughly brushed with Pot Oil to prevent the clay adhering to either of the tools. A potmaker's maul - a large wooden mallet - was then used to knock home the plug, thus bringing the clay uniformly up the sides; then by a twisting movement the plug was withdrawn, leaving the clay in the form of a crucible inside the flask. The mouth of the crucible was then trimmed of any excess clay. The flask was now lifted up and placed with its loose bottom plate upon a small post fixed in the ground. By allowing the flask to fall, the crucible remained in position. A mould of tinplate was now passed over the mouth of the crucible, pressing it inwards to make the form of the crucible complete. Then, by carefully lifting the pot with the aid of a pair of plates fitted round the sides, it was placed on the pot board. Each of these boards held two crucibles, which were placed at the back of the actual melting stack upon shelves. They remained in this position for three days, by which time the heat from the stack had rendered them sufficiently hard to be brought inside the furnace room and placed on the shelves over the holes, where they stood for a period of seven to ten days before they were actually used, by which time the weight of the dried out pot had been reduced to about 28 lb. The day before use they were put into a "nailing grate" (annealing stove) and remained heated in the grate for a period of 18 to 20 hours.

NEXT MORNING: The process the following morning would then be first the slagging of the holes; this was done with a Slagger. A Slagger is a poker with a broad chisel end. Two clay stands were then placed on the clean fire bars in each hole. On to the stands two of the pots were lowered. A handful of white silica sand was then dropped into each pot to make up the spindle hole and to "fritter" the stand to the pot. A clay lid was put on every pot. Hot coke from the lighting off grate was now put round the bases of the pots and the holes were filled up with beehive produced melting coke. The experience of the Melter enabled him to decide when the pots were ready for charging. One could discern a black ring coming from the bottom of the pot and until the ring had disappeared the sand had not frittered; hence, too early charging would have meant that, as the material melted, it would have run through the spindle hole into the cellar.

THE BOSH: At the door of the crucible melting shop stood a bosh. A bosh was a rectangular tank made in cast iron, six to seven feet long, two foot wide and three foot deep - the bosh was always kept full of water. The pokers ("potters"), pulling out tongs and teeming tongs were put into the bosh after use. The "potters" were often at melting point after the final "look o'er". After a time the end of the potter dropped off in the water and the tool was collected regularly to have a new nose welded on. Sometimes the end dropped off in the pot - not serious, all good mild steel. It was the duty of the puller-out to look over every pot towards the end of the melt. This was called "looking 'em o'er". He did this by tipping the lid slightly off the pot and putting the potter to the bottom of the molten liquid and, by practice, he could feel if any small piece of metal was still not melted.

The final decision as to which pot and in what order the pots were to be pulled lay with the Teemer. The Teemer was in charge of the melting shop; his boss was the Head Melter, who was in charge of all the melting shops and was present at teeming time. The teeming times were worked out according to the type of material being melted. High carbon steel first; lower carbon taking longer to "mature" followed.

One pot of steel made one ingot, 2½" square, about 50 to 56 lb. If larger ingots (4" square) were required then one pot had to be "doubled" into another. One pot could easily accommodate the contents of two pots for a few minutes. The amazing skill in teeming was taken for granted, but just think of being able to pour 50 odd pounds of molten steel into a 2½" square mould about 30" deep without catching the sides! A "catched" ingot was a black mark!

THE BESOM: The besom - "a bundle of twigs tied round a stick for sweeping; kind of broom". This is according to the Concise Oxford Dictionary; with the description I agree, but the besom was not used for this purpose in a crucible melting shop. The besom was always kept in the bosh. When the time came for the Puller Out to "look 'em o'er", he would be wearing a sack apron to his ankles. He would soak this apron in the bosh and return again and again to do this whilst "looking 'em o'er". When pulling out time came, this protection was not enough. Both the puller-out and the teemer wrapped their legs from ankles to above the knees in oilskin (where did the oilskins come from? I don't remember - I cannot recollect that the firm ever supplied them). On top of the oilskin were wrapped the "rags" - layers of sacking. Over the rags, a sack apron from waist to ankles. The rags had to be thoroughly soaked with water and this was done by splashing the legs with the besom. The apron was soaked by letting it drop in the bosh.

After teeming the first round of pots was put back in the holes, the back pot being put into the front and the front pot reversed to the back - the next mix was then put in. The ingot moulds meanwhile were broken down and the ingots pulled out of the melting shop to cool off in the open air.

TOPPING: Each teemer topped his own ingots - well, he didn't actually do the hard work. The teemer held the ingot at just the right angle on the anvil and the puller-out did the topping with a 7 lb. hammer. The topped ingot was passed to my father for examination. A pipe? - no, you can't get away with that, so back for further topping. If the steel was poured at the right temperature, then the fracture could be read for carbon content. If the fracture consisted of large crystals emanating from the centre, the indication was that the steel had been "tem" too hot - break it up and remelt. After topping and examining, the ingots were immediately placed on a weighing machine in one batch. Before leaving the scales each ingot was clearly marked with its symbol, indicating its grade. This was also regarded as a skilled job. I eventually received grudging appreciation of my skill - I would make a better sign writer than a steel maker! This for some long period was the break in the life of the ingot - it was stacked in the yard, often for up to six months, to weather - the sure but slow process of cleaning the surface by oxidation.

PULLERS OUT: The puller-out's job was to see how the melting was progressing. The control of the draught was manipulated by the alteration of the position of two bricks in the flue under the melting hole. The flue hole, in the cellar, was also covered or uncovered - according to instruction shouted to the cellar lad by the puller-out - by a piece of newspaper. "Tek paper off four", or some similar instruction with regard to the movement of the two bricks - so as to bring the draught to left, or to right, so as to control - increase or decrease - the heat on one of the two pots. All this meant that the pullers-out - and the teemers - were brain workers as well as strong and physically fit labourers. What would shop stewards have claimed for them today? The make up of the team for a twelve hole furnace was as follows: one teemer, two pullers out, two coakers, one odd man and one cellar lad: seven in all.

ODD MEN: My recollection of the Odd Man was that, by nature, he had to be a bit odd to start with or he would not have undertaken the job - certainly not under the Welfare State and full employment conditions. The routine in the melting shop required the cleaning of the interior of the half-moulds by scrubbing with a piece of melting coke. The half-moulds were then laid "inside down-most" on rack bars in a line and the reeking pan, filled with ignited pot-oil, burnt under the moulds. The smoke or "reek" covered the insides of the moulds with a thick coating of soot - this to prevent the molten steel from sticking to the mould surface during teeming. During this period of reeking the odd man had the melting shop to himself - all windows and sky-lights closed. It was, I suppose, the tea break for the rest of the team, but in our case the pub was next door and the team made good use of it. Whatever liquid was then consumed was quickly sweated away during the teeming period in the next hour or so. The odd man's other job was to help the teemer whilst weighing up, also to bring baskets of coke to empty into the holes at the puller-out's instruction. I find, with great regret, that it is now impossible to purchase a genuine coke basket. These were made by successive generations of makers, now extinct. A great pity, for they were ideal for use in the garden. The besom is still available, however.

WORKING HOURS: These varied according to the trade. Some of the firms "ran" three rounds, meaning that the pots were put back immediately after teeming both the first and second rounds for a third time round. My own firm never did a third round. The melting of high carbon steel for the production of pocket knives and razor steel demanded more than just getting melted and pouring out. It needed time. In the melting of high speed steel there was much more latitude in temperature than in the making of razor steel, which had to be just right. Razor steel was like watching the milk to see it didn't boil over. Two rounds was enough for clay pots - we never used "composition" graphite crucibles for best quality steels.

LIFE OF FURNACE: Rebuilding was done every four weeks - gannister rammed round a wooden mould called a building box. A hole was therefore at its smallest after rebuilding - daily slagging increased the size of the hole. The carbon content of the steels was reduced over the 'life' of the furnace. Starting with razor steel, then file steel - up to 1.3% carbon in pre-Siemens days - ending with our mildest quality with about 0.38-0.45% carbon for engraving plates - we didn't make our own bank notes, however!

APPENDIX YY

AN ATTEMPT TO DERIVE THE PATTERN OF PRODUCTION LEVELS FOR THE CEMENTATION AND CRUCIBLE STEEL PROCESSES FROM 1825 TO 1925

A revised version of the paper by the author which originally appeared in Historical Metallurgy, Vol.8 (1974), pp.103-111.

There are no official statistics for the production of steel by these processes in this country. There are a few contemporary estimates and there are vague traditions; for the last fifty years of their life even these are lacking. Set out below is an attempt to use what evidence there is and to couple it with a subjective and personal judgment based on a long term study of the factors involved. In no way, however, does it purport to be a definitive solution.

* * * * * *

The earliest figure yet discovered for an estimate of Sheffield steel production comes from the evidence given by William Vickers to the Select Committee on the Sheffield to Rotherham Railway Bill in 1835.[1] He quoted an annual output of 12,000 tons of cementation steel, a figure later confirmed by S. Jackson in the same discussions.[2] 9,000 tons of this blister steel was later remelted in crucibles. Some 10,000 tons of Swedish iron was used, together with 1,000 tons of scrap. This also appears to be the source of the information given by Porter[3] who also stated that there were, at this time, some 56 converting furnaces and 62 melting shops with a total of 554 melting holes in Sheffield.

The next evidence is that of Le Play. He reported that, in 1837, the production of cementation steel in South

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1 Lords Committee on the Sheffield to Rotherham Railway, 1835, Minutes of Evidence, p.11.

2 Ibid, p.34.

3 G. R. Porter, The Progress of the Nation (ed. Hurst), (London, 1912), pp.240-241.

Yorkshire was 180,000 metric quintals (just under 18,000 tons) but that the level of production had fallen, due to the bad state of trade, so that he computed the average production over the period from 1836 to 1842 to have been 16,250 tons per annum.[1] At the same time, various works near London, in Staffordshire, in Somerset and in Lancashire had delivered 4,000 tons of raw cemented steel. The raw materials came mainly from Sweden (63%) and Russia (22%); some 2% came from Norway whilst the remaining 13% was home produced. He reported that 33 works had a total of 97 conversion furnaces[2] and implied that they should have been capable of twice the achieved output, apart from the recession in trade. He stated elsewhere that the 51 steel melting shops, in 1842, consumed 52% of the blister steel produced, using some 165 tons per week,[3] and he also quoted the number of melting holes available as 774.[4]

E. G. Danielsson, in a report on a journey to England and the United States in 1843,[5] gave the consumption of imported iron in steelmaking, in this country, as 64% Swedish, 3% Norwegian and 33% Russian. The Swedish import was 92,000 skeppund (12,400 tons). In addition, some 15,000 skeppund (2,000 tons) of home produced iron from Low Moor, Milton and Bowling was used in the year, in Yorkshire steelmaking. From these figures a cementation steel total of 21,400 tons can be deduced, which agrees closely with Le Play's figure for the previous year.

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1 F. le Play, 'Mémoire sur la Fabrication de l'Acier en Yorkshire', Annales des Mines, 4me. Serie, Tome III (1843), p.687.

2 Ibid, p.621.

3 Ibid, p.640.

4 Ibid, p.692.

5 E. G. Danielsson, Anteckningar om Norra Amerikas Fri-Staters (Stockholm, 1845), pp.32-33.

Evidence for 1846 comes indirectly, via Swedish sources, but has its origin in evidence given by Henry Unwin. This was referred to by C. F. Waern in a motion put to the Riksdag in Stockholm in 1854;[1] he, in turn, was quoted by Scrivenor[2] who indicated that the number of cementation furnaces had increased to 105, whilst the total of melting holes was 974. The production of blister steel was given as 26,250 tons in the year; there is no separate estimate for crucible steel. Waern also quotes Gustav Ekman as reporting that the amount of home produced iron used in Sheffield had risen to 3,000 tons per annum by 1845.

Waern also included the recent evidence for 1853, having commissioned Unwin to make a special survey in the July of that year;[3] it tells that there were then 160 cementation furnaces and 1495 crucible holes. The estimated amount of blister steel was 40,000 tons per annum; again there is no separate figure for crucible melting. Of concern to the Swedish exporters was the amount of home produced iron being used. This Waern computed to be at least 7,200 tons annually.[4] Sanderson, commenting on these figures in 1855, suggested that the amount remelted in crucibles was probably about 23,000 tons per annum.[5]

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1 C. F. Waern, 'Om Jerntillverkningen och Jernhandeln', <u>Riksdag Bilaga</u> (1853-54), pp.49-50.

2 H. Scrivenor, <u>History of the Iron Trade</u> (London, 1854), pp.155-156. Scrivenor's translation repeats the misquotation of the estimate for 1835 (the Waern report states this as having been 15,000 instead of the 12,000 tons in the original).

3 The Waern business papers have been deposited in the Gothenburg Archives; a search through these has failed to discover any detailed document from Unwin, although the cataloguing is still incomplete.

4 Waern openly admits that he found it difficult to obtain any reliable data on which to base his estimates for the consumption of home produced iron.

5 C. Sanderson, 'On the Manufacture of Steel', <u>Journal Society of Arts</u>, Vol.3 (1854-55), p.458.

Hunter[1] dealt with the situation in 1856 and indicated 206 cementation furnaces and 2113 crucible melting holes were to be found in Sheffield, with a further 54 cementation furnaces and 245 crucible holes elsewhere in the country. He then computed the totals, on the basis of 250 tons per cementation furnace and 18 tons per crucible hole per annum, to give a national total of 68,000 tons of blister steel and 42,000 tons of crucible steel. The Sheffield totals were 51,500 and 37,834 tons respectively. Hunter also made the significant statement that some 3,000 tons of steel was made direct from iron in the melting furnaces, without going through the cementation furnace first.

The same source[2] gives a summary of the situation in 1862. The number of cementation furnaces had fallen from 206 to 205, but the average size had obviously increased since the production of blister steel was quoted as 78,270 tons, or a mean output of 384 tons per furnace. The number of crucible melting holes, however, had increased significantly, as had the output per furnace, 2437 holes producing a total of 51,616 tons of "saleable" cast steel.[3] Information, possibly relating to a year or two earlier, is available from a Continental source,[4] which reported Yorkshire to be producing some 50,000 to 60,000 tons of steel annually, more than half of which was made from imported Swedish and Russian iron imported through Hull. The remainder was said to be "common steel", derived from the use of English and colonial cast and wrought irons.

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1 J. Hunter (ed. Gatty), <u>The History and Topography of the Parish of Sheffield in the County of York</u> (Sheffield, 1869), p.214.

2 Ibid, p.216.

3 If it is assumed that this referred to bar steel, this was probably of the order of 85% of the ingot weight and could, therefore, refer to the melting of some 62,000 tons of steel.

4 L. E. Gruner and C. Lan, <u>L'État Present de la Metallurgie du Fer en Angleterre</u> (Paris, 1862), pp.788-789. The information is quoted on the authority of "Mr. Vickers, of the house of Naylor, Vickers and Co.". It seems from the text that it could refer to the year 1859 or 1860.

Official statistics for steel production in Britain are available on a continuous basis from 1868, but they are of no assistance to this survey since they only cover the Bessemer and Open Hearth processes, with no figures whatsoever for either cementation or crucible steelmaking. There is an isolated reference to the production of crucible steel in Siemens furnaces, in 1878[1] - some 3,500 tons; this, of course, ignores the bulk which was still made in coke fired crucible holes. A tradition that the peak figure for crucible melting was about 100,000 tons in the year, some time before 1880, has no firm foundation, but the idea was so prevalent some thirty years ago that it cannot be completely ignored.[2] There is also the statement by Robert Hadfield in 1894 that 14,000 crucibles were still made every week in Sheffield.[3] The implications of this statement are two-fold; first that by that time the production of crucible steel had passed its peak and, second, assuming that the 60 lb. crucible was in general use at that time and was used three times before discarding, that the output of crucible steel in 1894 was about 50,000 tons in the Sheffield area.[4]

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1 J.I.S.I., 1879, Part I, p.250.

2 This was quoted to me by the late W. H. Green; my notes indicate that there were over 2000 tons of cast steel ingots made every week in Sheffield, before the Open Hearth process took over. When I worked out that this meant over 5000 crucibles every day, he agreed, saying that Firths, Vickers, Cammells and Jessops could use half this number between them.

3 R. A. Hadfield, 'The Early History of Crucible Steel', J.I.S.I., Vol.XLVI (1894), p.234.

4 This calculation ignores the amount of steel produced in plumbago crucibles; the magnitude of their contribution is not known, but is considered to have been relatively small, even at this date.

The evidence so far presented is, indeed, the sum total that appears to be available. In addition to the scarcity of statistics, however, the validity of some of the figures must be queried and a recent critical survey[1] casts considerable doubt on several of the figures, particularly those due to Sanderson, whilst it is suggested that even Le Play's estimate of the number of steel melting shops is too low on the basis of the rate book evidence. In any case, however, a plot of the available evidence at its face value gives a curve which is almost the classical one of development, maturity, decline and obsolescence, with a terminal date of around 1900 (Figure A). This, however, does not meet the evidence for the twentieth century production of alloy steels by the process and, bearing in mind that statistics are available for the production of crucible steel in America, Germany and France, and that the peak year in each case comes during the period 1907 to 1917[2] it is clear that other means have to be sought if a credible pattern of production is to be derived for this country.

The first line of approach could be to study the flow of Swedish and Russian iron into Britain, since these formed a major item in the furnace charges. In can, indeed, be argued that, from around 1800 onwards, the import of such irons into this country was mainly for steelmaking, bearing in mind that by this time the domestic supply of wrought iron had reached a sufficiently high level for all ordinary requirements to be met. The fact that the price of British wrought iron had, for all time, fallen below that of the imported iron by 1800, together with the knowledge that Britain was to be the major producer of wrought iron for over half a century, must imply that special uses had to be found to justify the trouble and cost of importing Swedish and Russian iron. The only other valid use for

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1 J. G. Timmins, The Commercial Development of the Sheffield Crucible Steel Industry, unpublished thesis, (Sheffield, 1976), pp.66-72.

2 The American data come from the Official Statistics issued by the American Iron and Steel Institute. These values are actually plotted in Figure D from which it will be observed that the output for 1916 just exceeded that for 1907. The German and French information may be found in Iron and Coal Trades Review (Diamond Jubilee Issue, December 1927), pp.211-215. For both countries peak production was in 1917 (130,000 tons in Germany and 40,000 tons in France).

such pure irons, other than for steelmaking, would appear to have been for special wiredrawing applications, which can only have taken very small quantities. Some of the 959 tons of bar iron which came down the canal from Hull to the Sheffield area, in a twelve month period during 1771-72[1], was, without doubt, for normal blacksmithing needs as well as for steelmaking. On the other hand, the estimated 3000 tons which was anticipated as part of the annual freight from Tinsley to Sheffield, at the time of the canal survey in 1802, would almost certainly be a fair measure of the output of the Sheffield cementation furnaces at that time.

For the period 1825 to 1900, the enormously painstaking researches of Attmann have produced figures for the joint import of Swedish and Russian iron into this country, adjusted by the deduction of the Swedish iron re-exported.[2] Whilst it has been shown that there was a tendency towards a slowly growing use of home produced iron, a plot of the nett iron import, as in Figure B, will be seen to show a very close correlation with the curves from Figure A, until about 1855. Thereafter the divergence becomes progressively large.

It may be coincidental, but 1855 was the year in which Swedish cast iron became available. The possibility that the total Swedish export found its way into either cementation or crucible charges is a fairly strong one, given the two factors of direct combination of cast iron and wrought iron in the crucible and the puddling of the cast iron either to steel (for melting in the crucibles) or to bar iron (for cementation or as part of the crucible charge). All these were carried out in the Sheffield area. The argument of relative costs between the British and the imported supplies is again just as relevant as it was half

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1 This figure has been derived from a study of the Hull Water Bailiff's Records.

2 A. Attmann, Fagerstabrukens Historia: Adertonhundratalet (Uppsala, 1958), Diagram 1 (p.10) and Diagram 14 (p.245).

a century earlier in the case of wrought iron.[1] There is also evidence that British haematite pig iron was puddled in Sheffield and this, again, may have been for special uses, since the bulk of the available pig iron, quite suitable for armour plate production via the puddling furnaces, was phosphoric.[2] Added to this, there was the growing use of return scrap in the crucible charges. It is, then, not illogical to consider the possibility of estimating the steel production by adding together the retained import of Swedish and Russian bar iron and the Swedish cast iron import[3] and then estimating that these between them constituted some 75% of the raw materials for Sheffield steelmaking. This produces a plot as shown in Figure C. This shows a better agreement with the published estimates, but appears to be rather low in the period 1865 to 1870 and with an unexpected peak in the early 1870s. If this peak is a valid one, there was a phenomenal increase in steelmaking capacity between 1868 and 1871. The validity of such a peak has been assessed, elsewhere, by reference to the rate book evidence for the Sheffield area and a possible

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1 The Swedes themselves appreciated that there must be some special reason why the British were willing to pay twice as much for the cast iron from the Dannemora ores than they would have been charged for their domestic iron, which was available in plenty (see Chapter 8).

2 The wrought iron produced at Wortley Top Forge was typical of the local supply; all samples which have been analysed from that site contain between 0.2% and 0.3% phosphorus. This is perfectly good wrought iron as a constructional material - it was the proud boast that no Wortley Axle ever broke in service (although one was bent almost double in an accident) - but it was of no use as a raw material for steelmaking by the cementation or crucible processes.

3 Figures for the import of Swedish cast iron into London and Hull have been kindly provided by Miss Karen Hullberg, late of Jernkontoret, Stockholm. These cover the years 1855 to 1894.

capacity of 110,000 tons per annum in the 1870s has been calculated for the crucible steel output,[1] plus whatever cementation steel was, at this time, used without re-melting in crucibles. A figure of around 130,000 tons total is, therefore, not too fanciful.

It is worth while considering the American production figures, particularly as the imports of Swedish iron are also known. The information is presented in Figure D. This shows a very similar trend to the British case; the early years are very closely tied to the total iron import. It is, incidentally, interesting to note that the time scale is shifted since the Americans came later to crucible steel melting. As will be shown later,[2] the Americans became largely self sufficient in crucible steel during the 1870s; on the other hand, they relied heavily on imported technology from Sheffield in the early years of their crucible melting activities. Their procedures and their needs would, therefore, not be greatly dissimilar from those in Britain. If the proportion of crucible steel to total steel output in American can be taken as similar to that in Britain and this ratio then applied to the total steel production in this country, figures for which are available from 1868 onwards, the values shown as crosses in Figure C are obtained, and the agreement between the two sets of results, both arrived at by methods which can, at best, be described as being subjective assessments and against which many doubts may be set, is surprisingly close. At any rate, the general pattern of peaks and troughs seems to be established and, by and large, fits with the known cycles of trade.[3]

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1 Timmins, loc.cit., pp.186-194.

2 See Chapter 12.

3 Reference to production of ordinary steel and its price over the years appears to indicate a slump from 1875 to 1879, a peak in demand from 1880 to 1883, then a period of lower activity until 1889 when there was a sharp peak, to be followed by a slow decline which bottomed out about 1895, to give another period of activity around 1900. Representatives of the Sheffield Chamber of Commerce gave their considered opinion that trade in the town was at its normal level in 1868-70, 1876-77 and 1880-82, was distinctly above its normal level between 1871-73 and fell below its normal level in 1866-67, 1879 and 1884-85. (Second Report of the Royal Commission on Depression of Trade and Industry, C.4715, 1886, p.406).

Again returning to the American information, a check on the proportion of Swedish bar iron import to total crucible steel output indicates that the figure fell rapidly from almost 100% in 1870 to an average of 43% for the period 1872 to 1882; there was then a marked rise and, over the next thirteen years, it stabilised at around 55%. Bearing in mind the influence of Sheffield steelmaking technology on the American industry, and considering what is known of the trends in Sheffield steelmaking, it is felt that a similar pattern is probable in this country. In an endeavour to obtain a somewhat better correlation with the curve derived from the estimates in the literature, it has been thought worth plotting values derived from the retained import figure for Swedish iron. After considerable study, for the period up to 1851 it has been assumed that this constituted the whole charge; from 1852-55, 80%; from 1856-60, 65%; from 1861-75, 50%; from 1876-95, 60%. These are, on the face of things, somewhat arbitrary values, but they are chosen with the background of information such as is available, together with the considered opinion derived from involvement in steelmaking. They provide the curve shown in Figure E which is essentially similar to that derived from the bar iron and cast iron import figures, but it varies in certain respects. In the first instance, it gives a steadier rise in output over the years 1860 to 1870; this is more in keeping with what might be expected from the earlier published estimates, bearing in mind that we are here dealing with the total output of blister steel and crucible steel. The height of the peak is similar; slight shifts in the value chosen for the usage of the iron, obviously, would have their effect on this height. The other deviations from the previous curve are a lessening of the trough between 1875 and 1879 and a flattening out of the output between 1888 and 1895. That there was a slump in activity between these earlier dates is perfectly clear and the improvement in the early 1880s can be followed from the increase in steel prices; which of the curves is the more realistic is impossible to say. When it comes to the later period, however, it will be noticed that from 1885 onwards the import of cast iron becomes a major part of the total figure and it is suspected that some of this could, in fact, have been to feed the growing Open Hearth process. The line derived from the bar iron import, therefore, becomes the favoured one up to 1895.

Beyond 1895, a different approach is necessary. This was the period when the crucible process became more and more the producer of alloy and special steel. Again, there are no production records extant, other than a few random survivals from individual companies. On the other hand, it was a period whose traditions still remain in the memories of those with personal involvement in the process. There are also some charge books still available; those from Daniel Doncaster, which come from the early years of this century, indicate that imported Swedish iron formed some 64% of the total charge for some 2000 crucible steel melts. Most of this was converted to blister steel before melting. A similar but less complete record from William Jessop and Sons in 1909-1910 gives a figure of just over 60%, whilst isolated information from elsewhere at this time gives values between 55% and 70%. The figures for import of Swedish iron, less re-export, however, become less accessible for this period. Attmann gives figures for import via London and via Hull, but no global figure.[1] Combining these two will give the major proportion - indeed, over the later years the proportion through Hull assumes a major role - but could be on the low side. In addition, these figures are only available to 1912. Daniel Doncaster and Sons were, however, a major importer of Swedish iron over the whole of this period and their bar iron records, over the period 1904 to 1912, may be compared with the Attmann figures as follows, the figures being in thousand tons :

	Attmann	Doncaster	
	Weight	Weight	% of Total
1904-1906	147.2	41.6	28.3
1907-1909	134.4	38.7	28.8
1910-1912	196.6	54.6	27.8
1904-1912	478.2	134.9	28.2

These values appear to indicate a well established pattern and the bar iron import figures, via Doncasters, from 1913 onwards may be corrected on the basis that they represent 28% of the total input, to complete the series of values from 1895 to 1925. If, then, this is taken as representing 65% of the steel output, a further output line as shown in Figure F may be obtained and added to the previous graph. The fully derived curve may be seen in Fig.35, in the main text.

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1 Attmann, loc.cit., Diagrams 15 and 16 (pp.246-247).

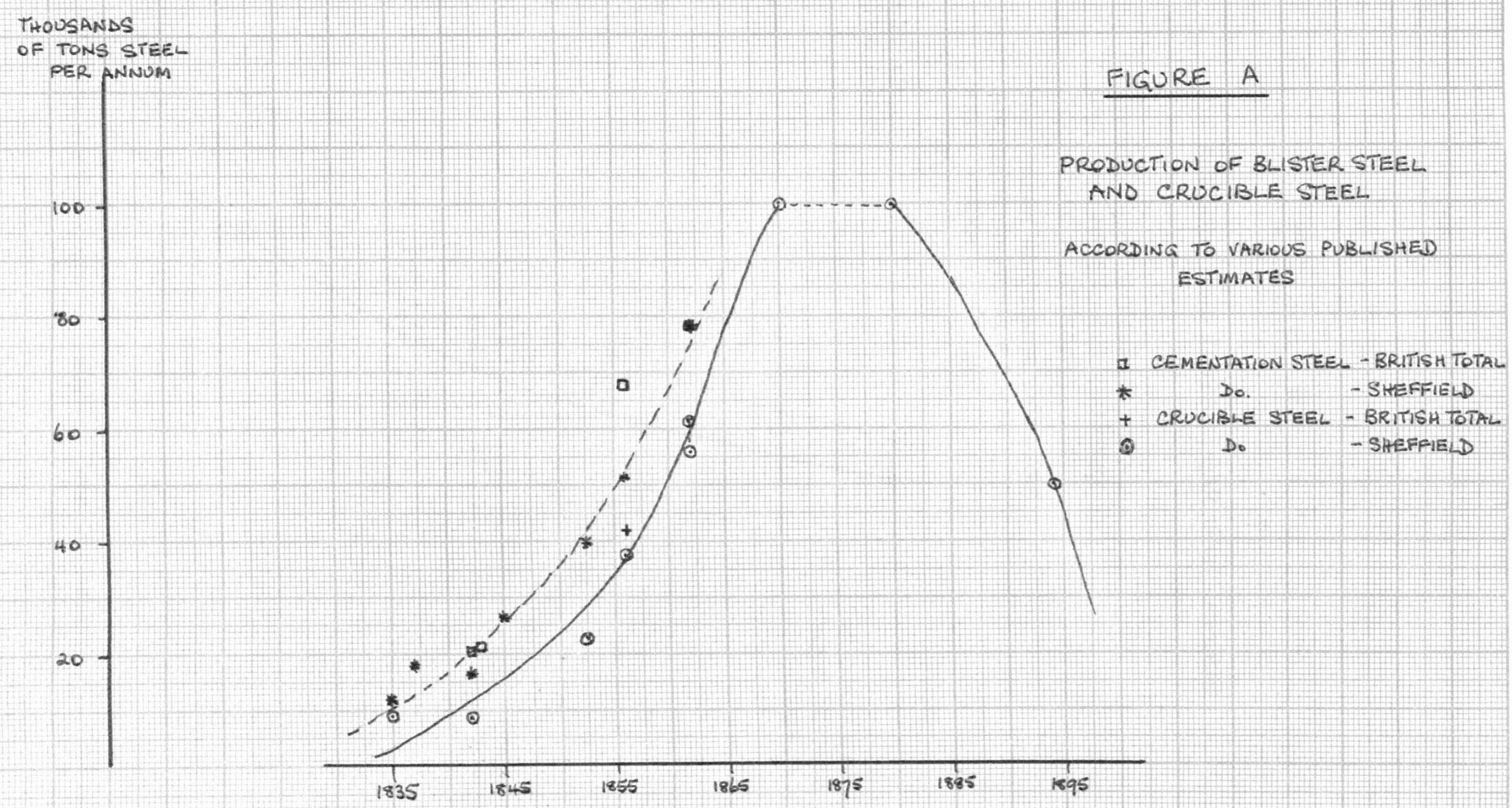


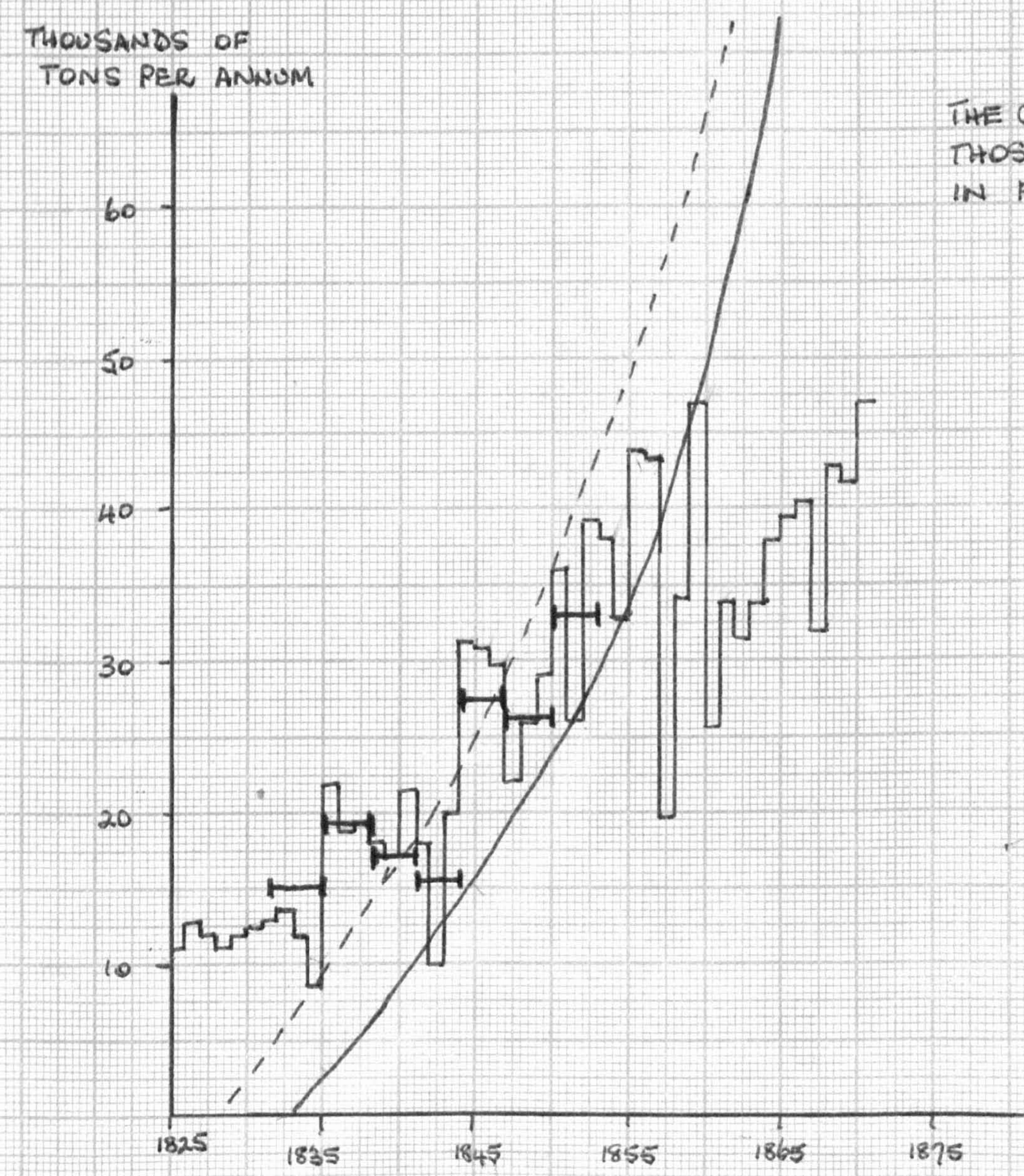
FIGURE A
PRODUCTION OF BLISTER STEEL AND CRUCIBLE STEEL
ACCORDING TO VARIOUS PUBLISHED ESTIMATES
THOUSANDS OF TONS STEEL PER ANNUM
100
80
60
40
20
1835
1845
1855
1865
1875
1885
1895
CEMENTATION STEEL - BRITISH TOTAL
Do. - SHEFFIELD
CRUCIBLE STEEL - BRITISH TOTAL
Do - SHEFFIELD

FIGURE B

SWEDISH (AND RUSSIAN) BAR IRON IMPORTS

STEPPED LINE REPRESENTS TOTAL BAR IRON IMPORT LESS RE-EXPORT (ACCORDING TO ATTMANN)

THE SHORT HORIZONTAL LINES ARE THE CORRESPONDING FIGURES FROM WAERN



THE CURVES ARE THOSE DERIVED IN FIGURE A.

FIGURE C

ESTIMATE OF CRUCIBLE STEEL PRODUCTION

BASED ON JOINT IMPORT OF SWEDISH BAR IRON (LOWEST LINE) AND SWEDISH CAST IRON (SHADED AREA)

FULL UPPER LINE DERIVED FROM TOTAL IMPORT × 100/75.

CROSSES INDICATE VALUES DERIVED FROM AMERICAN DATA (SEE TEXT)

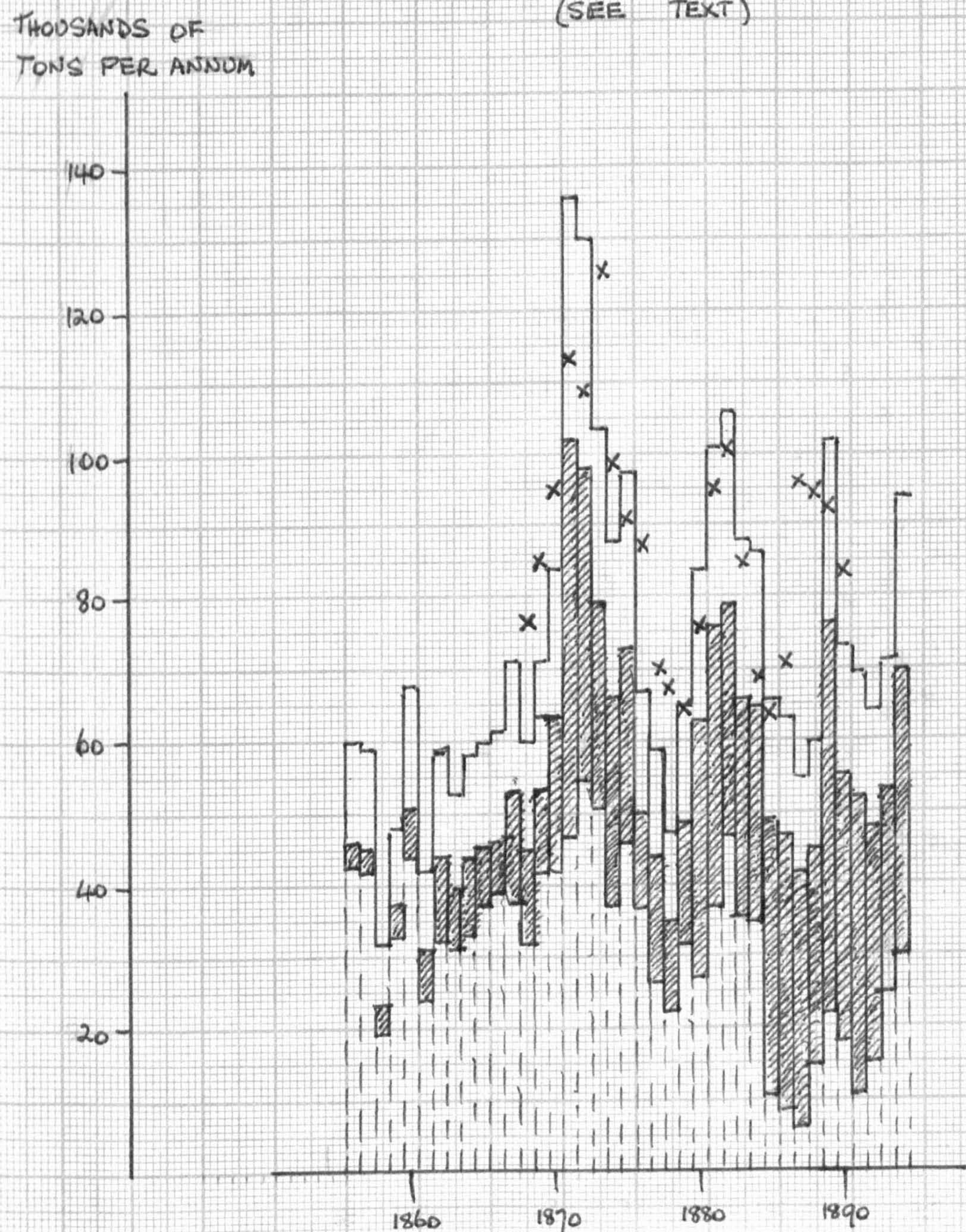
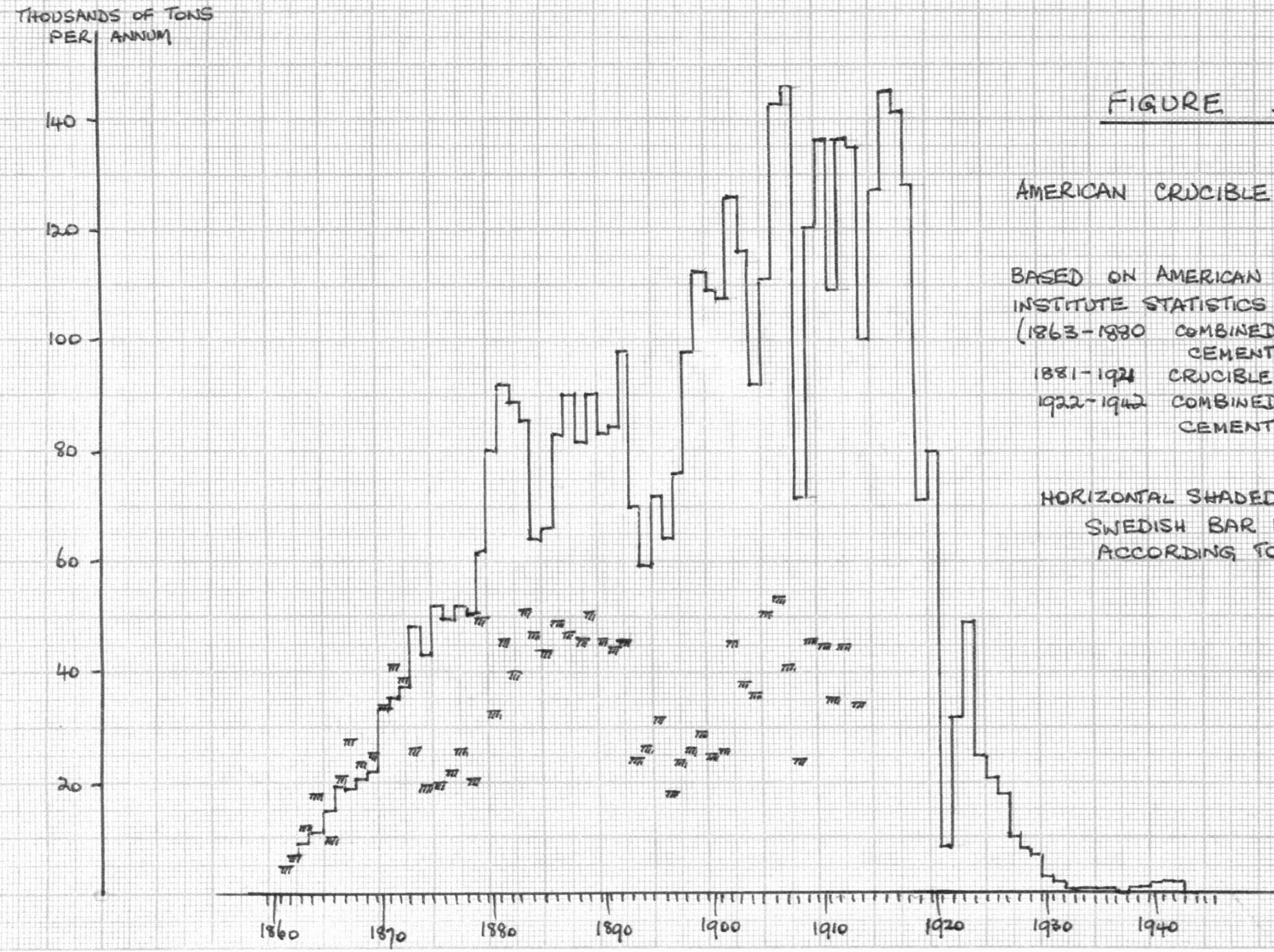


FIGURE D

AMERICAN CRUCIBLE STEEL PRODUCTION

BASED ON AMERICAN IRON AND STEEL INSTITUTE STATISTICS
(1863-1880 COMBINED CRUCIBLE PLUS CEMENTATION;
1881-1921 CRUCIBLE ONLY;
1922-1942 COMBINED CRUCIBLE PLUS CEMENTATION)

HORIZONTAL SHADED LINES INDICATE SWEDISH BAR IRON IMPORTS ACCORDING TO ATTMANN



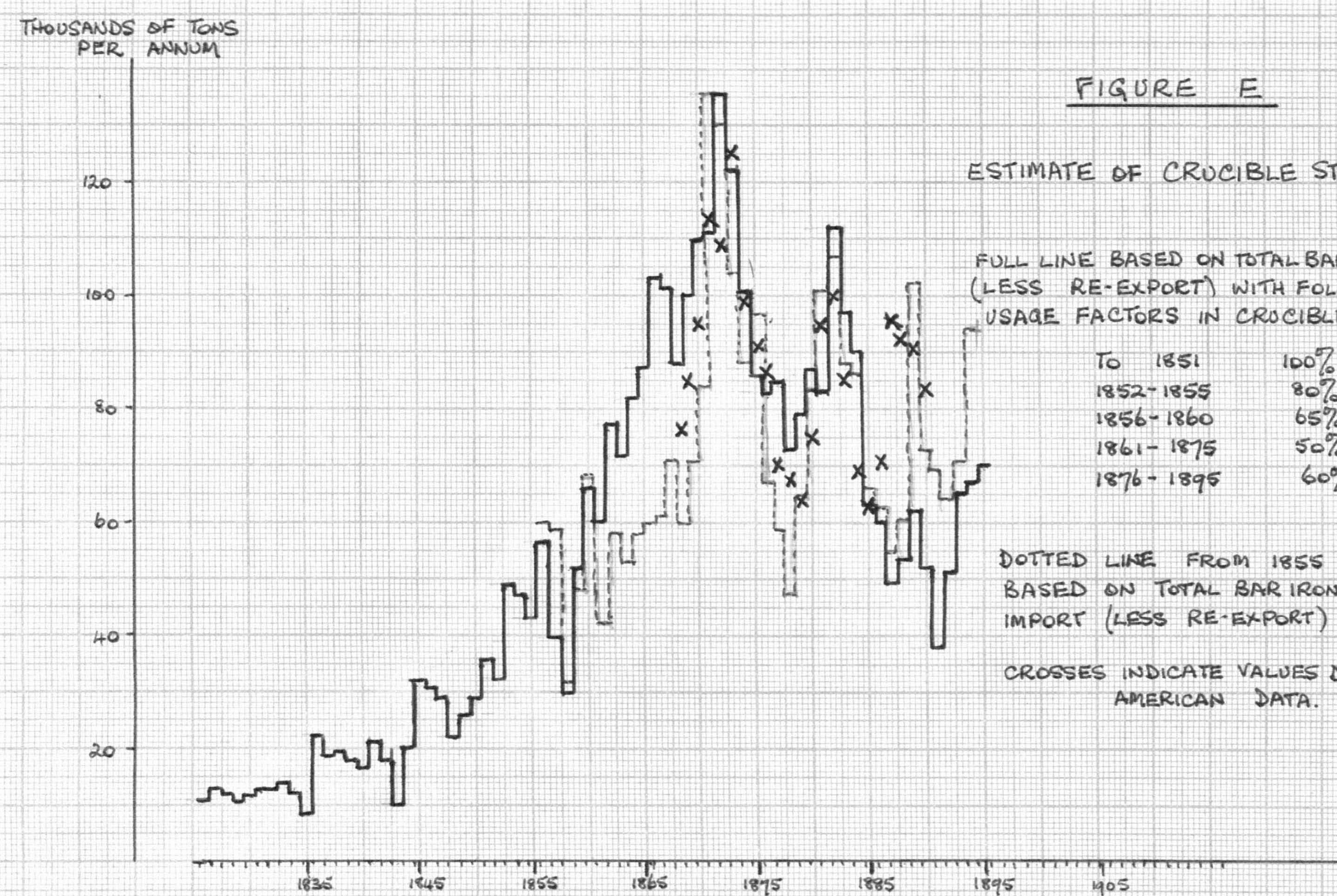


FIGURE E

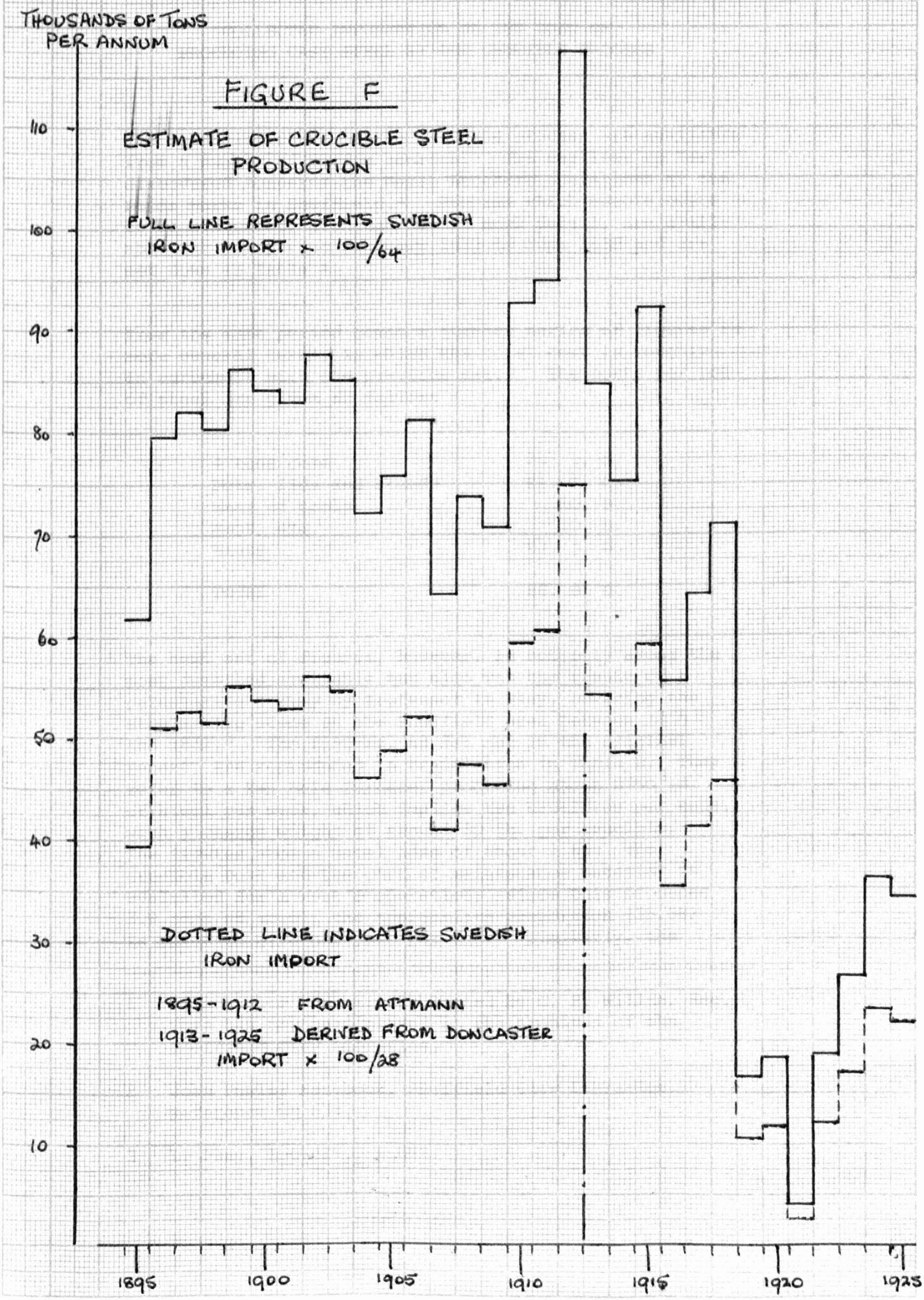
ESTIMATE OF CRUCIBLE STEEL PRODUCTION

FULL LINE BASED ON TOTAL BAR IRON IMPORT (LESS RE-EXPORT) WITH FOLLOWING USAGE FACTORS IN CRUCIBLE CHARGES

TO 1851	100%
1852 - 1855	80%
1856 - 1860	65%
1861 - 1875	50%
1876 - 1895	60%

DOTTED LINE FROM 1855 SHOWS ESTIMATE BASED ON TOTAL BAR IRON PLUS CAST IRON IMPORT (LESS RE-EXPORT) AS IN FIGURE C

CROSSES INDICATE VALUES DERIVED FROM AMERICAN DATA.


THOUSANDS OF TONS PER ANNUM
FIGURE F
ESTIMATE OF CRUCIBLE STEEL PRODUCTION
FULL LINE REPRESENTS SWEDISH IRON IMPORT × 100/64
DOTTED LINE INDICATES SWEDISH IRON IMPORT
1895-1912 FROM ATTMANN
1913-1925 DERIVED FROM DONCASTER IMPORT × 100/28
10
20
30
40
50
60
70
80
90
100
110
1895
1900
1905
1910
1915
1920
1925

APPENDIX ZZ

COLLECTED INFORMATION ON THE COST OF PRODUCING CAST STEEL BY THE CRUCIBLE PROCESS

The operating costs of the crucible process are available from a number of random sources. The earliest so far discovered concerns the Marsh Brothers operations at the Ponds Works in Sheffield.[1] Records which enable costs to be evaluated, although not in much detail, are available for the period February 1833 to June 1838 and are set down in Table A.

From the same period comes a further series of figures in more general terms, in which the total cost is roughly in agreement with the previous set.[2] The costs per ton of steel are given as follows :

4 tons coke	£3. 3. 0.
Pots, lids and stands	£1. 5. 0.
Wear of tools	10. 0.
Rent, etc.	10. 0.
Wages	£3. 3. 0.
TOTAL	£8. 8. 0.

The next set of figures, however, is not only among the most detailed available but also was the result of a painstaking survey by Professor le Play, covering the steelmaking scene in the Sheffield area between 1836 and 1842.[3] The figures, as set out in the original report, are reproduced in translation in Table B. They refer to a ten hole furnace, producing about 8750 lb. of steel per week, which implies two crucibles per hole, with a charge weight of around 30 lb. per crucible. The figures show a metal loss of about 1.8%. The crucible cost and the cost of maintenance material is evaluated for a week's operation; since this produces 3.9 tons of steel, the appropriate proportion (25.6%) is taken to give the cost per ton. Similarly, the

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1 From a note book kindly loaned by G. F. Willan, Esq. This has now been placed in the Archives of the Sheffield City Libraries.

2 John Fowler Notebook, Sheffield City Libraries, Reference WD 634.

3 Le Play, loc.cit., p.665.

total labour cost is 25.6% of the payment to the team of eight men for six days, giving the 12.5 man-days per ton. Taking the interest figures, the implied cost of a ten hole furnace is around £1500 and the floating capital, for stock and work in progress, around £450.

There are also available a number of examples of hire melting charges for this period. Tyzacks were charging 10/0d. per cwt. (£10 per ton) in 1840.[1] Thos. Turton charged £11 in 1857 but only £8. 10. 0. per ton in 1858; Stanley Bros. charged £10 per ton in both 1857 and 1859 whilst Waterfalls charged £8. 10. 0. in 1867.[2] The Doncaster price list of November 1860 quoted 9/6d. per cwt. with 5% discount for prompt payment.[3]

Costs are quoted in a French report on Sheffield steel-making[4] (published in 1862 but probably quoting costs current in 1859) as normally being £7 to £8 per ton, but for "soft steel", which required the use of specially large crucibles with a life of only one or two melts, the cost was as high as £10 per ton. The standard costs were itemised as follows :

Coke, 3.5 tons @ 16/0d. per ton	£2. 16. 0.
Crucibles, covers and stands	15. 0.
Labour	£1. 16. 0.
Maintenance	12. 0.
Various general costs	6. 0.
Interest on capital	9. 0.
Profit	16. 0.
TOTAL	£7. 10. 0.

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1 Tyzack Purchase Ledger, in private possession.

2 All these figures come from the Bramall Papers, Sheffield City Libraries, Reference LD 266.

3 Copy in the Doncaster Archives.

4 Gruner and Lan, <u>loc.cit.</u>, p.797.

R. F. Mushet set up the Titanic Steel Works in the Forest of Dean in 1862 and appears to have operated a five or six hole crucible furnace with two crucibles per hole. Costs as reported in a memorandum of 1871[1] are set out in Table C.

Seebohm and Dieckstahl built up an enviable reputation as crucible steel melters and it is interesting to have a number of their records available. In the first place, Henry Seebohm himself gave some details at a lecture in 1869.[2] He was at pains to point out that a sufficient allowance had been made for loss in topping the ingots and for a fair average of rejected ingots. Since this was for public consumption, it must be assumed they were somewhat inflated, particularly as he points out :

> 'In Utopia, where running pots are unknown and no waster ingots are ever made or any requiring to be topped and where BEST CAST STEEL is made out of common materials which melt quickly, the cost of melting has been in some cases reduced as low as £5 per ton'.

His quoted figures were as follows :

Coals and coke	£3. 15. 0.
Wages	£2. 10. 0.
Pots, lids and stands	12. 0.
Building furnaces	4. 0.
Rent and repairs	7. 6.
Moulds and tools	4. 0.
Bricks	2. 0.
Gas, charcoal, tar, baskets, manganese, sand, etc.	2. 0.
Sundry expenses, say 5%	8. 6.
TOTAL	£8. 5. 0.

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1 Sheffield City Libraries, Reference MD 1193-4.

2 H. Seebohm, On the Manufacture of Cast Steel (Sheffield, 1869). This was the text of a lecture given to the Sheffield Literary and Philosophical Society on 2nd March 1869 which was later printed privately.

Further, a notebook giving production figures for the last dozen years of the nineteenth century[1] has some notes at the front referring to costs at a 12-hole furnace at Plum Street, presumably hired by Seebohm and Dieckstahl for the period 18th April to 20th May 1882. The total production was 48 tons 7 cwt. 3 qr. of steel, using 111 tons 1 cwt. of coke and 9 tons 8 cwt. of slack. The figures read :

2.5.3.26 of coke/ton @ 15/6d.		£1. 15. 8.
3.3.5 of slack/ton @ 6/0d.		1. 2.
Wages)	as per 1881	£2. 0. 0.
Sundries)		£1. 2. 2.
TOTAL		£4. 19. 0.

There is a further note to the effect that on a previous occasion one Marsden, who seems to have been associated with Wilson, Hawksworth and Company, was paid £9 per ton, less 2½%, but had subsequently offered to take on 30 tons at £8. 10. 0. less 2½%, or even less 5% for prompt payment.

The most valuable information in the same volume, however, comes in the form of yearly summaries of production by Seebohm and Dieckstahl from 1887 to 1903 and this may be found in Table D. It should be noted that the firm moved premises in 1898, without apparently disrupting production.

The next available information comes from a famous firm - none other than the Huntsman establishment.[2] This covers the last five years operations at the old Attercliffe plant and then, with a gap of two and a half years, some seventeen years at the Coleridge Road plant. The information, which is quite detailed, is set out in Table E. The stability of costs during the first ten years of activity at the new establishment is remarkable. The addition of the six extra holes in 1912 only gives extra production in the following year;

1 Sheffield City Libraries, Reference BDR 76.

2 Sheffield City Libraries, Reference LD 1621.

thereafter it seems that shortages of raw materials and rises in prices led to some reduction in activity even with the extra need for steel for the war effort.

The charge book covering the period 1895-98 from the Wellmeadow Works, to which reference has already been made, also gives some valuable information relative to a small scale operation.[1] This melting shop had four "double-pot" holes and produced about 100 tons per annum, the mean charge weight was just over 50 lb. per crucible. Whilst it does not give any detailed costs, figures are added to the value of materials on each charge to give the ingot costs. Prior to May 1897, these indicate internal costs of 6/0d. per cwt. (£6 per ton), with a reduction to 5/9d. for "third round" melts (the last operation each day, which was usually the quickest and was generally only used for "common steel"). These prices were increased to 6/6d. and 6/3d. respectively in the latter pages, and it will be noticed that they are very similar to the Huntsman figures. This charge book also notes that the Doncaster hire melting charges were 8/0d. per cwt. in August 1895, increasing to 8/6d. per cwt. in July 1896, with a special charge of 9/0d. for "tool steel". Further information on this point comes from Doncasters themselves. In a note from Jack Barker to Mr. Basil Doncaster in 1953[2] he quotes hire melting charges of £8 per ton having been reported in 1904 at a time when the melting costs were about £7 per ton.

The cost of crucible steelmaking, some ten years later, is studied in detail in the only published text which deals with such matters.[3] These figures relate to

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1 A charge book from the firm of Samuel Peace and Sons, covering operations at the Wellmeadow Steel Works, Upper Allen Street, Sheffield. It is now in the possession of G. H. Peace, Esq., who kindly allowed me to study it. Further comments on it may be found in an article entitled 'A Crucible Steel Melter's Logbook', Journal Historical Metallurgy Society, Vol.12, No.2 (1978), pp.98-101.

2 Held in the Doncaster Archives.

3 D. Carnegie and S. C. Gladwin, Liquid Steel - Its Manufacture and Cost (London, 1913), pp.106-109, 477-478.

Sheffield practice, using a sixteen-hole furnace, each taking two 70 lb. crucibles, producing three heats every twelve hour shift and eleven shifts per week. The three heats are stated to be 70 lb., 56 lb. and 40 lb. respectively. The melting shop, therefore, would produce about 25 tons of ingots per week or 1200 tons per annum. The details are set out as follows :

(a) Interest and Depreciation With a furnace cost of £1200, interest at 5% and depreciation at 10% give a total annual charge of £180 or 3/0d. per ton.

(b) Repairs are assessed at £285 per annum, or 4/9d. per ton.

(c) Fuel The amount of coke required is averaged at 3 tons per ton of carbon tool steel or 3½ tons per ton of high speed steel. With coke at 28/0d. per ton, this gives a cost of £4. 4. 0d. or £4. 18. 0d. per ton.

(d) Crucibles are assessed as costing 1/0d. each. Since each crucible provides 166 lb. of metal, the cost per ton is 13/6d.

(e) Labour The details quoted for a 12 hour shift are as follows :

	Day Shift	Night Shift
One melter	7. 6.	9. 0.
Three pullers-out	19. 6.	£1. 2. 6.
Three coke wheelers	15. 0.	18. 0.
One labourer	5. 0.	6. 0.
One cellar lad	3. 0.	3. 6.
TOTAL	£2. 10. 0.	£2. 19. 0.

Working six day shifts and five night shifts, the total weekly labour cost is £29. 15. 0d; adding 100% for part expenses of foreman, chemist and management, the total weekly cost for 25 tons of steel is £59. 10. 0., or £2. 7. 7. per ton.

Summarising these figures, therefore, the authors arrive at an overall melting cost of £7. 12. 8d. per ton for carbon tool steel or £8. 6. 8d. per ton for high speed steel.

Details are also given of crucible melting costs as applicable to cheaper materials for the production of castings. These involve larger crucibles, cheaper coke and postulate less control, in that only 50% is added to the labour cost for management. In addition, there are details for modified types of furnaces. A summary, to which has been added the calculations for high speed steel melting, may be found in Table F.

A comparison of costs for coke furnace melting with those for melting in a gas fired furnace, in this case using a modified "Harvey Siemens Furnace" is available.[1] The figures quoted for the two different sets of furnaces for the six month period from October 1920 to March 1921 within the same works were as follows, per ton of topped ingots :

	Coke Fired	Gas Fired
Wages (Productive only)	£8. 1. 2.	£6. 6. 2.
Coke consumed	£13. 17. 9.	-
Gas men	-	£2. 8. 8.
Coal for heating prior to melting	-	6. 0.
Coal burned when not melting on nights	-	18. 0.
Coal burned during melting period	-	£4. 11. 5.
Repairs	£1. 10. 0.	£1. 7. 0.
TOTAL	£23. 8.11.	£15. 17. 3.

It was pointed out that these figures referred to a period of depression, with the furnace working very uneconomically

1 F. M. Parkin, <u>Gas Versus Coke Melting in Crucible Steel Making</u>. Manuscript text of a lecture given 19th April 1921 to the Sheffield Society of Metallurgists and Metallurgical Chemists.

on two shifts. For full time working on three shifts, with the current wage rates and coal costs, it was estimated that the true costs per ton of topped ingots would very likely have been :

Wages (Productive only)	£6. 6. 0.
Gas Men	£1. 3. 0.
Coal: a total of 38¾ cwt. @ 40/0d. per ton	£3. 17. 6.
Repairs	17. 0.
TOTAL	£12. 3. 6.

It was also stated that, if the manufacturers' claims for the life of silica bricks were substantiated, with full utilisation of the furnace the repair costs would be much lower than stated; pre-war runs of an average of ten months between repairs, with individual campaigns of thirteen months had been achieved, with repair costs of as low, at that time, as 2/3d. to 3/0d. per ton. The full pre-war melting cost was £4. 1. 11d. per ton.

The latest figures to be found are also derived from the Seebohm and Dieckstahl records (or, to be more precise, from Arthur Balfour and Son, since the name of the firm had been changed during the War).[1] These come at a very unsettled time of trade and are comparable with those quoted above. It is unfortunate that, whilst production records are continuously available from 1883 to 1922, there is a break in the yearly cost breakdown from 1902 to 1919. The figures for 1920 to 1922 are detailed in Table G and show quite clearly how the details for individual years at a time of marked variation in output can be completely misleading. The reduced production in 1921 and 1922 was obviously surviving on the basis of materials provisioned earlier, in the expectation of continued production at the previous year's higher level.

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1 Sheffield City Libraries, Reference BDR 96-1. These records cover further years than the three quoted here but the detail is not capable of interpretation in the same manner and some of the information does not appear to be available beyond 1922.

Certainly, labour costs were deliberately cut; laboratory salaries, for instance, were reduced by 90% in 1921. Although they rose to 30% of the 1920 figure the next year, the further information available appears to indicate that there was then no further increase until 1928, only to be cut back again in 1932.

There is evidence, from these records, that the proportion of alloy steel (probably mainly high speed steel) to carbon steel increased significantly over the period from 1920 to 1932, as the following figures will indicate :[1]

	Value of Ingots Passed to Works	Melting Costs	Ratio of Ingot Value to Melting Cost
1920	£244,437	£67,751	3.60
1923	£102,769	£18,991	5.41
1924	£119,050	£20,403	5.83
1925	£111,682	£19,093	5.84
1926	£109,705	£21,401	5.13
1927	£128,676	£21,162	5.94
1928	£111,007	£18,986	5.84
1929	£122,175	£17,554	6.95
1930	£93,995	£12,975	7.24
1931	£80,911	£8,371	9.66
1932	£88,023	£8,609	10.22

1 By way of illustration, the figures from Carnegie and Gladwin, loc.cit., pp.477-478, produce a factor of ingot cost to melting cost of 2.25 for common carbon steel, 2.75 for carbon tool steel and between 10 and 18 for high speed steel, depending on its composition.

TABLE A

CRUCIBLE MELTING COSTS AT PONDS WORKS, 1833-1838

	Feb.9 1833 to Dec.14 1833	Dec.21 1833 to Dec.13 1834	Jan.1835 to Dec.1835	Jan.1836 to Dec.1836	Jan.1837 to June 1838	Feb.1833 to June 1838
Tons melted	109.15.1.8.	141.13.2.27.	188.7.0.18.	193.18.3.3.	231.3.1.1.	864.18.1.1.
Total cost	£898.16.5.	£1017.18.6.	£1296.7.4.	£1488.12.7.	£1832.19.7.	£6534.14.5.
Tons of coke used	t.cwt. 434.15.	476.14.	695.18.	955.15.	961.0.	3524.2
Cost of coke	£286.4.2.	£281.7.8.	£434.18.9.	£602.0.6.	£620.12.11.	£2225.4.0.
Costs other than coke	£612.12.3.	£735.10.10.	£861.8.7.	£886.12.1.	£1212.6.8.	£4309.10.5.
Tons coke/ton steel	3.961	3.350	3.695	4.924	4.157	4.075
Total cost/ton steel	£8.3.9.	£7.3.8.	£6.17.8.	£7.13.6.	£7.18.7.	£7.11.1.
Coke cost/ton steel	£2.12.2.	£1.19.10.	£2.6.2.	£3.2.1.	£2.13.8.	£2.11.5.
Other costs/ton steel	£5.11.7.	£5.3.10.	£4.11.6.	£4.11.5.	£5.4.11.	£4.19.8.

TABLE B

COST OF MANUFACTURE OF ONE TON OF CAST STEEL IN YORKSHIRE

(F. le Play, 'Mémoire sur la Fabrication de l'Acier en Yorkshire', Annales des Mines, Tome III, 4me. Serie, 1843, p.665)

These figures are typical for a ten-hole furnace which produces about 8750 lb. of steel per week.

		Consumption or days work	Value of material or days work: Partial	Total
SPECIAL COSTS:				
Raw cemented steel		2280 lb.		
Coke at 13/3d. per ton		7380 lb.	£2. 3. 0.	
Crucibles: 108 per week for production of 3.9 tons				
Stourbridge Clay 1230 lb. @ 45/-	£1. 4. 9.			
Stannington Clay 1230 lb. @ 25/-	13. 9.			
Clay for stands and lids 990 lb. @ 25/-	11. 0.			
1 worker @ 26/- per week	£1. 6. 0.			
Miscellaneous costs, casual labour, making stands and lids, oil for moulding, moulds, etc.	14. 0.			
Total 3450 lb.	£4. 9. 6.	886 lb.	£1. 3. 0.	£5. 10. 4.
Maintenance Materials: 150 cu.ft. per week @ 3/10d. per ton (131 lb./cu.ft.)				
Total 19650 lb.	£1.13. 8.	5040 lb.	8. 8.	
Labour for Melting and Maintenance @ 2/5½. per day		12.5 days	£1.10. 4.	
Auxiliary Work: Preparation of moulds, sundry labour			5. 4.	

.... continued

TABLE B
continued

	Consumption or days work	Value of material or days work Partial	Total
GENERAL COSTS:			
Interest at 5% on fixed capital		7. 6.)	
Interest at 6% on floating capital		2. 8.)	
Sundry materials, tools, tongs,		)	18. 8.
moulds, coke baskets, etc.		3. 6.)	
Taxes, licences, carrying of letters,		)	
office costs, etc.		5. 0.)	
	TOTAL		£6. 9. 0.

TABLE C

CRUCIBLE MELTING COSTS AT TITANIC STEELWORKS
1868-1871

Year	Steel Melted t. c.q.lb.	Wages/ton £. s. d.	Coke/ton £. s. d.	Dead Expenses per ton £. s. d.	TOTAL £. s. d.
1868	138.16.2.22.	3.14. 9.	5. 5. 9.	1.11. 0.	10.11. 6.
1869	207.11.2.24.	2.15. 6.	4.16. 6.	2. 1. 0.	9.13. 0.
1870 (11 months only)	188.19.1.13.	2.17. 7.	4.12. 7.	1.15. 0.	9. 5. 2.
TOTAL	535. 7.3.13.	3. 1. 6.	4.17. 6.	1.16. 0.	9.15. 0.

TABLE D

CRUCIBLE MELTING COSTS AT SEEBOHM AND DIECKSTAHL, 1887-1903

Year	Tons Melted	Cost per Ton steel £. s. d.	Coke per Ton steel t. c.q.lb.	Price of coke per Ton s. d.	Coke Cost per Ton Steel £. s. d.	Costs Other than Coke £. s. d.
1887	1684	5. 0. 5.	2.10.3.16.	-	-	-
1888	2421	4.17. 0.	2.19.1.16.	-	-	-
1889	2946	5. 7. 7.	2.13.3. 5.	18. 1.	2. 8. 7.	2.19. 0.
1890	2973	6.13.10.	2.14.3. 6.	25. 7.	3. 8. 8.	3. 5. 2.
1891	2164	6. 4. 8.	2.15.2.23.	22. 3¾.	3. 2. 2.	3. 2. 6.
1892	2022	5.19. 1.	2.12.0. 0.	20. 3.	2.12. 8.	3. 6. 5.
1893	2042	6. 7. 5.	2.13.3. 0.	20.10½.	2.16. 1.	3. 9. 4.
1894	1913	5.17. 6.	2.13.2. 0.	18. 9.	2.10. 2.	3. 7. 4.
1895	2007	5.11. 7.	2.14.2. 0.	16.10½.	2. 5. 9.	3. 5.10.
1896	2547	5.13.10.	2.14.1. 9.	18. 9.	2.10.11.	3. 2.11.
1897	2759	6. 1. 6.	2.16.2. 3.	20. 4½.	2.17. 7.	3. 3.11.
1898	2904	6. 2. 6.	2.16.2.20.	20. 7.	2.18. 4.	3. 4. 2.
1899	3618	6.12. 3.	2.15.1. 7.	23. 5½.	3. 4.10.	3. 7. 5.
1900	3446	7.18. 8.	2.15.2.23.	30. 8.	4. 5. 4.	3.13. 4.
1901	2360	7. 3. 6.	2.17.1.14.	25. 1¾.	3.12. 1.	3.11. 5.
1902	2217	7. 0. 0.	2.18.1.26.	23. 9.	3. 9. 5.	3.10. 7.
1903	2161	6.16. 7.	2.14.1.16.	23. 9.	3. 4. 7.	3.12. 0.

TABLE E

CRUCIBLE MELTING COSTS, BENJAMIN HUNTSMAN LTD.
1894-98 at Attercliffe Works, 1901-18 at Coleridge Road

(Abstracted from Ledger, Ref. LD 1621, Sheffield City Libraries)

Year	Ingot Tons	Tons Coke used	Tons Coke per Ingot Ton	Coke Cost per Ton s. d.	Melting Cost per Ton Steel: Coke £. s. d.	Wages £. s. d.	Moulds, etc. s. d.	Bricks s. d.	Clay and Pots s. d.	Dozzles s. d.	Coal s. d.	Sundries s. d.	TOTAL £. s. d.
1894	308	1242	4.03	16. 9.	3. 7. 6.	2.12. 8.**		18.10.**			-	-	6.19. 0.
1895	308	1091	3.54	17. 0.	3. 0. 2.	2. 4. 3.	2.10.	7. 2.	13.11.	1. 4.	-	-	6. 9. 8.
1896	356	1160	3.26	17. 0.	2.15. 5.	2. 3.11.	2. 2.	7. 7.	12. 3.	1. 3.	-	-	6. 2. 5.
1897	377	1139	3.02	17. 0.	2.11. 5.	2. 3.10.	1. 8.	5. 8.	12. 3.	1. 3.	-	-	5.16. 1.
1898	419	1265	3.02	17. 0.	2.11. 4.	2. 3. 2.	1. 4.	4. 8.	11.10.	1. 3.	-	-	5.13. 7.
1901/2	373	1183	3.17	18. 0.	3.10. 7.	2. 6. 2.	4. 4.	9. 1.	13. 5.	1. 4.	3. 2.	2.10.	7.10.11.
1902/3	433	1392	3.21	18. 0.	3.11. 6.	2. 6.10.	2. 0.	8. 6.	13. 6.	1. 3.	1. 8.	1.10.	7. 7. 1.
1903/4	428	1398	3.27	18. 0.	3.12. 9.	2. 6. 3.	2. 6.	7. 9.	13.11.	1. 4.	1. 0.	1. 6.	7. 7. 0.
1904/5	398	1342	3.37	21. 8.	3.13. 0.	2. 5. 4.	1. 7.	6.10.	14. 6.	1. 4.	11.	1.10.	7. 5. 6.
1905/6	446	1443	3.24	21. 8.	3.10. 0.	2. 5. 2.	2. 7.	7. 1.	14. 1.	1. 4.	10.	2. 9.	7. 3.10.
1906/7	504	1625	3.22	21. 8.	3.10. 0.	2. 5. 1.	2. 4.	6.10.	14. 2.	1. 4.	1. 1.	2.10.	7. 3. 8.
1907/8	472	1430	3.03	23. 8.	3.11. 8.	2. 5. 1.	2. 7.	7. 1.	14. 0.	1. 4.	1. 4.	2. 9.	7. 5.10.
1908/9	443	1370	3.09	21. 6.	3. 6. 1.	2. 5. 4.	2. 8.	6. 9.	13. 4.	1. 4.	1. 2.	1. 7.	6.18. 3.
1909/10	477	1467	3.08	20. 0.	3. 1. 4.	2. 4. 0.	2.11.	7. 2.	13. 8.	1. 3.	1. 1.	3. 3.	6.14. 8.
1910/11	495	1545	3.12	20. 6.	3. 3.10.	2. 5. 6.	2. 1.	7. 4.	13. 7.	1. 3.	1. 0.	2. 2.	6.16. 9.
1911/12	493	1521	3.09	21. 0.	3. 5. 2.	2. 6. 0.	2.10.	6. 9.	13. 6.	1. 4.	11.	2. 2.	6.18. 8.
1912/13	500	1601	3.20	23. 2.	3.14. 1.	2. 6. 6.	5. 5.*	9.10.*	15. 6.*	1. 4.	1. 5.	6. 3.*	8. 0. 4.*
1913/14	606	1863	3.07	25. 0.	3.16.10.	2. 8. 0.	3.11.	7.11.	14. 4.	1. 4.	1.11.	2.10.	7.17. 3.
1914/15	303	970	3.20	24.10.	3.19. 7.	2.10. 4.	3. 5.	9. 7.	15. 1.	1. 4.	1.11.	3. 2.	8. 4. 5.
1915/16	465	1431	3.08	31. 4.	4.16. 5.	2.19. 0.	4. 4.	10. 2.	16. 5.	1. 5.	2. 7.	3.11.	9.14. 3.
1916/17	490	1585	3.23	38. 3.	6. 3. 8.	3. 8. 9.	2. 5.	14.10.	17.11.	1. 4.	2. 7.	7. 9.	11.19. 3.
1917/18	491	1605	3.27	43. 0.	7. 1. 0.	4. 4. 8.	4. 9.	17. 4.	23. 3.	1. 4.	2. 7.	6. 1.	14. 1. 0.

* These figures are stated to contain some items from the addition of six new holes.

** The figures for wages includes pots and dozzles; that for bricks includes moulds and clay.

TABLE F

COMPARISON OF CRUCIBLE MELTING COSTS
(based on output of 25 tons/week)

	CARBON TOOL STEEL	HIGH SPEED STEEL	CARBON STEEL FOR CASTINGS				
	Coke Fired Huntsman Furnace	Coke Fired Huntsman Furnace	Coke Fired Huntsman Furnace	Coke Fired 4-pot Holes	Coke Fired Forced Draught "Radio"	Gas Fired Ordinary Siemens Regenerative	Gas Fired "New Form" Siemens Regenerative
Cost of Furnace	£1200	£1200	£900	£1200	£700	£3500	£2000
No. of shifts	2	2	2	1	1	2	2
No. of heats per shift	3	3	3	3	4	3	3
Size of crucible	55 lb.	55 lb.	75 lb.	75 lb.	85 lb.	75 lb.	75 lb.
No. per hole	2	2	2	4	3	6	12
No. of melting holes	16	16	12	12	10	4	2
Fuel used	Coke	Coke	Coke	Coke	Coke	Coal (gas producer)	
Price of fuel per ton	28/-	28/-	23/6	23/6	15/0	10/0	10/0
Costs:	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Depreciation & Interest	3. 0.	3. 0.	2. 3.	3. 0.	1. 9.	8. 9.	5. 0.
Repairs	4. 9.	4. 9.	4. 6.	5. 0.	5. 0.	6. 6.	5. 6.
Fuel	4. 4. 0.	4. 18. 0.	2. 1. 1.	1. 9. 4.	1. 10. 0.	15. 0.	12. 0.
Labour	1. 3. 8½.	1. 3. 8½.	1. 4. 6.	1. 0. 0.	19. 8.	1. 5.10.	1. 4. 6.
Management	1. 3. 8½.	1. 3. 8½.	12. 3.	10. 0.	9.10.	12.11.	12. 3.
Crucibles	13. 6.	13. 6.	19. 0.	19. 0.	1. 15. 6.	19. 0.	19. 0.
Power	-	-	-	-	1. 3.	-	
TOTAL COST PER TON STEEL	£7. 12. 8.	£8. 6. 8.	£5. 3. 7.	£4. 6. 4.	£5. 3. 0.	£4. 8. 0.	£3. 18. 3.

The above information has been taken from D. Carnegie and S. C. Gladwin, 'Liquid Steel - Its Manufacture and Cost', (London, 1913), pp.106-109, 477-478.

TABLE G

CRUCIBLE MELTING COSTS AT ARTHUR BALFOUR AND SON, 1920-1922

	1920		1921		1922	
Tons steel produced	2311		526		659	
	Total £. s. d.	per ton £. s. d.	Total £. s. d.	per ton £. s. d.	Total £. s. d.	per ton £. s. d.
Steelworks light & heat	1126. 9. 3.	9. 9.	1126. 9. 3.	2. 2.10.	1126. 9. 3.	1.14. 2.
Crucible furnace material	3742.19. 4.	1.12. 5.	193. 9.11.	7. 4.	638.17. 2.	19. 7.
Pot making material	3148. 5. 3.	1. 7. 3.	141. 4. 7.	5. 4.	664. 5. 8.	1. 0. 2.
Coke for melting	34527.19. 9.	13.12.10.	5248.15.11.	9.19. 7.	5182. 3. 5.	7.17. 3.
Ingot Moulds	1135.10. 6.	9.10.	nil	nil	116.16. 7.	3. 7.
Stores	1393. 1.11.	12. 1.	48. 0. 2.	1.10.	198. 1. 4.	6. 0.
Rent, Rates, Insurance	1786.13.11.	15. 6.	922.16. 4.	1.15. 1.	2128. 1. 8.	3. 4. 7.
Repairs, Crucible Tools	713.11. 9.	6. 2.	79.15. 3.	3. 0.	233.19. 8.	7. 1.
Crucible Furnace Repairs	828.14. 7.	7. 2.	58. 0. 8.	2. 2.	108. 3. 2.	3. 3.
Building Repairs	1673. 1. 1.	14. 6.	254.19. 3.	9. 8.	266.14. 1.	8. 1.
Wages: Melting	16575.13. 8.	7. 3. 5.	1246.11. 5.	2. 7. 4.	3204. 4.10.	4.17. 3.
Pot Making	1792. 8. 0.	15. 6.	75. 6. 2.	2.10.	307. 8. 0.	9. 4.
Repairs	319.15. 9.	2. 9.	20. 4. 4.	9.	39.16. 3.	1. 3.
Melting Whse.	1451. 1. 6.	12. 7.	254.13. 4.	9. 8.	628.17.10.	19. 1.
Laboratory	566. 2.10.	4.11.	59. 1.10.	2. 3.	150.17. 4.	4. 7.
TOTAL COST PER TON		29. 6. 4.		18. 9. 8.		22.15. 3.

A P P E N D I X AAA

CEMENTATION STEELMAKING IN THE NO.5 FURNACE AT OSTERBY BRUK

Extracts from a translation of a paper by K. L. Hoglund in Fagersta Forum (1951), pp.11-15, kindly made available by R. T. Doncaster, Esq.

The chests had refractory brick walls and measured 136" long, 37½" wide and 50" high. Under and round the chambers there were twelve flues from the two hearths a little below the base of the chests, separated by a central firebrick wall some 12" thick, the hearths being 83" long and 26" wide. At a height of 32" the chests were roofed by an arch with a 110" span, made of 12" bricks on edge, covered with sand to prevent too much loss by radiation. At the level of the springing of the arch there were four 5" square horizontal flues on each side to carry off the smoke to the main flue and then to the chimney. The heat round the chambers could be controlled by moving the covering bricks on these eight openings. The chests were carefully bricked up, using special shapes, and a layer of quartz sand and clay was spread over the bottom. There was a square hole at the end of each chamber through which sample bars could be withdrawn. The "manhole", through which the men crept in and out when the furnace was charged or emptied, measured 21½" x 31½".

The charge consisted of Walloon iron,* 2½" x ⅝", but in later years rolled Lancashire bars were used. It is probable that in the latter half of the nineteenth century bars with the special stamp "DOOS"** were employed. After straightening and stacking the iron, charging began. First a 3" layer of crushed birch charcoal was spread over the bottom and carefully levelled off. The charcoal powder was prepared in a large box by mixing equal quantities of newly crushed and previously used charcoal, the mixture being wetted with a common salt solution, 4½ gallons of salt water

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* This, of course, was the renowned O O, or "double bullet" mark of iron.

** Dannemora Osterby Staljarn (Steel Iron), the O O again representing the Osterby Forge.

to 140 cubic feet of charcoal per heat. Three layers of iron bars were laid flat, with a ⅝" layer of charcoal between each; every fourth layer of iron was placed on edge, the length of the bars being about 8" less than the length of the chests. A board, ⅝" thick, was used to get the charcoal as level and even as possible. When the level of the sampling holes was reached, three bars half the length of the others were arranged to project into each. (After 48 hours firing, these holes were closed up, first with ash and then with sand). Each chamber held thirty layers of iron, weighing about 23 metric tons in total. The top layer was covered with an arched layer of charcoal powder, then a layer of ash on top and finally a mixture of two parts sand with one of finely crushed grog, which on heating sintered into an airtight cover.* During the latter part of this work those men who could not squat low enough simply had to lie down within the confined space. After this, the manhole was filled in with sand, the covering bricks put in and firing commenced.

This was begun simultaneously in both hearths. Heating was kept at a slow rate during the first twenty-four hours and then gradually speeded up. Only pine was used as fuel at first but, when the full driving rate was reached, 50% birch wood was added to the fuel. This firewood, prepared in the "stave house", was in 6½ foot lengths, dry and of the best quality (but in later years thinnings or even second class cord wood were used). The firing was done by one man per shift and it went on continuously until the carbon had reached the percentage desired. This was usually about 1.2%. The temperature had to be kept above 750°C. The higher it could be held the sooner was the heat ready. When the heat was finished the furnace had to be shut down. This was done by thoroughly cleaning out the hearths; covers were placed over the ash openings and coverbricks were placed over the flues. The furnace stood like this for ten to twelve hours, when the coverbricks were pulled half way back; the ash opening covers were also opened half way. After a further twelve hours the coverbricks were completely withdrawn, as were the ash opening covers. The furnace was then allowed to cool for twelve to thirteen days before removal of the charge could commence;

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* This procedure was referred to as the "hyllning" - literally, the preparation of the table for a feast.

this was considered a minimum cooling period.

If charging had been completed on a Saturday it was quite unthinkable to wait until Monday for lighting up. As a silent protest against this, and Sunday work in general, we used to let our beards grow as firing proceeded - a little like modern artists! Taking out the steel, as it was called, was the worst job imaginable; the dust was a thick cloud within the furnace. Before electric light was fitted in 1915, small paraffin lamps were employed; when one of these stood at one end of the chamber and a man worked at the other end its light could hardly be seen. The oldest clothes one possessed were used and it was impossible to get them clean by washing. Neither was it possible to clean oneself with a bath and generally one's face would be smarting on account of the salt. During the First World War, when steel was wanted in a hurry, a hole was made in the roof with picks. By putting plates in front of the draught holes, the carbon dust was made to pass direct to the chimney. This made a world of difference to the work and the introduction of electric light made the work much better too.

All the work was paid by the hour. For the skilled workers this was 20 öre for day work and 21 öre for shift work; for the ordinary workers it was 2 öre less. Emptying the furnace took three men about eighteen hours but it was paid for as three twelve-hour days, plus two kroner extra, which would now be called "dirty money". The story goes that this extra was the equivalent of the brandy which used to be issued on the emptying of a furnace.* There was also an extra 50 öre for firing on a Sunday. The conditions related here refer to the turn of the century and the years immediately following. I am probably the last in Sweden to be described as a "steel-burner" in the ratepayers' and trade unions' registers.**

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* There is a parallel in the Cutlers' Company records, where ale is issued for each discharging of the furnace; later Sheffield steelworks provided "lowance" (that is, allowance) as a reward for any tricky or dirty task.

** The Swedish term for cementation is literally to be translated "steel-burning", hence the term "steel-burner" for the steelmaker at the cementation furnace. There is an interesting use of the same term in the first Sheffield Directory of 1774, where Jonathon Makin, who had been in charge of cementation for both the Fell Partnership and the Cutlers' Company, is referred to as "Mason and Steelburner".

In the old days it must have been a very important job to take out the test bars and judge how the carburising was going, especially before the carbon could be determined by chemical analysis. A fairly reliable estimate could be made by studying the fracture. These "steelburners" and "steelsmiths" were no doubt fully conscious of their skill and took a pride in their craft; the term "steelsmith" applied to the work before crucible steel began to be produced and forged. Prior to this all cemented steel was forged out to suitable dimensions before it was sold and the "steelburner" himself became the "steelsmith" and had to do the forging and be responsible for the steel.

Quite large quantities were made at Osterby by cementation. The highest figure, 582 tons, was achieved in 1898. There must have been at least ten heats per furnace that year.

In 1918 about a hundred tons of unhammered cemented steel, 2½" x ⅞", was supplied with the carbon brought up to 2%. This was accomplished by three weeks firing, in spite of poor fuel. This confounded what had previously been stated by the scientists that it was not possible to raise the carbon above 1.6% by cementation. One of these furnaces, due to the urgency, was discharged after only seven days cooling; the steel had to be pulled out with tongs; ten minutes was quite enough to work in the furnace, with twenty minutes to cool off, the thermometer showing 55 to 60°C in the chamber.

These are a few facts about this branch of steel production which is now only a memory. This works was the last in this country to operate the cementation process and, indeed, the Walloon forge at the same works was the last in the world to close down.

A P P E N D I X BBB

REPORT ON WORK AT MUNKFORS

Extracts from an article by G. Kraus
(Technical Manager at the Munkfors Works),
Jernkontorets Annaler (1848), pp.289-291.
Translation by courtesy of the late
Torsten Berg, Esq.

For the chests in the steel furnace, sandstone imported from Newcastle has been tried a few times, but in general the sandstone from Kinnekulle is used. The English stone is better; one set of chests replaced last year has cemented nearly 6000 skippund bergvikt (almost 900 tons, since 6.8 sk. bv. are equivalent to one ton) during 55 heats, instead of about half this quantity from Kinnekulle stone, but the English stone costs almost three times as much at the works. The advantage of the lower price, however, is decreased by the fact that the labour cost connected with the rebuilding must be paid oftener. On the other hand, the cementation does not proceed as well with an old set, because the flues of firebrick masonry around the chests in due course are subject to undesirable deterioration which renders the heat distribution more and more uneven; in addition, the walls and bottoms of the chests begin to warp and may easily become leaky. These disadvantages may compel earlier changes of the chests than strictly necessary if one only takes into consideration the refractory nature and the lasting qualities of the sandstone slabs themselves.

The chests in the steel furnace have generally been charged with 55 sk. bv. (about 8 tons) of iron each, or 110 sk. bv. (16 tons) in the two chests within one furnace. In the furnace provided with new chests last summer, however, the size was increased, to the extent that the furnace now holds 150 sk. bv. (22 tons) without the steel being less well cemented than previously. This seems to be an argument for the use of larger chests, since the consumption of wood per skippund is thereby considerably decreased. It is considered that the heat from the first three days of firing is mainly absorbed by the heavy external masonry and this loss is just as large irrespective of the weight charged into the chests. The consumption of wood for one campaign is generally 640 cubic alnars (about 4800 cubic feet). In the furnace with the enlarged chests the firing takes twelve hours longer than previously and also uses a further 35 cubic alnars of wood. If you calculate the relative quantities of wood compared with the amount of iron converted you arrive at 5.8 cubic alnars per skippund for the small chests and 4.8 cubic alnars per skippund for the large chests. (300 and 230 cubic feet per ton respectively).

The steel iron is 2" to 2¼" wide and ⅝" to ¾" thick; occasionally, due to the demands of the customer, it has been 1" thick. Some of the steel of this size has been too soft and has had to be recemented. The wood for firing has, as usual, been fir. 32 barrels of charcoal breeze, made from birch wood, is required for the cementation of 110 sk. bv. of iron. Generally speaking the iron increases in weight by 0.5 to 0.6%; last year the usual increase was 0.8%. One does fairly soon learn to judge the hardness of the steel from the appearance of the fracture before drawing down, but to judge it from the appearance of the surface requires much experience and training. It is, however, necessary for the steel inspector to acquire such experience if the steel is to be forged, because in such a case it is best for the smith to be given bars of a length which is determined by the order he has to execute and it is, therefore, highly desirable to avoid breaking the bars. I have reason to believe that I have discovered a pretty good indication of the hardness from the colour of the steel.

After successful cementation most of the bars have a somewhat mauve colour on the surface. These bars are found to be harder than those which show a blue colour, the colour of the usual iron scale, without any red tinge, and in such bars the hardness becomes less as the depth of the blue decreases, such that the light blue are the softest. A pure dark blue colour I have only seen in patches and then always surrounded by a copper colour. Bars showing this pattern are harder than the first mentioned, which always has a tinge of red, but they themselves are exceeded in hardness by bars with a grey surface, particularly if the scale has come off in places exposing the true surface of the steel. A red colour, the colour of the iron oxide, is generally found on an edge of the bar, if it occurs or sometimes in patches on the flats and is always a sign of accidental decarburisation and "iron skin".

Amongst bars of the same colour, those showing most blisters are usually harder than those with fewer. The hardness is high if the sharp edges of the bars have disappeared; it is even higher if the edges of bars have begun to melt together. If so, it is still possible to draw them down under an ordinary tilt hammer, but they do tend to give longitudinal cracks and to become "shelly". If the bars have melted together in a lump - which I have heard happens but have never seen - the product is treated as though it were pig iron.

APPENDIX CCC

FRENCH CEMENTATION TRIALS IN 1780

Extracts from a Mémoire presented to the French Academy of Sciences in Paris, September 1782 by Chevalier Grignon. It is printed as an appendix to _Analyse du Fer_ (Paris, 1783), a translation of Bergmann's _Dissertatio Chemica de Analysi Ferri_ (Uppsala, 1781). The translation here given covers pp.234-251 of the volume and is by the author.

Having presented many mémoires to the Administation in which I have demonstrated the necessity to endeavour to increase the production of fine steel in France, so as to remove from foreigners a source of trade that is so detrimental to the nation - Nerouville being the sole manufacturer on a large scale of fine cementation steel is alone in employing Swedish iron* - I am assured after the trials I have now made that it is possible to convert French irons into good fine steel.

The Government, anxious to provide commercial competition and encourage commerce for the national arts and manufactures, authorised me in November 1779 to make the necessary tests to establish the relative propensities which the best kinds of French irons had for conversion into fine steel by the cementation route.

Monsieur le Comte de Buffon wished to participate in this effort which the Government was making for the public good; he offered the use of his forges and of a furnace which this justly celebrated man had put up, at great expense, to follow up his trials with steel. We persuaded the Administration to accept these offers without much difficulty, since this position enabled us to consult an authority on the subject during the course of operations and to profit from his knowledge and counsel and since, in addition, the means he offered considerably reduced our expenses.

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* M. le Comte de Broglie has made cementation steel for about fifteen years in the forge at Ruffecq in Angoumois with iron from the same forge. In 1781 M. Mongenet, Forge Master in Franche Comté, set on an outside steel-maker who showed him a steelmaking method using iron from Provence. All the other steelworks in the kingdom work in natural steel produced direct from cast iron.

I then took steps to prepare all the necessary items. I wrote to the different provinces of the kingdom to forward to Buffon the best qualities of iron known to me. I drew these from the Pyrenees, the Alps, the Vosges, from Franche Comté, Lorraine, Champagne and Berry. During the examination of the irons, I recommended the actual forges where they should be prepared.

It was necessary that I should assure myself of the state of the furnace destined for these operations, so as to anticipate and carry out any repairs which might be necessary. I therefore went in December 1779 to the Forge at Buffon. I examined the furnace and found the arch stones and the stone slabs prepared for the chest, some four inches thick. I had these set up inside the furnace and built up as though the chest were filled for cementation. I then had a wood fire made for a whole day, to know the draught and the degree of heat of which it was capable. By this preliminary trial, I recognised that this furnace was capable of fulfilling the aims of my operations with but slight changes which were, however, essential to the control of the fire.

The furnace was a mass of masonry set against a strongly constructed wall; the base was in the form of a rectangle, 170" long and 98" wide. All the exterior was built from large square blocks of dressed stone in which were made three rows of vent holes, thirty in number, disposed over the three open walls of the furnace block. In the centre of the mass was left an open space to contain the hearth, the chest and its supports. This space was 26" wide; it went right through the mass and rose to a height of 87" from the floor to the keystone of the brick vault, which was 12" thick. The vault was pierced by five regularly spaced openings, each furnished with a cast iron flue, 5" square. It was through these flues that the flames escaped into five channels formed in brickwork of the same dimensions as the flues. These channels were set obliquely; their bases opened on to the flues and their mouths led to the opening of a chimney raised above one side of the furnace block. The top of this was raised well above the roof and it was this chimney which determined the draught of the furnace and made it so active.

The open interior was built on all sides in brick. The thickness of each portion of the brickwork was divided into two parts. The exterior part, which received the action of the fire, was generally a lining some 13" thick, but was only 8" thick at the base since there was a protruberance of masonry all round for the bottom 20" of the structure. This lining, rising perpendicularly, supported the interior vault of the furnace. It was not tied with the brickwork intermediate between it and the stone masonry since, being subject to the degradation occasioned by the fire, it could then be demolished and rebuilt without altering the remainder of the furnace. The intermediate brick wall itself was only 6" thick; it served as a protective shell to the outer stonework in defending it against the action of the heat.

In order to fit the chest to the furnace, thirteen arches were made. The outer two, abutting the end faces on two sides of the doors, were only 6" thick and wide; they only served to support the brick wall built up on each side to close the furnace when the charging was complete. The other eleven arches were 8" wide and 6" thick; they gave spaces 6" square to allow issue of the flame which heats the chest, and rose to a height of 37", where they finished in a horizontal plane to receive the platform for the chest.

The longitudinal space which ran the whole length of the furnace below these arches, to provide the hearth, was 16" wide and 29" high below the keystones.

The chest which was carried on these arches was made of slabs of stone, a Semur sandstone, 4¼" thick. Those for the base were laid flat on the arches; those for the four sides on edge, with a height of 27" from the base, all joined together with a mortar of red clay. The fire was fed from both ends, throwing in brushwood and faggots under the vault; it was activated by the draught. When we opened up the furnace by removing the false walls at the ends, we found that the fire which we had made in December had calcined the stone of which the chest was built. This made me aware that the Semur stone was nothing more than a coarse grained quartzite held together with a cement of calcareous spar and that it was unsuited for constructing a chest of this type. I therefore replaced it with bricks from Montbar and Ancy le Franc, having been unable to procure a better quality.

I thought it well to divide the hearth, which ran the whole length of the furnace, into two, since the air entered more freely from one end than the other, according to the impulse which it received from the pressure of the atmosphere; this rendered the fire uneven, taking away some of the heat and inconveniencing the workers, an event which did not occur after I had built a central diaphragm wall, dividing the interior of the hearth into two parts without intercommunication.

I also recognised that the method of heating these kinds of furnaces was faulty, in that the wood was thrown under the arches, as is practised in brickworks and other different kinds of furnaces. The difficulties that arise are a loss of heat, more expense of fuel and a less active draught. I had fire-irons placed at each end, such as are used in several porcelain kilns, 27" high, 32" long and 12" wide internally. They were crossed by two bars of iron, ¾" thick, and I arranged an opening, 12" high and 15" wide, in the forepart to allow the raking of ash if necessary; until such time as this was necessary, this opening was closed by a cast iron plate. The method of feeding the fire, using the fire-irons, has several advantages of which the following are the main :

1 A boy of 15 or 16 years can feed the fire, since it is only necessary to throw successive logs some 28" to 30" into the furnace;

2 The firer is never upset by the heat; on the contrary, by putting the faggot in the centre where the furnace draws the greatest heat, he feels the effect of a freshness occasioned by the column of air which flows through rapidly and constantly renews itself;

3 There is no clinkering-up of such furnaces, since they have a good draught, except perhaps on the first day or so until the fire has become sufficiently active to bring to heat rapidly the bodies submitted to its action; thereafter all the combustible matter is decomposed in order to augment that heat; at worst, a few cinders remain;

4 No excess air enters the furnace across the faggots which cover the fire-irons which is not decomposed by the conflagration of the wood, a very important and essential point, on which those who have written on pyrotechnics have not sufficiently reflected or which possibly they have not appreciated.

When we had learned that all the irons we had requested had arrived at the Buffon Forge, we went there. We had taken the precaution of recommending to the forgemaster that he should put these irons in bundles, that he should carefully mark their distinctive characteristics and the methods used in the forges whence they came, to avoid confusion to be quite certain of the origin of each of the irons and finally to see they were forged virtually to the same sizes.*

Wishing to test the properties of the iron from the Buffon Forge and, persuaded that, by taking special precautions to purify it, the resulting steel would be of better quality than that made with iron according to the normal usage in the forge, I chose a pig, bearing the number "49"; its grain was grey, small and shiny; there were few facets in it. I took down a finery hearth in order to put in a furnace to treat part of this pig; 458 lb. was melted off and the surplus pig was refined in the normal manner in a finery hearth. The 458 lb. of pig melted off gave us 330 lb. of iron; this was in the ratio of 1387¼ to 1000.

I had procured irons from Spain, Sweden and Siberia, by way of Le Havre, so as to have points of comparison with the irons of France. The Spanish iron was in the form of plate, a sample not convenient for my operations. I therefore had it cut and forge welded, so as to reduce it

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* M. de Lauberdière, forgemaster at Buffon, granted us, in the most obliging manner, all the help we needed; workers, plant, all kinds of material, and the use of his house, with the greatest generosity. We owe him this public acknowledgment of our gratitude.

under the hammer to dimensions approximately the same as the other qualities of iron.

The Spanish iron, which came from Bilbao, was found to be cold short and forged with great difficulty but it had a great strength when cold.

I proceeded to mark all the bars at each end and on each flat face with a cold chisel, to put on each a number peculiar to its kind, by which I could recognise them after cementation, and then placed each kind separately in cases, marked with the corresponding numbers.

I had the irons fractured, so as to learn the quality of each; then I had them cut to length proportional to the chest, cutting them to two inches less than the chest, which had an internal length of 127". All the irons were first chiselled on all four faces and then broken by blows from a sledge hammer on a breaking iron. Whilst I was getting the iron ready I was at the same time busy with the materials suitable for cementation and in the construction of the chest.

I had the arches erected, to the dimensions given above, in brick from Montbar, as well as the internal separation of the two hearths. I had placed on the arches a platform, 136" long and 20" wide and 5" thick, made from brick from Ancy le Franc which was less ferruginous than that from Montbar. I was careful to make the first layer of this platform with large squares, which overlapped the arches by two inches, and to cover the joints with the second layer, and so on with the other three layers, so as to tie in the whole securely, using well moistened red clay mortar but avoiding thick joints. I then raised the four walls of the chest in bricks of the same quality, 4" thick and 37" high. I took care to support these chest walls with columns, 4" wide, made in brick and tied to the chest, lying at intervals 4" apart and 8" long for the whole height of the chest, to allow passage of flame. When the chest had been built, I allowed it to dry for a day and then I placed in it, row by row, the iron, with intermediate layers of cementation powder, pressed down by the foot, the first and last layers of powder being 1½" thick and the others of the same thickness as the iron. There were fourteen layers of iron. On the uppermost layer of the cementation powder I placed a bed made from a triple layer of brown paper, well moistened, and over that a bed of vitrifiable sand, taken from the river at Armançon, to keep in the cement and to protect it from the immediate action of fire and air. This bed of sand was carried over on to the bricks and described an arc with a chord of 20" and a rise of 4".

I made at each end of the chest two openings, 2½" wide and 1½" high, for the placing of test bars and, when placing the iron in the chest, I paid attention to passing through these holes the ends of bars, which protruded 8", in order to be able to withdraw them and thereby judge the action of the cementation. Then the two temporary brick walls, which closed the furnace, were erected, care being taken to make gaps opposite the test bars, gaps which could be filled with bricks whilst the furnace was being fired. I let the masonry dry for a day.

I kept a register of the kinds and the weights of iron which made up each layer; there were in all 3737½ lb. in 73 bars, with 65 ends and two wire drawing plates from the wireworks at Lod in Franche Comté; there was also 22 cubic feet of cementation powder.

The fifth day of August, at 5.15a.m., I put fire to the furnace, starting with a small fire to dry the mortar. The following day, at the same hour, the furnace was emitting much vapour and the fire began to be increased. On the ninth of August, at three hours in the morning, a fall of brick was noticed and towards midnight an arch failed. On the tenth, at six o'clock in the morning, this arch was running with slag and the bottom of the chest was opening. It was necessary to stop the firing. This accident was due to the very poor quality of the brick from Montbar and of the mortar.*

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* In 1780 a similar accident was very nearly a disaster at the works at Nerouville; on the eighth day of firing the mortar in the furnace fused and formed a vitreous matter which ran through all parts and came together in the firing area, where it formed a mass of 6,000 lb. of a very dense glass. It was fortunate that the cementation was finished and that the accident did not damage the steel in any way, since there was more than 73,000 lb. of steel altogether in the chests.

When the furnace was cold, the entire interior was demolished. The part of the iron which had received the full action of the fire, when the chest broke on account of the fusion of the iron-rich bricks which made up the arch, was very much damaged and the steel which had been formed was in large part destroyed by the heating it had received. Those parts of the bars which had remained surrounded by the cement were two thirds converted, that is to say, there remained about one third of iron in the centre.

I proceeded promptly with the construction of a new chest. I followed the advice of Monsieur le Comte de Buffon and made the arches in freestone, since they only had to serve but once. Only the sills or bases of the arches were in brick and the division of the hearth was made in brick from Ancy, not having to hand a sufficiency of the right kind of stone. The bottom of the chest was made from slabs of stone, 5" thick, on which were raised the side walls in brick from Ancy, tied with a mortar made from pottery clay, powdered and sieved and then mixed very thinly with water. I gave a height of 33" to the chest and filled it with 24 layers of bars of iron and 26 layers of cementation powder. Between them, there were 4070½ lb. of iron, filling $7^{1}/3$ cubic feet, and 24 cubic feet of cementation powder, in total $31^{1}/3$ cubic feet, although the chest, which was 127" long, 12" wide and 33" high, only held $29^{1}/9$ cubic feet; thus the cementation powder had suffered a diminution in volume of $2^{2}/9$ cubic feet, under the compression given it during the loading of the furnace.

I observed all the same precautions for this furnace as in the previous case. All being ready, the test bars being set, and the temporary walls having been built by 22nd August, I allowed it to settle for the whole of the 23rd.

On the 24th, at five in the morning, the fire was started on the hearth, that is to say, on the floor of the ashpit, without using the fire-irons, so as to make a small fire to dry and slightly warm the furnace. The following morning, the fire was pushed towards the diaphragm wall in the hearth, very gently, with only three faggots of oak each time, arranged lengthways on the full hearth. During the night the furnace appeared to be warming up, particularly in the middle; the odour of burnt horn was noticed, which denoted that the fire was beginning to act on the interior of the chest.

On the 26th, at five in the morning, I began firing on the fire-irons, after raking clear part of the ashpit; the two upper ranges of vent holes began to emit much aqueous vapour and, by the middle of the day on the 27th, the fire took on a very great intensity, such that the diaphragm wall partly melted, as did some of the brick bases of the arches. The parts in stone did not take any harm and although several bricks, reduced to a soft paste by the heat, were retrieved from within the furnace, no accident occurred which might have prejudiced the success of the operation. The same day, towards seven in the evening, a slight sulphureous odour coming from the cementation materials could be detected, although they contained nothing sulphureous in themselves.

On the 28th, at seven in the morning, I drew out a test bar which showed me that the cementation had not penetrated more than a third of the thickness of the iron; but whereas the end of the bar serving as a test sample was made of a very fibrous iron, difficult to break, it had become very brittle, not only the part which was already good steel but the iron part also.

There then came a very violent wind which, driving against the chimney, somewhat cut down the activity of the fire, caused accumulations of ash in the hearth and made black smoke come out of the vent holes with an odour of soot and sulphur. It was necessary to clear the hearth through the doors beyond the fire-irons and I noticed that there were also cakes of vitrified matter, which rather disturbed me; but not noticing anything out of place, I continued to push the fire.

Although on the 29th the wind had constrained the fire, the furnace was very hot and rumbled evenly; the vents also ceased to emit black smelly vapours. The fire kept up well with a uniform draught.

At dawn on the 30th, the wind was still against us. I pulled out a second test bar at eight o'clock in the morning which showed a beautiful uniform grain, similar to a good grey cast iron, without the appearance of any central iron part. This steel, heated to a cherry red, forged well; heated to white heat, it sparkled on the anvil before being forged but, being treated gently, it stood the sweating heat and welded well. I made a cold chisel from it which lifted up chips of iron without spalling or burring of the edge.

At ten the same day, I took a third sample, which was entirely converted into steel of uniform grain; since the dimensions of this bar were a little less than the major part which had been submitted to the effect of cementation, I continued the firing up to seven o'clock in the evening.

The fire had continued for 6 days and 13 hours, of which 37 hours were with a small fire, one day with a medium fire and four days with a very strong fire. Twelve cords of wood, 8 feet at the base and 4 feet high - such would have made 16 Paris chaldrons - had been consumed. The billets used were 28" long, in oak, beech, ash or aspen, together with 500 faggots of poplar. Between them they produced 9 cubic feet of ashes, weighing 37 lb. per cubic foot, in total 333 lb., neglecting the cinders left by the faggots, which were mixed with the rubbish, and those ashes carried out through the chimney by the torrent of ventilation.

The following day, 31st August, I took down the temporary walls of the furnace, which was still red, in order to cool down the chest, which had sunk down 3" on the west side and 2½" on the east side by the fusion of the mortar between the bricks but, since this fusion had been slow and continuous, the bricks had settled and welded the one to the other and this had prevented the chest from taking in air through its upper parts - except for the upper edge at the west side, where there was a small opening, which had given rise to a depression of about 2½" in the cementation powder cover where it had been largely consumed. The iron here was not slate coloured, like the rest, but was reddish and these parts had returned to iron again on the outside from the effect of this reheating.

The upper vault was considerably damaged by the effect of the heat; several bricks had become detached and it was flattened to a depth of 8" in several places where the mortar had fluxed.

The cast iron flues which had served for the passage of the flames had suffered various kinds of degradation; the openings of the three in the centre were considerably closed up by the swelling of the cast iron which had been badly burned. One part appeared to have been completely converted to calx; mostly, however, they had become covered by successive layers of slag, considerably diminishing the size of their openings. The two end ones were partly calcined, but had also melted for a considerable portion, this having fallen in the nature of a regulus on the sand layer above the chest and partly penetrating it.

The internal faces of the furnace chamber and making the shell, having enlarged internally, had swollen and consequently had partially closed the openings which gave passage to the flame. This effect proceeded on the one hand by the softening of the bricks under the action of the fire and on the other by the effect of the expansibility of the vapours which, acted on by a centrifugal force in the central block, carried themselves in a stream up the gap between the freestone masonry and the brick wall; the massive nature of the former opposed a superior resistance to the effect than the brick walls, the softened surfaces of which yielded to these forces.

On the fifth day of firing, however, a small surface crack appeared in one of the outer walls of the furnace and from this came a thin vapour condensing to a limpid water.

After four days cooling, on 3rd September, I had the chest ends demolished, to pull out the steel, which was still sufficiently hot for the workmen to be obliged to use protection for their hands.

The vitrescible sand which covered the chest had agglutinated into a whitish mass, full of grain and crystalline, making a sort of artificial granite. This cover had to be forcibly removed; it was only cracked in a few places. The total mass of iron and cementation powder had shrunk almost 2" which, added to the 2½" shrinkage of the chest walls, gives a total depression of some 4½" over the whole of the surface of the chest, amounting to about 4 cubic feet or one sixth of the cementation powder employed. But this loss of cement is produced from several causes, some natural and some artificial, presenting a number of phenomena which merit attention.

The soot and animal matter which form part of the cement are not originally reduced to the perfect carbonised state which they acquire during the heating of the steel; this effect to which they are submitted diminishes their volume, a first cause of shrinkage. Whenever substances of a diverse nature, combined in the same mass, are exposed to fire, they undergo a reaction of their constituent parts, the one with the other; this results in a penetration which diminishes their volume and increases the specific weight; a second physical cause for diminution. A third case, which is accidental, proceeds from the passages produced either by small cracks in the sand cover or by the opening at one end of a brick by the fusion of the mortar; in as much as some portion of the cement comes into contact with air and fire, it is consumed. Finally a fourth cause comes from the calcareous nature of the porous stone at the bottom of the chest, which has consumed part of the cement or has otherwise destroyed its effect in that the bars at the base, after the operation, touch the internal surface of the stone and become adherent to it and these surfaces revert to iron, whilst their opposite surfaces, still covered with cement, are perfectly good steel.

I had drawn out, on the 4th September, all the cemented iron from the chest and, with my inventory in my hand, I sought out the numbers in order to arrange each kind separately and then I had the batches weighed. The total weight was found to be 4131½ lb; the raw iron before cementation had weighed 4070½ lb. There was therefore an increase of 61 lb. (1.498%). This increase in weight came in part from carbonaceous materials from the process still attached to the surface of the bars and, in order to arrive precisely at the weight increase produced by cementation, I subsequently submitted to cementation some 509 lb. of scoured bars, so as to be free from rust; they were scoured in the same way after cementation to remove carbonaceous matter and after reweighing they were found to be 6½ lb. heavier (1.277%). This could only be attributed to the quantity of the principle incorporated with the iron in this way to convert it into steel, something which not only increased its weight but also its volume, by 10½ lines per 100" of length in the bar, independent of the raising of the surface of the bar, giving rise to the blisters.

A P P E N D I X DDD

PROCEDURES FOR THE CONVERSION OF IRON INTO STEEL

Extracts from a Memoire, signed by Sanche, the proprietor of the Steel Works at Amboise, dating from 1780-85, entitled 'Procédés sur la fabrication de l'acier propre a la taillanderie et le coutellerie' (Procedures for the manufacture of steel suitable for edge tools and cutlery). A copy of the document was kindly provided by Professor J. R. Harris. The translation is by the author.

IRON: Up to the present, it has been found that only the irons from Sweden and those of the Ardente and .....* forges in Berry are suited to conversion into steel, as much from their softness as from their purity. Those from Berry have rather more body than those from Sweden for the making of fine steel, commonly called cast steel by the cutlers. Consequently, it is necessary to give preference to them, observing, nevertheless, that the forgemaster should be instructed to manipulate the iron in the best possible manner, since it is ordinarily very roaky. These irons should be worked at the finery in a way in which they will become completely fibrous .....** The ordinary price of iron from Ardente is 175^{++} to 180^{++} per hundredweight but in order to have it made in the manner stated above, it is necessary to pay 10^{++} to 15^{++} above the current price. In such case, if it not be made with all the care demanded above, the extra costs are at the expense of the producer.

The Swedish irons of 27 to 28 lines broad by 6 to 7 lines thick are the best, having been refined in large forges. It is said that the bars marked "KM" are to be preferred, being from a purer ore than those with other marks.

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* There are a number of places where the copy of the text provided is not clear; this would seem to be due to deterioration of the original. The name here is missing.

** The next few words are not decipherable but it is clear that some forging instructions are involved.

In general, iron for conversion should be 5 to 6 lines thick and 18 lines or so wide. If it is too thick, it may be feared that it is still iron in the middle of the bars when it is taken out from the furnace.

CEMENTATION: To two bushels of soot, well pulverised and sieved, it is necessary to add a bushel of wood charcoal, well pulverised and sieved, and to mix the whole together by passing through a mill or between rollers.

When there is old cement which has already been used to make steel, it is well crushed and passed through the mill; subsequently one can put three bushels of this to one made completely new, putting it through the mill to mix to a uniform composition.

When the cement is so prepared, the bars of iron are taken and cut to a length suitable for the chests and they are then plunged into a large lead tank full of river water containing fifteen to twenty pounds of English salt, commonly called Glauber, or with a similar quantity of sal ammoniac. When the bars are well soaked in this compound water, they are taken out and placed in another container in which the following cement is contained :

> One part of cow horn or hoof, roasted in a fire, well powdered and milled
>
> One part of soot
>
> One part of charcoal, similarly milled.

When the bars are well coated with this cement, a bed of the main cement is made on the bottom of the chest .....* and on this is placed a layer of the iron bars, left at a distance of 4 lines between each bar, in such

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* There are here some indistinct indications as to the form in which the bed of cement mixture is to be laid down.

manner that they do not touch and that the cement can make its effect on the sides as well as on the flats. This is repeated, layer by layer, until the chest is full; on the final layer it is good to place a bed of fine sand or crushed brick, so that the fire cannot attack the cement or the iron in such case that the chests be not hermetically sealed, for which purpose white tiles, which resist the heat, are set on top, with yellow clay mixed with horse manure to serve as mortar.

At the end of each chest it is appropriate to have a hole precisely at its centre and to take the precaution of placing a bar of iron with its end passing through this hole, to serve as a sample to confirm that the iron is converted into steel. It is necessary to take great care that the test hole is well sealed around the end of the bar with the same clay which was used to seal the chest.

When the steel is thus made with charcoal cement, the iron should be converted in a period of 36 to 40 hours; one may then take out a test bar and, if it is then observed that the steel is not yet finished, which it is easy to see by forging it, quenching it in water and fracturing it, then the fire is continued for a further four hours, at the end of which period a second test bar is withdrawn, and the operation continued until one is sure that all the iron has been converted into steel. Then the furnace is closed down and allowed to cool, since if it is opened up too soon, the cement may take fire and this does much harm, as much to the steel, which would be burned, as to the furnace, which would be much more damaged than if it were allowed to cool naturally.

When the furnace is cold, the steel which is now fit for edge tools and files of all sorts and sizes, may be withdrawn. If it is wished to make fine steel, the bars are taken and forged to 18 lines wide by 6 lines thick and then nine to eleven bars are put together, the one on the other, at a length of around two and a half feet, and they are then all forge welded together in the form of a bloom, which is then drawn down to 18 lines by 6 lines. These bars are then put into the furnace in the same way as the iron bars which were converted into the steel which may be called No.1. In this way the steel takes on an extra degree of fineness and can be called No.2. To make still finer steel, suitable for making razors, lancets and other surgical instruments, it is necessary to treat No.2 steel in exactly the same way, to forge it and to return it again to the furnace with the same cement and the prescribed precautions. In this way is produced a steel which has a very fine grain and is called No.3 or "cast steel".

(The remainder of the report deals with the production of files and edge tools).

COMMENTS

1 The unit of currency stated is probably the "livre tournois", worth about 10d. This would make the cost of the normal iron about £15 per ton, with a charge of about £1 extra for the more careful refining.

2 It is interesting to note that the word used in the text for cement or cementation mixture is "semen". This leads to the thought that the origin of the term "cementation" could be an indication that the process involved an impregnation of the body of the material by the added agent.

3 "English salt, commonly called Glauber" would appear to refer to the use of sodium sulphate; this can hardly have been a beneficial addition. The use of ordinary salt, sodium chloride, was more usual; it will be noted that the alternative is "sal ammoniac", ammonium chloride. The reference to Glauber, therefore, seems wrong.

4 The production of something called "cast steel" by repeated forging and re-cementation should be noted.

A P P E N D I X   EEE

INSTRUCTIONS CONCERNING THE MANUFACTURE OF STEEL AND ITS USES

Extracts from a translation of Avis aux Ouvriers en Fer sur la Fabrication de l'Acier, published by order of the Committee of Public Safety in Paris around 1793, based on the work of Vandermonde, Monge and Berthollet. These extracts are from Nicholson's Journal, Vol.2 (1799), p.102 and p.106.

Cast Steel is produced by fusion of natural steel, particularly that of cementation. The fluid state assumed by the metal in this operation causes the flaws and veins to disappear, and renders the whole mass more uniform.

According to the description which Jars has given us of the manner in which this operation is performed at Sheffield, all kinds of fragments of broken steel are used. The furnace is of the same kind as that of the brass-founder, but much smaller, and supplied with air by a subterraneous communication. At the mouth of the furnace, which is square, and level with the earth, there is an opening against a wall where a chimney is carried up. These furnaces contain only one large crucible nine or ten inches high, and six or seven in diameter. The steel is put into the crucible with a flux, the composition of which is kept secret: and the crucible itself is placed on a round brick standing on the grate. Coak is placed round the crucible and the upper part of the furnace is filled with it. It is then set on fire; and the upper opening of the furnace is entirely closed by a covering formed of bricks, bound together with iron.

The crucible remains five hours in the furnace before the steel is perfectly fused. Several operations are afterwards made. Moulds formed of two pieces of cast iron, which fit together, and form an octagonal or square cavity, are prepared for casting the steel, which is afterwards hammered out in the same manner as blister-steel, but with less heat and more care, because of the danger of breaking it.

Chalut, officer of artillery, has made experiments on the flux which is best adapted for making cast steel. He is convinced that every kind of glass may be used as a flux, except that which contains lead or arsenic.

The steel being broken into small pieces, is to be covered with the glass. The cover of the crucible must then be put on, and the heat urged to the greatest degree of the brass-founders furnace.

It appears that an extraordinary hardness is sometimes required to be given to cast steel, and that this effect is produced by mixing coaly matter with the flux, to saturate the steel, and give it the highest degree of hardness. It is probable that certain instruments are manufactured by some process of this kind; such as cylinders and laminating rollers, of which the hardness is very great, and the grain perfectly uniform through the whole mass - but on this subject we have nothing to offer but conjectures.

One of the greatest difficulties we find in this country (France) in the fusion of steel, is to procure good crucibles. The art of pottery, which is truly important in every one of its parts, is that which, of all others, the most strongly solicits our industry.

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Among the notes appended to the French report is the following which contains some interesting comments :

p.106 Cast-steel being made out of broken tools of every kind, cannot of itself possess a larger dose of plumbago than the average quantity contained in those steels. But the English cast-steel is more fusible and more tender under the hammer than German steel, or the steel of cementation; which circumstances appear to indicate that it contains more plumbago: and the truth of this induction is confirmed by its exhibiting a much darker spot than other steels, when tried by an acid. Chalut did not therefore make this kind of steel when he used glass only for his flux. It cannot be doubted but that the flux of our manufacturers must contain charcoal, at least. If it be animal coal, which is most probable, it will also contain phosphorus; an ingredient to which the superiority of this coal, in case-hardening, is probably owing.

A P P E N D I X   FFF

PUDDLED STEEL PRODUCTION AT ESSEN

Extracts from F. G. Muller, Krupp's Steel Works (London, 1898), 'an authorised translation from the original German', pp.33-35.

It is not, however, the puddling of wrought iron but a variation of the process which makes Krupp's puddling works specially interesting, namely the production of steel by puddling. This is done in the same furnaces, with the same appliances by the same workmen. The pig iron* too is of the same character but its mean percentage of phosphorus must always be less than 0.1%. As to the work itself, only the eye of an expert would distinguish a slight difference.

The mode of reheating the steel blooms is as unusual as it is rational. They are not, as in other factories, put into special reheating furnaces but are replaced in the puddling furnaces from which they were taken, while the pigs for the next charge are disposed along the border of the hearth. The steel blooms, returning red from the hammers, are put on the hearth and well covered with slag; then the fire is started as usual; half an hour later the blooms are taken from the furnace. They have the proper heat for the finishing mill and at the same time the pigs for the next charge have been melted. After every three charges most of the slag is removed, in order to prevent its contents of sulphur and phosphorus rising above 0.3 per cent. The furnace yields 550 lb. of steel twelve times daily from a charge of 594 lb. of pig. In iron puddling the output is 572 lb. fourteen times a day.

The bars of steel are sorted separately for every furnace. Then about a finger's length of their ends is struck off and expert workmen divide the day's work into three classes, guided by the appearance of the fractures. Class A contains 0.9 to 0.75 per cent carbon; Class B 0.75 to 0.65; Class C under 0.6 per cent. Work is paid for by weight for these bars but the price for Class A is considerably higher than for Class B, whilst steel of Class C is refused.

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* It is stated elsewhere in this account that the pig iron is produced in Krupp's blast furnaces near the Rhine and is a white iron, with about 2 per cent manganese, very low in sulphur and phosphorus, smelted from spathic ironstones mined in Krupp's own mines.

Puddling for steel demands great skill, attention and exertion. The chief difficulty lies in the interruption of the decarbonisation at the right moment. Krupp's foremen and workmen, however, are so skilful and experienced and have, by the system of payment, been taught to be so careful, that Class C appears but rarely on the labour records.

In its chemical composition the steel obtained in this way is of the very finest quality. Apart from its carbon content and 0.2 per cent of manganese, it shows but slight traces of foreign elements; in particular, of phosphorus and sulphur it shows respectively maximums of 0.03 and 0.01 per cent. The real averages are only half these quantities. Therefore the material equals at least the Dannemora iron from which Sheffield makes its best steel.

Nearly the whole of the output of puddled steel remains at Krupp's works, not for immediate use, but as raw material for the manufacture of cast steel ..... Krupp's cannon factory is the major consumer of the puddled steel. Of course, its managers put the highest conditions on the quality of this material and the strictness shown by them is more dreaded in the metallurgical department than that of any outside customer. The business management of all the great departments is on a similar basis and has a most wholesome effect on them. Alfred Krupp's dictum that "in my factory second rate material will not be used and shall not be made" has become law and is the rule for the organisation of all the establishment, including the blast furnaces and the mines.

A P P E N D I X GGG

CRUCIBLE STEELMAKING IN AUSTRIA

Extracts from R. F. Bohler, 'Tool Steel Making in Styria', _School of Mines Quarterly_, Vol.xxix (1908), pp.329-341.

Different from the type in use in this country,[1] the modern Styrian crucible furnace is of the overground pattern, allowing an easy handling of the crucibles by means of suspended tongs. One furnace holds forty to fifty crucibles, the object of limiting the number being to ensure uniformity of temperature which could not so well be obtained if the furnace were built to hold more. The furnaces are fitted with Siemens regenerators and have a fore-warming pit with two separate compartments kept at 400°C and 800°C respectively. The empty crucibles are placed in the first compartment and, after remaining there for four hours, they are filled with the raw materials and transferred to the second chamber for another period of four hours. They are finally shifted red-hot into the melting furnace.

The melting takes from three to four hours; its progress is tested by the foreman with a search iron.

The chemical reactions now taking place in the interior of the crucibles build up one of the most complex problems of scientific metallurgy. Certain amounts of iron oxide are inevitably brought into the crucible on the surfaces of the pieces of raw steel and pig iron and also by the slag contained in the weld steel.[2] Moreover, there is air in the spaces between the material. On melting, the oxides present and those formed under the influence of the enclosed air, first form an oxidising slag, rich in iron, that acts on the carbon content of the bath. Carbon monoxide is formed and produces a slight boil. If the crucibles are

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1 That is, in America, where this paper was read.

2 Weld steel was the American terminology for what was previously referred to as "puddled steel".

poor in graphite, a decrease in carbon can thus take place during the first period of the process; if, however, the crucibles contain a considerable amount of graphite, no loss of carbon will be noted in the steel.

During the following period of the melting, the slag gradually grows poorer in iron. This is partly due to the carbon in the steel and in the crucible material now acting on the iron oxide in the slag, partly to the dissolving of the crucible material bringing about an increase of the total quantity of slag. The slag, by and by, loses its oxidising influence and the graphite laid bare by the dissolving of the crucible wall is absorbed by the steel. At the same time, some of the silica from the clay is reduced and is conveyed into the bath.

The temperature is of great influence on these reactions and so is the presence of manganese. The role of the latter is particularly complicated. It makes a great difference whether the manganese is contained in the raw materials or added as manganese dioxide and at what stage of the process the addition is made.

As to the last stage, the "killing" and the nature of the changes taking place during that time, the views of the different authorities do not coincide. The general belief is that the killing may be due merely to the evolution of gases. It is more likely, however, that killing acts chiefly through enabling the metal to absorb further silicon from the walls of the crucible, thus increasing its solvent power for gas and thus enabling it to retain in solution during solidification the gas which it contains when molten.[1]

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1 This appears to have been the theory current at the time. It would now be explained on the basis of the removal of dissolved oxygen from the melt by reaction with the silicon introduced by reaction of the carbon in the steel with the silica from the crucible wall. This is a slow reaction, favoured by the higher temperature during the killing period. The oxygen thus being held as silica within the steel (apart from that which has coalesced and floated out from the melt) remains unattacked by the carbon in the steel during the short period of solidification of the metal, particularly as this is at a lower temperature, and thus no gas is evolved.

When this stage is reached the foreman operating the charge will give the signal for teeming.

Such slight differences in temperature as should happen to exist between the different crucibles are equalised by uniting the forty crucibles of one charge in a ladle, previously heated, from the bottom of which the steel is cast into iron moulds.

By a special device in the form of a collar of refractory material, the pipe due to shrinkage is localised at the very top of the ingot and entirely removed. Every ingot is tested as to physical homogeneity, grain structure and purity of surface, any flaws being carefully removed with emery wheels or pneumatic chisels, before the ingot is taken to the hammer plant or rolling mill.....

.... Styrian steel will be met with everywhere. Besides all kinds of tools, it is used for scores of other purposes in which highest quality is the main requirement: army rifles, armour piercing shells, shrapnels, shot-proof screens are now made of it and so are the vital parts of recoil field guns, motor cars, steam turbines and so on.

APPENDIX HHH

EARLY AMERICAN STEELMAKING

Extracts from Rev. Daniel Little, 'Observations upon the Art of Making Steel', Memorials of the American Academy of Arts and Sciences, Vol.1 (1785), pp.525-528.

As steel is an article of commerce, and of great use both in the arts, manufactures and husbandry of every nation; and as we have the best of iron already manufactured in America, it is thought that the manufacturing of steel of a good quality deserves the attention and encouragement of those who wish the welfare of the United States. What time I could redeem from other necessary business for several years past, has been employed in such disquisitions and experiments, as might tend to facilitate the art of making steel, and others near akin to it.

Those writers upon the subject which I have met with tell us, that the principal difference between iron and steel consists in this, that the latter is combined with a greater quantity of phlogiston than the former. Phlogiston exists in all inflammable substances, and in some that are not inflammable. Charcoal, and the coals of bones, horns and hoofs of animals, have been used as fit substances for communicating phlogiston to iron in making steel.

Steel is sometimes made by fusion of ore or pig-iron. The method is similar to that of reducing pig-iron to malleable iron, with this difference, that as steel requires more phlogiston than is necessary to iron, all the means must be made use of that are capable of introducing into the iron a great deal of phlogiston; that is, by keeping it, while in fusion, encompassed with an abundance of charcoal, etc.

The other method of making steel is by cementation, as it is called; that is, to convert bar-iron into steel; which is done by a cement made of those substances which contain the greatest quantity of phlogiston. Put the bar-iron with this cement into a vessel that will bear a strong fire; lute on a close cover, so as to prevent the cement taking flame and consuming; put the vessel in a furnace where the bars may be kept red-hot till they are converted into steel, which will be in a longer or shorter time, according to the bigness of the bars, and the quantity of cement.

This latter method has chiefly engaged my attention, which method is pretty well known in some parts of America, and, for many years past, steel has been made by it in several of the United States. Yet, so far as I have been informed, it has generally been of an inferior quality, and very little used for edge tools, which I supposed could not arise from the quality of the iron, for we have the greatest variety, and the best sort, in many parts of the country. I then conjectured there might be found some other inflammable substance for a cement, which, if properly applied, would impregnate the iron with phlogiston more advantageously. And, after many experiments, I found a particular marine plant that requires no other preparation but drying and pulverizing, and is commonly known by the name of rock-weed or rock-ware, and is in the greatest plenty on our rocky shores, coves, creeks and harbours of the sea. In making some experiments upon this plant for a flux powder, a small bit of iron was put into a crucible and filled with the said cement; and, very unexpectedly, after it had been in a little more than a cherry heat for five or six hours, it was converted into steel, which gave me the first hint of its use in making steel, since which I have had repeated experience of its excellency for the same purpose.

In needs no other preparation than to be cut off from the rocks with a scythe or sickle, spread on the dry land 'till the rains have washed off the greater part of the sea-salt, then dried and pulverized, then used as other cements are in making steel: or, instead of washing off the sea-salt, it is better for some particular kinds of iron, to neutralize it by adding a fixed alkali.

To two parts of the plant well dried, and pulverized, add one part of good wood-ashes; mix together and moisten the whole with water or rather urine to the consistence of a very thick paste.

It is well known that in every new art, and in perfecting old ones, many unforeseen difficulties arise, and sometimes considerable fortunes have been spent before the manufacturer or the public have been much benefited. And since honest but too credulous minds are often deceived by uncertain proof, and being willing to satisfy myself and others, by a better testimony than my own, I engaged a gentleman (Col. Eliot of Connecticut) of ability in the steel way for many years, whose furnace was complete and large, to make experiments upon my new discovered substance for a cement, who has written me that "this steel is preferable to any he had ever made before". After all, I suppose different modes of preparation and further experiments will more fully ascertain its utility.

The matter of the furnace must be of such substances as will endure a strong fire without fusion. Asbestos has been used to advantage, but a sufficiency of it is not found in many places. Pipe-clay with one third part of pond-sand, or, which is better, white stones free from grit, well burnt, and pulverized, instead of sand, some species of slate and talc may be used with pipe-clay for furnaces and crucibles.

The chest or interior part of the furnace, for depositing the cement and bars of iron, must be covered so close that the inflammable substance within may not be consumed, but changed like wood in a coal-kiln. The iron to be chosen of the best quality; its toughness and malleability are marks of choice.

A P P E N D I X III

STEELMAKING AT PITTSBURGH

Extracts from a document of unknown origin, dating from 1877-78, kindly provided by the Crucible Steel Company of America.

The ease with which an abundance of fuel admirably suited to the manufacture of steel - the low price at which both coal and coke can be secured - together with its being a good market for the purchase of charcoal irons, renders Pittsburgh, perhaps, the best location in the United States for the manufacture of Cast Steel and some of the earliest attempts to manufacture common steels were made there. Some forty years ago experiments were made in the manufacture of what is known as German Steel or Blister Steel. The charcoal irons used were admirably suited to the purpose, were eminently successful, yet the article met with that severe prejudice on the part of consumers that Pittsburgh Cast Steel afterwards encountered. Notwithstanding, expert workmen were sent to visit the consumers to prove (and they did prove it, too) that the German or Blister Steel of Pittsburgh manufacture was equal in quality to that brought across the Atlantic, many were so blindly prejudiced in favour of the English product that the Pittsburgh manufacturers adopted the expedient of rusting their steel by throwing salt water over it, thus simulating the appearance of the imported article, when it was found to be, in quality, all that the consumers could desire.

The first Cast Steel made in Pittsburgh to any extent was produced at the great iron works of Schoenberger and Co., who in 1840 erected six "melting holes" and brought a skilled man from England to superintend the manufacture. In 1850 Samuel McKelvey invested considerable capital in the erection of cast steel works, locating his buildings and furnaces near those of Schoenberger and Co. He too brought skilled workmen from England, but owing to the wanted protection in the shape of a tariff and the still strong prejudice in favour of English steel he soon ceased manufacture.

When we consider the present condition of the steel business as compared with what it was at the period we have referred to, we cannot but feel gratified at its importance as a branch of American manufacture. We are of those who believe that upon the growth of our manufacturing pursuits largely depends our present prosperity and future greatness, and consequently that whatever tends to build up and continue such industries adds to the permanent wealth of the country. If our legislators at Washington seek to know what policy would be best calculated to assist the people of the whole country and to bring prosperity all over the land, they must take lessons from the past and ignore all theories which have proven incorrect. It has been proved again and again, and can be shown by unmistakable evidence, that there is no branch of manufacture throughout the broad extent of our territory which has received the protection needed to induce capital to be invested in it, and to enable the proprietors to compete with foreigners for the trade of the country, but has resulted in material reductions in the price of the product to the consumer. Cast Steel is a striking instance and gives strong evidence in proof of our declaration.

We have previously noted briefly some facts in relation to early attempts to manufacture steel and are obliged to record the fact that they were failures - partly because of the prejudice against home-made steel, but to a still greater extent because the manufacture was not sufficiently protected. If an American house engaged in the business, the price of foreign goods was fixed below the cost of production in this country until the home producer was crushed out - then, with an open field and no competition, the price was raised again. It is only sixteen years since, under the fostering care of a protective but not high tariff, the first successful effort was made to manufacture cast steel on a large scale in the United States, yet we now have the satisfaction of knowing that our enterprising steel manufacturers have secured about two thirds of the American market, being equal to fifty thousand tons annually, and are now supplying the consumers of this important article at a price nearly equal to three cents per pound below what they were compelled - in the absence of home competition - to pay the English steel manufacturers, and this too at a time when the duty was at the low rates of 12 and 15 per cent ad valorem. In answer to this, it may be asserted that the cheapening of the price is not due to the increased rates of tariff on steel but that the foreign manufacturer brought the price down because of his ability to cheapen the production of his article and that the lowering of the price was not due to the competition which was encountered on this side of the Atlantic. We are aware that this argument has been abduced, but when we know that the description of iron used in England in the manufacture of steel and the labor required to convert it are now higher in price than was the case when the consumers in this country were compelled to pay nearly three cents per pound more than they now do for the finer grades of steel, this argument must fall for want of evidence to sustain it. The quality, uniformity and finish of the American article is conceded by all unprejudiced minds to be fully equal to any imported.

In the article of homogeneous crucible cast steel boiler and fire box plate, that made by our Pittsburgh manufactures is unequalled and it affords us more than ordinary pleasure to be able to state that several shipments of this important material have been made to railroad companies and steam boiler builders across the Atlantic who pronounce it superior in every respect to any produced in Europe.

To the stranger who tarries for a day or so in the smoky but industrious and thriving city of Pittsburgh, a visit to some of the steel works cannot but be interesting and he will surely be gratified when informed of the rapid strides our people have made in the production of an article so essential to the success of other industries as cast steel, and of all the material for the national defense the most important. There are in the city eight firms engaged in the manufacture of steel in all its varieties and two others in the immediate neighbourhood, one at Beaver Falls, 28 miles distant, and the other at McKeesport, distant 14 miles. These are not embraced in the following statement :

The eight works located at Pittsburgh have, in aggregate, 23 Siemens gas regenerative melting furnaces, 292 coke melting furnaces, 40 trains of rolls, 54 steam hammers, 18 helve hammers, 48 puddling furnaces, 145 heating, welding and annealing furnaces. 2,000 hands are employed to whom are paid, annually, $1,100,000. 15,000 tons of pig iron and 21,500 tons of blooms and steel scrap are used annually, together with 1,000,000 firebricks, 750 tons of fireclay, 500 tons of iron ore, 200,000 tons of coal and 1,000,000 bushels of coke, with oil, belts and "mill findings" to a large amount. The capital invested amounts to about $6,000,000, while the production is 27,000 tons per annum, representing a value of $4,200,000. The capacity for production far exceeds these figures; fully 50% addition can be turned out and, should the demand come up to 40,000 tons per annum the works now in operation by running "double turn" can meet it.

One of the principal establishments in Pittsburgh is the Black Diamond Steel Works of Park, Brother and Co., located on the Pittsburgh bank of the Allegheny River, the site embracing an area of nearly seven acres, bounded by Thirtieth, Thirty-first and Railroad Streets and Spruce Alley. We have selected this establishment as a fitting representative of the steel manufacturing interest and will attempt to briefly describe the works.

Having introduced ourselves to the proprietors at the general business office, corner of Thirtieth and Smallman Streets, and obtained the necessary permission we will at once enter the Puddling Forge. This, with its auxiliary buildings, occupies a lot of ground, 124 by 336 feet. It may be well to remember that nothing but crucible cast steel is manufactured at these works. We cannot fully describe all the processes, but hope to convey a correct general idea of the method pursued in converting wrought iron into steel by the cementation process, which is acknowledged to be the best. But first the pigs of No.1 charcoal iron must be converted into blooms of wrought iron. The process is so fully described in articles on iron manufactures that we deem it unnecessary to repeat it here. Suffice it to say that in the forge the iron is puddled and worked under a 3 Ton double acting steam hammer, the steam to drive which is generated in boilers near the furnaces. About 12 tons of blooms are made each day. This, however, does not represent the quantity of iron used, as the remainder is made elsewhere and received in the form of billet and bar iron. After the iron is formed into hammered blooms, it is taken to the bar mill and there heated and reduced to bars 2½" x ⅝". The bars are cut into lengths of about 12 feet and then taken to the Converting House where they undergo the process of cementation or carbonization. This building is 60 by 186 feet and contains six immense furnaces, each capable of holding 30 tons. In these the iron bars are packed with alternate layers of pulverized charcoal, a high degree of heat is applied but not sufficient to fuse the material, and continued for six to ten days, the iron absorbing the carbon of the charcoal. When the heat is withdrawn we have Blistered Steel.

Cast Steel is Blistered Steel broken into fragments and fused. Blistered Steel is at best irregular in structure, being unevenly carbonized; by melting, the carbon is evenly distributed and steel of a close and even texture is obtained. From the Converting House, the Blistered Steel is taken to the Melting House, an immense building 420 feet long by 32, and containing no less than 72 coke steel melting furnaces and 3 of the improved Siemens regenerative gas furnaces, giving in all a daily capacity of 35 tons. The gas is fed into the Siemens furnaces through a 40 inch pipe connected with 8 Siemens patent gas producers. The crucibles made of graphite (black lead) are filled with carefully selected Blistered Steel broken into small pieces. They are then placed in the Siemens furnaces and the heat is worked up to 3000 degrees* and yet, in spite of this intense heat, it takes four hours and a half to melt the steel. As the process of melting approaches completion the ebulition of the metal ceases and the colour of the melted metal appears to be almost white. When all is ready the crucibles are drawn out of the furnaces and the steel is poured into iron moulds. When sufficiently cooled the ingots are removed and after being carefully inspected in the Ingot House are piled in the spacious yard attached. Such of them as are intended for rods, sheets, slabs, plates, etc. are taken to the rolling mills.

All the Rolling Mill machinery is under one roof and driven by four engines, the steam being drawn from six double flued boilers each 42 inches in diameter and 30 feet in length. The building is 140 by 217 feet with an L 65 by 116 feet. Here are six trains of rolls, the smallest an Eight Inch Train on which small sizes of steel are rolled - such as stock for cutlery - wire rod, etc. The next in size, the Ten Inch Train, consists of four pairs of rolls on which are rolled a great variety of general styles and special shapes to meet the wants of customers. These trains are driven by a vertical engine of 150 horse power, 23 inch diameter, 30 inch stroke, with a fly-wheel weighing 30 tons. The Twelve Inch Train, four pairs of rolls, is used for the larger

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* Fahrenheit, or $1648^{o}C$.

sizes of machinery steel, round square and flat - railroad frogs and side bars, shaped axle steel, etc. This and the Sixteen Inch Bar Train is driven by a vertical engine of 30 inch diameter of cylinder and 30 inch stroke with 40 tons weight of fly-wheel and 250 horse power. The largest engine is also vertical, with cylinder of 42 inches diameter, stroke 42 inches, 62 tons weight of fly-wheel and 600 horse power. This great engine drives two Sheet and Plate Mills. The Eighteen Inch Sheet Mill or Train is used for the heavier sizes of Plow steel, saw plates, etc. On the large Plate Mill are rolled the well known Black Diamond Homogeneous fire box, boiler, flue and smoke stack plates and large circular saw plates, etc. The fourth engine, horizontal, has a 12 by 24 inch cylinder, 50 horse power, and drives the 18 shears used in trimming the sheets, plates, etc., to the required dimensions and in cutting scrap iron and steel. With all these trains of rolls and shears in operation and with the sixteen large heating and annealing furnaces in full blast, a busy scene is presented which words cannot describe.

In addition to the buildings above noticed, there are two Forge Shops, one 96 by 125 feet, the other 60 by 132 feet. We lack the necessary room to describe them but here is made the Black Diamond Tool Steel, and almost every description of steel forgings. Then there is the Inspecting House, where every finished plate, sheet bar and forging is critically examined by experts before it is allowed to leave the works; the warehouse from where all products of the works are shipped; a crucible warehouse, where from 1,500 to 2,000 crucibles are constantly kept - over $500 worth are used up every day - a Blacksmith Shop, a completely appointed Machine Shop, and many auxiliary buildings which we cannot even enumerate. A few briefly stated facts will aid the reader in estimating the size and importance of this establishment. The subterranean vaults which enable the workmen to remove the ashes and cinders from the various furnaces are 8 feet deep, 8 feet wide and, if joined together, would be 1301 feet long. Over 5,000 bushels of fuel are consumed daily. 400 men are constantly employed and the production amounts to 10,000 tons of steel per annum. The product is sold all over the country from Maine to California. Much more might be written but the space allotted to this subject is filled.

A P P E N D I X   JJJ

THE LAST PHASE OF CRUCIBLE STEEL PRODUCTION BY CAMMELL LAIRD AND COMPANY, CYCLOPS WORKS, SHEFFIELD

A compilation of information based on surviving documents kindly provided by T. R. Middleton, Esq.

Towards the end of 1923, a decision was made at the Cyclops Works to replace the old "Huntsman type" coke fired crucible holes with forced draught furnaces, still coke fired, of a type being made by the Morgan Crucible Company. The case for the modification was made out as follows, based on the melting of 0.75% carbon steel :

	OLD TYPE FURNACES	NEW TYPE FURNACES
Number of furnaces	12 holes, 2 pots each	6 holes, 4 pots each
Scale of operation	2 rounds daily, alternating with 3 rounds	3 rounds daily
Daily output	33 cwt.	42 cwt.
(Mean output per pot)	(61.6 lb.)	(65.3 lb.)
(Crucible life)	(One day = 2.5 times)	(Four days = 12 times)
Direct Labour Cost	£3. 9. 0. daily = £2. 1.10. per ton	£3. 5. 0. daily = £1. 7. 2. per ton
Coke Consumption per Ton Steel melted	2.75 tons	1.75 tons
Coke Cost, based on coke @ 38/6d. per ton	£5. 5.11. per ton	£3. 7. 5. per ton
Crucible Cost	1 clay pot @ 1/6d. for every 2.5 x 61.6 lb. or 14.54 clay pots per ton = £1. 1.10. per ton	1 plumbago pot @ 15/0. for every 12 x 65.3 lb. or 2.86 pots per ton = £2. 2.10. per ton
Crucible Lids	1 clay lid @ 3d. as above = 3/8d. per ton	1 plumbago lid @ 3/4d. as above = 9/6d. per ton
Building Cost	£28 for 40 tons output = 14/0d. per ton	£28 for 50 tons output = 11/3d. per ton
TOTAL WORKING COST	£9. 7. 3. per ton	£7.18. 2. per ton

APPENDIX JJJ
continued - 2

The use of clay lined pots for special applications was noted; since these cost 17/0d. each, they would increase the cost on the new furnaces by a further 5/9d. per ton of steel.

A copy of the agreement with regard to payment for working the new furnaces, dated December 1923, is attached. The effect on the weekly wage can be judged from the following figures :

	Coke Furnaces	Morgan Furnaces	
	July 1923	October 1924	May 1925
Teemer	£4.12. 4.	£4. 8. 4.	£5. 5. 2.
Puller Out	£4. 4. 0½.	£4. 3. 1.	£4.18. 2.
	£4. 4. 0½.	£4. 3. 1.	£4.18. 2.
Coker	£2.19. 2.	£2.16. 5.	£3. 7.10.
	£2.19. 2.	£2.16. 5.	£3. 7.10.
Odd Man	£3. 3. 2.	£2.16. 5.	£3. 7.10.
Lad	14. 8.	14. 0.	18. 8.
TOTAL WEEKLY WAGE BILL	£22.16. 7.	£21.17. 9.	£26. 3. 8.

Initially, it seems, the anticipated savings were not achieved, as the demand apparently fell :

	Coke Furnaces Jan.-July, 1923 (30 weeks)	Morgan Furnaces Sept.-Nov., 1923 (13 weeks)
Direct Wages	£3.19. 1.	£2.19. 8.
Indirect Wages	£1. 4. 9.	£1. 9.10.
Maintenance	13. 3.	£1. 5. 5.
Materials and Stores	£2.10. 7.	£3.10. 4.
Power and Light	2. 8.	5.10.
Fuel	£5.11. 1.	£4. 1. 2.
Miscellaneous Expenses	£1. 9. 5.	£3. 2. 9.
Overheads	£4. 9. 2.	£5.14. 2.
TOTAL	£20. 0. 0.	£22.10. 0.
Total Ingot Tonnage	232.5	71.7
Tons per Week	7.75	5.52
Yield of Ingot from Metal Charged	94.90%	94.94%

It will be noted that the two main savings, on direct labour and, particularly, on fuel, were achieved. A few months later output had improved; unfortunately, only a resumé of labour costs is available :

	Four Day Working	Three Day Working
July-August 1923	117.64 cwt. per week	88.31 cwt. per week
Old Coke Holes	£3.18. Od. per ton	£3.18. 6. per ton
March 1925	198.71 cwt. per week	150.07 cwt. per week
	£2.12. 9. per ton	£2.16. Od. per ton

Two charge books have survived, covering July 1924 to March 1927 and August 1928 to October 1929. Despite the indications earlier, it seems that the standard charge was 60 lb. and the use of plumbago crucibles was the general rule. A note of expected crucible lives has the following information :

High Speed Steel	8 lives
Low Alloy Steel	10 lives
Medium Carbon Steel	12 lives
High Carbon and File Steel	15 lives

Plumbago pots, however, did give trouble due to the release of carbon into the steel. In particular, there was a fair demand for a 36% nickel steel (a low expansion alloy used extensively in temperature controllers at the time); this material had to contain less than 0.1% carbon and for its production the use of crucibles, made from the normal plumbago mix but then coated internally with a clay lining, to prevent contact of the metal with the carbonaceous outer refractory, became usual practice. The use of an all-clay pot would not have been suitable due to the fierce flame attack in the forced draught furnace - for this the plumbago was ideal. The clay lining of such pots eventually became eroded and they then were used for normal melting. Extracts from a report of October 1926 give some details of the problems involved :

'18 cwts. of 36% nickel steel were melted. For this 36 new lined pots were used. As no appreciable amount of carbon steel is being melted, these were put aside after one heat until such time as they may conveniently be used. They are not suitable for high speed until they have previously melted about three heats of other steels.... When new unlined pots are used, it is not safe to melt high speed or chromium steels for the first heat owing to the large amount of carbon absorbed, so that one heat of carbon steel in the first place is essential. Owing to the heat which must be maintained for melting high speed steel, the holes become badly slagged during a third heat and to melt high speed for this last heat of the day is rarely satisfactory, the steel tending to go back resulting in loss of output. A fairly easy third heat is therefore advisable .... After the ninth heat the pots are thin and it is usual to melt medium carbon steels in them; many pots have accumulated which are good for melting little else than one heat of file steel or steel of similar temper and quality'.

The same report gives some valuable information on the consumption of coke in melting the various types of steel; these should be compared with the 1.75 tons coke per ton of steel originally anticipated:

36% Nickel	3.5-4.0 tons per ton of steel
High Speed Steel	2.8-3.0 tons per ton of steel
Medium Carbon	2.0 tons per ton of steel.

It would appear that the use of the lined plumbago pot was not the complete answer to the problems on 36% nickel steel since there was a reversion to the melting of this material in clay crucibles in the remaining bank of Huntsman type furnaces, which were occasionally brought back into service. At this stage there were no crucibles being made on the premises, they were bought in; they were referred to as "Moore's Pots". This rather casts a new slant on the old tradition that it was essential to make the pots on the premises since they would not travel; on the other hand, we are dealing here with a very small proportion of the total usage, and special care could be taken. It would seem, at the same time, that lids and dozzles were made on the premises, since a "mix" is given, comprising 12 parts of clay, 4 of grog and 4 of coke dust. The problems met on the 36% nickel steel are interesting. It is reported that some melts in lined pots gave ingots with blowholes and that this problem could not be cured by the normal expedient of adding aluminium. In addition, it was found that the problem was lessened, if not entirely cured, by a pre-roasting of the crucible prior to use. To the modern steelmaker this is obviously a case of hydrogen absorption by the metal. It is not clear how the lining was put into the plumbago pot but it is conceivable that it would retain some moisture. It so happens that the high-nickel, low-carbon steels are among the most prone to this kind of problem and, indeed, the reversion to the use of a well roasted clay crucible was a sound move in these circumstances. Melted in this way, the crucible furnace provided quite a few tons of such material. The overall close analysis range achieved in the product is impressive and one which would be most welcome today, considering the small unit size of each melt, almost forty analyses to each ton :

Carbon 0.06-0.11%; Silicon 0.11-0.24%;
Nickel 35.82-37.37%.

A typical charge for the production of this steel was :

20 lb. cut Swedish Bar Iron
12 lb. Swedish Bar Ends
10 lb. 36% Nickel scrap
19½ lb. Nickel
12 oz. Charcoal.

These materials were melted out together and then 3 ounces each of ferrosilicon and ferromanganese added prior to the killing period.

The use of Swedish material in this special steel was not an exceptional feature. A general pattern of the use of from 15 to 30% of scrap of domestic origin, together with the necessary ferroalloy additions, with the remainder as Swedish iron, is quite clear from the evidence available. True, very little was top grade Dannemora iron, although some Hoop L and GL iron was used in the special grades of carbon steel. AOK iron was widely used, together with "Crown and Anchor", DU, DGL and "MR Box Ends".* Quotations and analyses of some of these materials were provided by Daniel Doncaster and Sons in 1925 :

Grade	C	Si	Mn	S	P	Price per Ton
Hoop L	0.10	0.05	0.28	0.009	0.011	£37.10. 0.
DGL	0.08	0.03	0.16	0.007	0.011	£29. 0. 0.
AOK	0.04	0.01	0.15	0.015	0.017	£16 - £17.10. 0.
MR Box Ends	0.05	0.02	0.04	0.008	0.030	£12.15. 0.

* The use of the "AOK" stamp is interesting. As has been reported elsewhere in this study (see pp.139-141) this was the stamp used in the eighteenth century by the Gysinge Forge. It can be seen in its original form in Appendix J. Significantly, it does not appear in either the 1845 or the 1897 issues of the "Stampelbok" of official stamps of the Swedish Iron Forges. In the quotation from Daniel Doncaster and Company in 1925, the stamp assumes a different shape from the eighteenth century one in that the three letters are enclosed in a rectangular outline with the letters separated by small crowns. Even more surprising, Doncasters indicate that this is a product of the Leufsta Forge, but is a rolled bar product; in addition, the "DGL" stamp is also indicated as a second grade Leufsta forged bar, the "Hoop L" still being the top grade.

Three years later some notes on prices give the following information :

Hoop L Bar	£35. 0. 0.	White Iron	£9. 0. 0.
Hoop L Ends	£24. 0. 0.	Ferrochrome, 60%	£32.10. 0.
GL Ends	£24. 0. 0.	Ferrosilicon	£13.18. 3.
AOK Bar	£16. 0. 0.	Ferromanganese	£13.15. 0.
AOK Bar, Converted	£20.15. 0.	Nickel	£165.18. 0.
Crown and Anchor Bar	£14. 5. 0.	Ferrovanadium	14.0d. per lb. V
MR Box Ends	£12.12. 6.	Ferromolybdenum	4.3d. per lb. Mo.
Styrian Steel	£27.10. 0.	Charcoal	£8. 8. 4.

(All prices per ton except for V and Mo).

In general, the bulk of the steel produced was carbon steel, together with fair quantities of high speed steel, some low alloy engineering steel and a few percent of the output was what might be termed "specials". The last week of production recorded, indeed, was all carbon steel or high speed steel.

Week Ending 5th October 1929

	Make	Yield
A Quality (Prime Carbon Steel)	81.2.20.	96.19%
Cyclone (14%W H.S.)	38.0.10.	95.50%
Cyclone Special (18/4/1 H.S.)	32.0.26.	94.85%
Cyclone Extra Special (Cobalt H.S.)	18.3.10.	94.62%
TOTAL	170.3.10.	95.48%

Coke usage .... 17 tons

The "specials", apart from the 36% Nickel which has been discussed, included both 13% chromium and 18% chromium stainless, with from 0.3 to 0.5% carbon, melted in clay lined pots. Still more interesting, however, are what were quite clearly very early trials with heat resisting steels, such as the 13% chromium-13% nickel-3% tungsten steel, produced in a lined pot in November 1928; this material still survives as a valve material, covered by an Aircraft Specification. Similarly, a high carbon 30% chromium material was made for furnace castings under the name of "Pyrista"; via the merger of Cammell Laird with Vickers, which gave rise to the English Steel Corporation, this name eventually passed to Firth Vickers and still applies to a steel with similar chromium content. Likewise, the material later to be known by both E.S.C. and Firth Vickers as "Immaculate 4W", an 18% chromium-8% nickel-4% tungsten alloy, was made in lined pots in June 1929. Castings were also produced in materials with 17% chromium and from 22% to 28% nickel under the name of "Camloy", which did not seem to survive the various mergers. Even a cast of "Nichrome", with 20% chromium and 70% nickel, was tried; a comment in pencil alongside reads rather significantly "Bad to Forge".

Most of the material produced seems to have been intended for the production of bar, although the making of castings has already been mentioned. There is no indication in the charge book as to the size of product but some larger ingots must have been produced since there is a comparative list of prices of dozzles pencilled in for domestic production against a few selected sizes on the official Wragg quotation for the manufactured items, rather indicating that these represent production items :

Size	Own Cost, each	Wragg Price, each
3"	1½d.	-
4"	2¾d.	3d.
5"	3½d.	4½d.
6"	5¾d.	7d.
8"	10½d.	1/2d.

There seems no interest in the larger sizes quoted by Wragg; it could be commented that the total metal available at any one time, from 24 pots, was capable only of providing a 10" or 12" ingot.

MEMORANDUM OF AGREEMENT

made between

CAMMELL LAIRD & COMPANY, LIMITED

and

THE MEN WORKING IN THE CRUCIBLE STEEL DEPARTMENT, CYCLOPS WORKS, SHEFFIELD, IN CONNECTION WITH THE INTRODUCTION OF 'MORGAN' FURNACES.

DATED THIS FIFTH DAY OF DECEMBER 1923.

WHEREBY IT IS AGREED : -

That in the working of the 'Morgan' Furnaces, the wages and working conditions shall be as follows : -

1. That datal rates as at present in existence shall be paid, viz - Teemer 8/-, Puller Out 6/6d., Coker 5/6d., Oddman 5/6d., except in the case of the lad who in lieu of any premium or tonnage shall receive an 'all-in' rate of 4/8d. per day when a 'Full' set is worked and 5/- per day when a 'Half' set is worked.

2. That a 'Full' set is understood and recognised to be the working of 24 pots and a 'Half' set, the working of 12 pots.

3. That the stint shall remain at 14 cwts. for a 'Full' set but shall be 7 cwts. only for a 'Half' set.

4. That a premium or tonnage payment shall be made on output of useable and saleable steel, as follows -

   Up to 15 cwts. over and above the recognised stint @ 2/6d. per cwt., and for all weights over and above the said 15 cwts. @ 1/- per cwt.

5. That the aforementioned premium or tonnage payment @ 2/6d. per cwt. shall be divided as under current arrangements.

6. That the aforementioned premium or tonnage payment @ 1/- per cwt. shall be divided as follows -

	Full Set 24 pots		Half Set 12 pots
1 Teemer	2½d.	1 Teemer	5d.
2 Pullers Out	5d.	1 Puller Out	5d.
2 Cokers	3d.	1 Coker	3d.
1 Oddman	1½d.		
	1/-		1/1d.

7. That for High Speed Steel an extra Premium or Tonnage of 6d. per cwt. shall be paid on all useable and saleable material made, divided as follows _

	Full Set		Half Set
1 Teemer	1¼d.	1 Teemer	2¼d.
2 Pullers Out	2½d.	1 Puller Out	2¼d.
2 Cokers	1½d.	1 Coker	1½d.
1 Oddman	¾d.		
	6d.		6d.

8. That the existing allowance of 2/6d. to the Oddman for lighting fire and annealing shall be reduced and as the annealing will not now be required the sum of 1/- only shall be paid for lighting up fire.

9. That the allowances for Big Ingots, Outs, and the calculation of weights &c., shall remain as at present.

10. That the allowances for Pot Making &c. and Building will be discontinued.

11. War Bonus will be paid under current conditions.

Signed for and on behalf of,

THE EMPLOYEES	CAMMELL LAIRD & CO. LIMITED
"P. SHAW"	"WALTER COCKER"
"T. E. COTTAM"	"C. J. HARDY"

B I B L I O G R A P H Y

A UNPUBLISHED MATERIAL

I Theses, etc.

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G. F. Hammersley, The History of the Iron Industry in the Forest of Dean, University of London, 1972.

J. Kenworthy, A History of Stocksbridge, Sheffield City Libraries, Reference MD 3336-4.

R. M. Ledbetter, Sheffield's Industrial History from about 1700 with Special Reference to the Abbeydale Works, University of Sheffield, 1971.

W. Lewis, The Mineral and Chemical History of Iron, c.1775-1780. Manuscript held in Cardiff Public Library, Reference 3.250.

A. McPhee, The Growth of the Cutlery and Allied Trades to 1914. Manuscript held by Dr. R. A. Mott.

F. M. Parkin, Gas versus Coke Melting in Crucible Steel Production, text of a lecture given to the Sheffield Society of Metallurgists and Metallurgical Chemists, 19th April 1921. Manuscript held by Sheffield Metallurgical and Engineering Association.

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III Legal and Official Documents

(a) Held in Sheffield City Libraries

Indenture dated 23rd September 1709; Wheat Collection No. 1966.

Deed of Transfer dated 1st January 1717; Reference MD 401

Deed of Transfer dated 15th January 1734; Tibbitts Collection No. 699.

Agreement setting up steel furnace, 1766; Tibbitts Collection No. 200.

Items from the Fairbank Collection :

Field Book No.25, 1763
Plan, SheD 71 S, 1783
Plan, HAN 23 L, 1795
Survey of Attercliffe, CA 13-1, 1819.

Dunn Papers, relating to the Canal, 1802; Reference MD 1740-21.

Mushet Papers; Reference MD 1193.

(b) Held in the Northumberland Record Office

Inventories of the Newburn Steelworks: Reference ZAN/BELL/70/09 and 70/11.

(c) Held in Birmingham City Libraries

Papers in connection with the Brades Works; Reference Lee Crowder Nos. 915 to 931.

(d) Held in the French National Archives

Mémoire from M. le Trudaine "Concernant les Ouvriers Anglais", 1765; Reference F^{12}.1316.

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Extract from "Procès Verbal des Essais d'Acier Cementé fait par Ordre du Gouvernment par M. le Chevalier Grignon", 5th March 1778; Reference F12.1303.

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Black Diamond Steelworks, Pittsburgh. Document provided by Crucible Steel Company of America, dating from around 1877.

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H3/231	Boulton to Huntsman	19th January 1757
B8	Boulton to Huntsman	9th August 1764
B33	Boulton to Huntsman	26th November 1764
H3/232	Huntsman to Boulton	7th July 1769
G41	Boulton to Huntsman	24th June 1774
G54	Boulton to Huntsman	2nd July 1774
G496	Boulton to Huntsman	28th December 1775
G517	Boulton to Huntsman	25th January 1776
G767	Boulton to Huntsman	7th December 1776
H3/243	Huntsman to Boulton	1st September 1781
H3/244	Huntsman to Boulton	4th May 1788
L112	Boulton to Huntsman	24th April 1789
H3/233	Huntsman to Boulton	22nd May 1789
H3/234	Huntsman to Boulton	24th May 1789
H3/235	Huntsman to Boulton	2nd August 1789
Q26	Boulton to Huntsman	23rd January 1790
Q51	Boulton to Huntsman	21st May 1790
H3/238	Huntsman to Boulton	29th September 1791
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LD 1612	Ledger, 1787-1806
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John Percy Papers. A collection of documents made by Dr. John Percy preparatory to the reissue of his "Metallurgy", now held by The Metals Society.

A Brief History of Park Works. A typescript provided by the Crucible Steel Company of America.

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1784	1420	H. Cort	Manufacturing Iron and Steel.
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1804	2767	S. Lucas	Separating Impurities from Cast Steel.
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	5263	N. Kimball	Converting Iron into Steel.
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1836	7142	J. I. Hawkins	Manufacture of Steel.
1839	8021	J. M. Heath	Manufacture of Iron and Steel.
	8129	W. Vickers	Manufacture of Cast Steel.
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1844	10204	C. Low	Manufacture of Iron and Steel.
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1849	12705	J. Holland	Making Steel.
1850	12950	E. Riepe	Manufacture of Steel.
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1854	243	R. A. Brooman	Manufacture of Steel.
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	2175	J. F. Boullet	Manufacture of Steel.
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	630	H. Bessemer	Manufacture of Iron and Steel.
	851	W. E. Newton	Manufacturing Steel.
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	1589	A. Chenot	Machinery for Compression.
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	2695	C. Binks	Converting Iron into Steel.
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	609	C. Pauvert	Manufacture of Cast Steel.
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	802	R. Mushet	Manufacture of Cast Steel.
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	3125	R. Mushet	Manufacture of Cast Steel.
1859	100	R. Mushet	Metallic Alloy.
	101	R. Mushet	Manufacture of Cast Steel.
	139	P. Sicard	Converting Cast Iron into Steel.
	501	R. Mushet	Manufacture of Cast Steel.
	1115	R. Mushet	Manufacture of Cast Steel.
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I N D E X

Geographical locations, works premises and steel companies appear in ordinary type.

PERSONAL NAMES ARE GIVEN IN CAPITAL LETTERS.

Technical Entries appear in Italic type.

(1), (14), etc. refer to the Figures.

(I), (XI), etc. refer to the Tables.

A, AA, AAA, etc. refer to the Appendices.

These are all to be found in the Supplementary Volume.

Other references are to the pages in the Main Volume.

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