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Mushet, David

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II. Principles of iron and steel.

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II.

ON THE PRINCIPLES
OF
IRON AND STEEL.

The general diffusion of coal and ironstone, in rich and extensive tracts throughout the island of Great Britain, while it has stamped an additional value on land, has rendered the manufacture of iron of such national importance and advantage, as to weigh considerably in the scale of our commercial interests. Of late years it has gained in a great measure that just preponderance to which its magnitude and general utility have fully entitled it. At present, however, it must not be concluded, that the business has attained those bounds which set limits to its improvement; or that it has attained its utmost consequence as a source of national and individual wealth. Its future progress will greatly depend upon the liberal exertions of individuals, and the self-denial of the legislature, by abstaining from cramping in its enlightened march the genius of this native manufacture.

Impressed with these truths, the following details will be found more allied to the practice of the manufacture of iron than attached to any systematic arrangement of science; where oftentimes the practical student is obliged to smile, bewildered at the lengthened assemblage of phrases expressive of a simple substance or meaning.

It is much to be lamented that the scientific arrangement of the mineralogist was not more consonant to the ideas of the manufacturer; and that the labours of the former were not more directed to assimilate to the just results of practice his preconceived theories.

With heartfelt pleasure we should then peruse the history and analysis of the many strata of argillaceous ores of iron with which both England and Scotland so plentifully abound; their richness in iron, and capability of being manufactured; their contiguity to coal, and the local advantages which nature may have bestowed, by the addition of waters sufficient for turning machinery: these would form interesting and instructing branches of information, and ultimately would tend to the advancement of our real interest.

It is also much to be wished, for the improvement of all, that the method and order of the new nomenclature of the French school should pervade every branch of chemical and mineralogical science; and that the celebrated Kirwan would so far bend as to new model his excellent system of mineralogy on these principles.

The metallic substance called iron, is susceptible of a greater variety of modifications, and possessed of more properties singular and useful, than any other metal. Iron, properly so called, is malleable. All the other states of the metal contain certain substances in combination with the iron, which render it fusible, brittle, more or less elastic, &c. Pure iron is destitute of foreign admixture,* and is therefore perfectly malleable. A variety of methods have been established to produce the metal approaching to that pure and ductile state: in the pursuit of this laudable attainment the following distinct modifications of iron have manifested themselves:—

1st, Crude, cast, or pig iron; 2nd, steel; and, 3rd, malleable iron. Crude iron is a brittle metal, obtained by the simple fusion of ores in contact with pitcoal charred, or the charcoal of wood, united with a

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* See Note A.

certain proportion of calcareous earth as a solvent or flux: its component parts are iron, carbon, and oxygen.* Carbon is imparted to the iron from the fuel which is used in smelting the ore; oxygen is conveyed to the iron in a twofold manner: it exists in the ore in a concrete state, and unites to the iron previous to separation; a portion is also communicated by the great compression of air used to excite the degree of heat necessary for reduction.

These are the foreign substances which alter and contaminate the quality of the iron; but, as they exist in different proportions in various irons, it is obvious that these alterations of proportion will form varieties of crude iron. The following are distinguishable:—

1st. Oxygenated crude iron, where a small portion of carbon is united to the iron, and where a superabundance of oxygen exists. The fracture of such iron presents a white surface destitute of grain, frequently diverging in streaks, resembling an early variety of crystallization; sometimes it is mottled with specks of a black colour, which plainly exhibit the scanty portion of carbonic concretions. The external surface of such iron always cools concave, rough, and covered with oxyde. In commerce this variety of iron is known by the names of white iron, forge pigs, ballast iron, &c., and its present value is from *5l.* *5s.* to *5l.* *15s.* per ton.

2nd. Carbo-oxygenated crude iron,† or iron united with equal portions of carbon and oxygen. The fracture

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* See Note B.

† I am fully aware of the novelty of this term, and that by some I may be liable to be censured. I have, however, the great Lavoisier for my precedent, who, in naming the compound radicals of the vegetable kingdom, used hydro-carbonous and hydro-carbonic, to express the ternary combination of hydrogen and carbon with oxygen; in the former, into that of an oxyde—in the latter, into that of an acid. It may, however, be remarked, that in this way the prevailing substance was marked by a precedency given to its sign, which implied that there existed a larger proportion of this than the following substance. Let the present, however, express the combination of iron with carbon and

of this iron is light grey, presenting a small distinct grain; the surface of the pig partially punctured, less concave, and more free from oxydation in cooling than the former state. In commerce it is known by the names of grey iron, No. 3, &c., and its present value is reckoned from 5*l.* 15*s.* to 6*l.* 5*s.* per ton.

3rd. Carbonated crude iron, wherein carbon fully predominates, and where an extra privation of oxygen has taken place. The fracture of this iron is dark grey inclining to blue, presenting large brilliant concretions of a metallic lustre in the centre of the pig, but diminishing in point of size as they approach the surface. In this quality of iron, the upper surface, which is left to cool in contact with the open air, after being run from the blast furnace, is partially convex and full of punctures; it is then called by the workmen honey-combed, and its quality is often inferred from the size and depth of the puncture. Its tendency to oxydation in cooling is still less than that of the second variety of crude iron. This quality is well known to the manufacturer and founder, under the names of No. 2, good melting pig iron, &c. Its present value is from 6*l.* 15*s.* to 7*l.* 10*s.* per ton.

4th. Super-carbonated crude iron, or iron saturated to excess with carbon, and having united to it but a scanty portion of oxygen. The fracture of this iron presents an astonishing group of large, regular, metallic grains, each presenting a prominent edge outwards; in this state the saturation of carbon has been so complete, that it exists united to the iron in the state of plumbago; lustre rich and brilliant, inclining to dark blue; the upper surface smooth and convex, frequently covered with a beautiful coating of shining plumbago, and com-

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oxygen in equal portions: the precedency given to carbon in beginning the compound, is meant to denote its superior agency, and its presence being essential in the manufacture of crude iron.

pletely free from oxyde. This is the No. 1, and smooth-faced iron of the manufacturers: its present value is 8*l.* to 8*l.* 10*s.* per ton.

These are the principal varieties of crude iron. A number of intermediate qualities are produced, exactly dependent upon the quantity of mixtures, and their relative proportions to each other. The greater the quantity of charcoal used in smelting the ore, the more saturated with carbon and the more valuable will be the pig iron. A sparing proportion of charcoal in the blast furnace is productive of effects completely contrary to these.

It most naturally occurs to inquire, what extreme degree of combination these alterative principles are capable of with iron, and in what state the metal is when this excessive saturation is completed.

If crude iron is exposed in fusion, for a length of time, to absorb carbon, and at the same time is protected from oxydation, it will receive this principle to such excess as to form a true plumbago. In this state it either resembles steel, grained lead ore, or assumes an imperfect cubical crystallisation, wonderfully brittle, and possessed of a real metallic appearance and weight: in this state it is powerfully attracted by the magnet.

Specimens of this singular combination are extremely rare; several that I am in possession of, have regular faces approaching to a cubical structure, with surfaces chequered with numerous diagonal lines intersecting each other, and forming rhombuses: these are easily displaced with a knife, and exhibit them composed of the thinnest laminæ imaginable: in this state they are not obedient to the magnet, unless a considerable number of them are attached together. The specific gravity of this mixture of iron and carbon is to water as 6·9694 to 1·000; a cubic foot weighs 435·58750 lbs. avoirdupoise.

In manufacturing crude iron, the highest possible pitch to which it can be united with oxygen is productive of a coarse metallic substance, whose fracture is dark and porous, and whose surface on cooling becomes covered with a deep earthy oxyde; incapable of being fused but by a violent heat; capable of receiving some impressions of malleability, though still possessing excessive brittleness when cold. The specific gravity of iron thus united with oxygen is 6·5325.

These states of extreme saturation of carbon and oxygen only relate to these principles as they become united to the iron in fusion; they may also be presented to crude iron in the process of cementation; in which case carbon unites to iron in an aeriform state, distending the particles and softening the mass: oxygen, on the contrary, attacks the metal, and reduces it to a dark blue oxyde, destitute of metallic brilliancy and weight; but of this more hereafter.

Steel, from its great affinity to crude iron, ought next be mentioned; but as manufacturers hitherto have placed it as the third existing state of the metal, it will be mentioned in that order.

To produce malleable iron in its pure state, many and various have been the processes adopted: these however have all in some measure fallen short. Malleable iron ought to possess no foreign mixture whatever, to be in a state of purity; but as the modes of operation have hitherto consisted in manufacturing this state of the metal from crude iron, and as crude iron is always found to contain principles inimical to malleability, it is obvious, that the quality of malleable iron will at all times depend upon the degree of expulsion of the alterative mixtures contained in the crude iron; the destruction of which, and the consequent malleabilization of the iron, constitute the universal acknowledged principles of bar iron making.

From the imperfect dissipation of oxygen and carbon in the process of malleability, arise the various qualities of malleable iron; these may be arranged in the following order: 1. Hot-short iron; 2. Cold-short iron; and, 3. Iron partaking of none of these evils; and so far it may be denominated pure malleable iron.

1st. Hot-short iron is possessed of an extreme degree of fusibility when in contact with a high degree of heat,* and is incapable of receiving the weight of a small hammer without dissipating; it is, however, possessed of an extreme degree of softness and ductility when cold, and may then be bent or twisted in almost any direction. Various reasons have been assigned for this destructive property in hot-short iron. I am of opinion, that it arises from the iron containing a small portion of concrete of carbon, not extirpated during the operation of rendering the iron malleable; and that in proportion to the quantity of carbon united, so will be the shortness or fusibility of the iron: this variety of iron is always of a dark-coloured unmetallic fracture.

2nd. Cold-short iron is possessed of the property of withstanding the most violent degree of heat, without exhibiting the least indication of fusion; it remains firm under the heaviest hammer, and is capable, while hot, of being beat into any shape; when cold, however, it is brittle, and possessed of a small degree of tenacity; its fracture is always clear and large grained, of a light bluish colour. A small portion of iron dissolved in the phosphoric acid is now believed to constitute the cold-short principle of iron. Besides the difficulty of conceiving how an acid could exist in the violent and long-continued heats of the refinery, the puddling and balling furnaces, wherein the metal is subjected to motion, frequently agitated, and extremely divided, how does it happen, that that iron on which the cold-short principle

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* See Note C.

is impressed, becomes more and more cold-short, by a continued exposure to the combination of oxygen with caloric, either excited by blast or the attenuated heat of a wind furnace? This fact would imply a generation of the alterative principle—which is indeed the case—but which cannot be admitted, if the cold-short quality is attributed to the phosphate of iron; unless recourse is had to the supposition of a new combination of this metallic salt during the operation.

If highly oxygenated crude iron, of any manufacture, is exposed to the action of a current of flame, after its small portion of carbon is burnt out, and after the mass has exhibited the proper signs of malleability, it will pass into the state of cold-short iron; and this principle will exist in proportion to the length of the exposure; or, in other words, in proportion to the oxygen presented to the metal, and its tendency to quit the caloric to unite with the iron.

3rd. Pure malleable iron derives its strength, tenacity, malleability, and ductility, by being totally deprived of the principles which constitute the cold and hot-short qualities of iron. This is effected in the course of rendering it malleable, either by the attention of the workmen, or from the proper quality of the crude iron used: its fracture is generally clear, consisting of small regular dark blue grains; by much hammering the iron commonly gains fibre, and is then of a light blue colour, uncommonly tenacious when cold. The excellence of pure malleable iron is also manifested by the astonishing degree of heat it withstands without exhibiting the least sign of fusion,* or without losing much of its metallic parts by oxydation.

A line of distinction ought to be drawn between the iron produced by wood-charcoal and pitcoal. As the present relation of the simple principles of the metal

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* See Note D.

does not immediately interfere with that distinction, it will more properly arrange itself along with the observations on the various modes practised for rendering iron malleable.

However variously conducted the modes of operation are at different works, and in different countries, to produce malleable iron, yet the principle of operation is the same, namely, that by dissipating the carbon and oxygen, contained in the crude iron, bar or malleable iron is the result.

Furnaces of a multiplicity of shapes have been erected for this purpose; but in the most perfect conducted processes hitherto, it has been found, that a heavy loss of metallic parts accompanied the manufacture:* 40, 35, to 30 cwt. of crude iron have been used to fabricate one ton of finished bars; the quantity used always depending upon its aptness to become malleable, the skilfulness of the workmen, the operation adopted, and the quality of the malleable iron wished to be produced. These observations more immediately relate to the home manufactures of iron with pitcoal; but in many instances they will also apply to those of other countries where the charcoal of wood is used for fuel.

Since crude iron exists of such a variety of qualities, owing to the various proportions of mixture united with it; and since it is almost universally used to produce bar or malleable iron; it is natural to infer, that there must exist one particular variety of it, which could be appropriated to the manufacture in preference to any other. Theory says that crude iron, carbo-oxygenated, which contains the alterative principles in equal portions, requires only to be exposed in a fluid state to the action of fire, either in a wind furnace or small blast. By this exposure the carbon becomes volatilized,

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* See Note E.

and carries off the oxygen along with it.* Practice has however confined the operation chiefly to the forge pig (oxygenated crude iron). This variety of iron becomes sooner malleable, but is likewise susceptible of early oxydation, and consequently liable to become cold-short. Neither can it unite to bar iron those properties from whence are derived great strength and ductility.

When carbonated crude iron is used, the waste then is apt to be excessive : the metal retains for too long a period its fusible principle, which must necessarily expose the mass to a longer continued action to the flame, whereby oxydation on the metal in a fluid state takes place, and a considerable portion of it is destroyed before the iron exhibits signs of infusibility. Malleable iron made from this state of the metal has a great tendency to be red-short, and loses also considerably in weight, under the forge hammer.

It has at all times been asserted, that crude iron contains a considerable proportion of its parts, by weight, inimical to malleability ; and that, in the operation of refining, it then parts with this proportion of mixture, which renders the remainder malleable. A conclusive inference from this would be, that some crude irons contain one-half, some three-fourths, and others again an equal portion of mixture for iron ; seeing these are the proportions lost by iron in the operation of rendering it malleable. The mischief with which this fallacious opinion is fraught is inconceivable ; especially as it has been supported by men, who have laid claim to scientific and practical abilities : the belief of it slackens the industry of individuals to attempt lessening the loss of real metal ; on the contrary, workmen are taught to

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* A definition more consonant to chemical language would be to say, that the oxygen unites to the carbon, and forms carbonic acid, which is expellable even in a moderate heat. The escape of the last portion of the acid is indicated by the disappearance of fusion, and the coalescence of the clotted iron.

look upon a large proportion of it as incapable of being metallized, and as only fit for destruction.

If manufacturers of bar iron would more frequently deprive a given weight of the scoria of the refinery and puddling furnaces, of its iron, they would be more able to estimate the portion of unmetallic parts contained in their crude iron; upon finding the scoria to contain 30, 40, to 50 per cent. of iron, equally fit for converting into malleable iron as any part of the original mass, their attention would be more frequently arrested, and employed to devise means, either to prevent the escape of such a considerable proportion of iron, or to fuse such scoria so as to deprive them of the last portion of metal.

The relative proportion by weight of carbon and oxygen united to crude iron is small indeed; the possible proportion in which they can exist will be more easily conceived by adducing the weight of a specific bulk of each and their analogy.

1 cubic foot of oxygen gas	·0792859 lb. av.	S. gravity ·001053080
1 ditto carbon	24·519	S. gravity ·39214
1 ditto carbonated crude iron	453·70325 lb. do.	S. gravity 7·2593680

The vast disproportion between the cube of iron and the aggregate of the mixtures renders further illustration on this head superfluous,* though at some future period I hope to be able to state the exact weight of mixture united with a given quantity of crude iron.

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* I wish not to be understood as if I meant to say that the quantity of oxygen in a concrete form in iron is to be considered as having no greater specific gravity than an equal bulk in a gaseous state, that is combined with caloric, instead of being combined with the metal. The enormous waste of real metal, in converting a given quantity of crude into malleable iron, is generally so great, that, at present, I merely wish to call the attention of artists to the prevention of this waste, instead of satisfying themselves with saying they had only a given product, because the crude iron employed, was of such a nature as to be incapable of yielding more.

Some, however, may contend for the existence of some metallic substances along with crude iron, which may also form part of the unmetallic mass; we are, however, unacquainted with any capable of enduring the violent heats used in manufacturing iron, except manganese; and this semi-metallic substance is found in bar iron and steel, nearly in the same proportion as in crude iron, hence it can form no part of the supposed heterogeneous matter expelled during the process of malleability.

Steel is a mixture of iron with carbon in an aeriform state.[*] Carbon is given to iron by heating it violently, unexposed to air, in contact with charcoal dust. The proportion in which carbon exists in steel is various, depending upon the degree of purity existing in the malleable iron previous to cementation. In absorbing this principle it gains weight; and this augmentation of weight, by the addition of carbon, is dependent upon the reason already mentioned. Some iron, in passing to the state of steel, gains $\frac{1}{140}$th part of its original weight, while others gain not more than $\frac{1}{175}$th part.

If malleable iron was entirely freed from carbon in the manufacturing, the inference would be just, to state that the weight gained was the exact measure of carbon necessary to form steel; but as some malleable irons afford a considerable portion of carbon, it is evident that the total measure of carbon will depend upon the pre-existing quantity contained in the iron. The greater the quantity introduced, the more brittle will the quality of

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[*] In the works of those who have treated on iron, I have never yet seen carbon which exists in crude iron, distinguished from that absorbed by malleable iron, in the process of converting into steel. I could adduce many facts, which to me appear conclusive, to prove that carbon exists in crude iron in a concrete state, separable by mechanical division; and that it is united to steel in a gaseous state by the combustion of its base, inseparable in any form by the most minute mechanical reduction.

[†] See Note F.

the steel be found, and the less capable of preserving its nature and a solid form when exposed to intense degrees of heat.

Steel, at certain degrees of heat, possesses all the softness and malleability of iron; but, when cold, partakes of the eager brittleness of crude iron. When properly hammered, it gains fibre, and then becomes the most elastic state of the metal. It is also capable of fusion at a high degree of heat; it may then be run liquid into iron moulds, and afterwards beat out into the most solid shapes, possessing cohesion and closeness of grain, with an astonishing degree of flexibility and tenacity. In this state it is called cast steel, and is used for fine instruments, where durability, polish, and edge are requisite.

In so far, therefore, as steel is capable of fusion, without destroying its nature, and as it contains iron and carbon alone, it must be considered as a variety of crude iron free of oxygen, and so far is partially malleable. The fusion of steel destroys its property of being welded. This change of nature is occasioned by the addition of oxygen in the cast steel furnace; hence we find, that fusion is incompatible with an extreme degree of malleability.

Since a small portion of oxygen is added in the fabrication of cast steel, the component parts of this modification of the metal will be iron, carbon, and a small portion of oxygen. Admitting then for a moment that the carbon is in the same state as in crude iron, here then exists a similarity of principles with carbonated iron. Yet there are few but know the very wide difference between crude iron and cast steel when applied to use

This, amongst many other positions, might be adduced to prove that carbon exists united in a gaseous state to iron, and constitutes steel; or, in other words, that iron to constitute steel, must hold in solution a portion of carbon, not less than $\frac{1}{175}$th part of its own weight.

Some of the foreign writers account for the difference betwixt steel and crude iron, by affirming that the former is iron perfectly reduced, to which carbon is given, and that the latter is only iron imperfectly reduced, and which also contains carbon. This is a feeble distinction. Iron knows of no state of imperfect existence as a metal; the particles of iron in a crude state are equally disposed to become malleable, so soon as the carbon which has interposed itself betwixt them is burnt out. The same operation must take place before steel is brought back to the state of malleable iron; hence, according to the reasoning of the French writers, they are both imperfect states of the metal.

Crude iron is only so far imperfect, because it contains carbon in a material state. Steel may be said to be more perfect because it is united to carbon in an elastic state; and iron, properly so called, is perfect in proportion as it is void of these impurities.

Steel also possesses the sole property of acquiring a degree of hardness, when immersed at certain degrees of heat into cold water, which enables it to perforate and act upon all other metallic substances. This is occasioned by the sudden expulsion of the caloric from the interstices of the metal, which brings on an instantaneous aggregation of the particles, and which renders the fracture uncommonly close and regular. Exposure to a similar degree of heat, and cooling in the open air, brings it back to its usual state, capable of being again and again hardened, and not to the state of malleable iron, as a late essayist on iron has erroneously stated.

Having thus simply stated the principles, and the various modifications of iron, those operations which have been practised for obtaining the various states of the metal come next to be related; prefaced by some account of the materials used; the manner in which they are obtained; their preparation and application to use: previous to which, I shall forward, for the next number of the Philosophical Magazine, a few remarks relative to the history of the manufactures of iron and steel in Britain, which may not prove unacceptable to those who feel themselves interested in this important branch of national industry.

ILLUSTRATIVE NOTES.

Note A.

ON THE PURITY OF MALLEABLE IRON.

Experience has taught me to qualify this assertion as to the purity of iron, as I have met with no manufactured iron entirely free from carbon. Iron manufactured through the whole operation with charcoal, still retains a portion of the fuel in intimate union with the iron, so as to communicate to it some of the incipient properties of steel, viz. greater hardness and stiffness when cold, becoming harder to a certain extent on being plunged into water, and thereby presenting a whitish silvery surface.

In whatever proportion carbon may exist in charcoal iron, probably from 1-150th to 1-200th part its weight, it is evident that it exists in a much less quantity in the iron now commonly made in this country by puddling—the severe decarbonating process which the iron undergoes in the running-out fire, and in the puddling, accounts for this, and also for the greater softness of puddled iron over iron made with charcoal.

It has been found, by numerous experiments, that charcoal bar iron is fusible in proportion to the quantity of carbon it contains; but when this exists in the iron in the usual limited proportion, it is found much less fusible than puddled iron, although this is more destitute of carbon. This extra fusibility has been attributed to a portion of earthy matter, such as silica, alumina, lime, cinder, &c., which, in the process of puddling, unavoidably becomes lapped up in working, and ultimately forms part of the bar.

Independent of humid analysis, this fact has been ascertained by fusing portions of charcoal iron and puddled iron in separate crucibles, but in the same furnace. It was uniformly found that a much higher temperature was required to fuse the charcoal than the puddled iron, and that when the angles of the pieces of the charcoal iron were merely rounded and welded together, the puddled iron was completely fused and resolved into a smooth button of cast malleable iron, without any trace of crystallization. On the contrary, the charcoal iron, when melted, would possess on its upper surface a perfect crystallization in radii from a common centre, without any trace of earthy or vitreous matter adhering.

The addition of 2 per cent. of charcoal to puddled iron, was found to decrease its fusibility, and communicated to the fused result the same regular crystallized surface before described to have taken place in the fusion of the charcoal iron, but with this remarkable difference, that either a portion of glass would form a slight ring round the edges of the button, or portions of the unfused silica be found adhering to its upper surface.

At one time, when iron was puddled on sand bottoms, and was consequently of a very inferior quality to what now is produced, from 2 to 3 per cent. of silica in granules has been frequently obtained, in pursuing these experiments, adhering together upon the upper surface of the metallic results.

This appearance has nearly vanished as a characteristic of puddled iron, but in its place we have in these fusions a rim, more or less strong, of glass of iron, surrounding the metallic button, the consequence of using, as in late years, an unlimited proportion of cinders in the puddling furnace; and although by careful heating in the balling furnace and subsequent rolling, no trace of them can be perceived in the comparatively perfect fracture of the iron; yet the fatal alloy is easily discovered in the experiments to which I have now alluded, both by the separated glass, and the easy fusibility of the iron.

The fusibility of bar iron, made by the puddling process, was early ascertained, for, about the year 1790, a nail-moulder, by name William Mucklejohn, in the employment of Mr. Coterell, of the Leith foundry, and who was in the habit of melting the pig iron, from which the nails were made, in clay pots or crucibles, obtained from his master a piece of puddled iron, made by Mr. Cort, the inventor of the puddling process, which, at that time, had created a considerable sensation in the metallurgical and chemical world in Edinburgh. This he introduced into one of his pots, and without any difficulty, or extra preparation, reduced it into a fluid state, very much to the annoyance of Mr. Cort.

Note B.

ON THE COMBINATION OF OXYGEN IN PIG IRON.

My early opinions are considerably changed upon the question of pig iron containing oxygen, either as directly united to the iron, or existing in it through the medium of the ore. In either case it would denote that the iron united with a portion of its own oxyde, and remained, to all appearance, metallic—a thing most difficult to conceive, when the strongly oxydable nature of this metal is taken into the account.

Considering the superior affinity of oxygen to carbon in preference to iron, I feel inclined to deny the possibility of oxygen uniting with pig iron at any stage of its carbonization beyond a dark mottle: up to this stage or period, there may be considered an excess of carbon in the pig iron, which would be acted upon in the first instance by the blast, and shelter the iron from its influence. In the receding qualities of pig iron from dense white to honeycomb fractured white, and steel grained, the case may be, and is no doubt materially changed.

Where a minimum dose of carbon is united to the iron, as is the case with the qualities just now described, there is a great want of fusibility, and consequently of perfect separation in the blast furnace. There may be coke, charcoal, or carbonaceous matter in its burden sufficient to reduce and metallize 95 per cent. of the iron, but not the whole. The deficient produce may therefore get enlarged in the state of oxyde in that part of the produce which is metallized, or it may, as frequently it happens, when the quantity is in excess, pass over in combination with the scoria of the cinders, which, when it exists to the extent of 1½ to 2 per cent., uniformly changes the colour of the same to black.

Whatever loss may be sustained in the operation of converting cast iron into bars, the perfect quality of the latter which is produced, at many of the foreign fabrics, leaves us little or nothing to regret on this subject, and little to be hoped for from following any other line of operation. At the time this paper was written, sanguine expectations were afloat of obtaining a superior quality, not only of bar iron, but of steel, by an entire new line of process, viz. the deoxydation of rich ores of iron in high temperatures in contact with charcoal or other carbonaceous matter. The ore thus metallized was sunk in charcoal refineries and after being heated and welded, drawn into bars under the hammer; some good iron was obtained in this way, but at so great a waste and cost of production as speedily to ensure the discontinuance of the process.

After an interval of upwards of 40 years, a similar operation in many respects has been revived, but with what eventual success, time only can prove. One decided property has been developed, viz. uncommon tenacity when cold, requiring a much greater tensile force to separate the parts.

NOTE C.

ON THE CAUSES OF THE HOT AND COLD-SHORT IN IRON.

This definition of hot-short, or red-short iron, as it is now commonly called, ought, in reference to the iron made by the present process in this country, to be considerably qualified.

Red-short iron is now found to stand the high or welding heat well, unless it is alloyed with too great a proportion of iron, obtained from the scoriæ of the bar iron operations, but is brittle at a particular stage, in passing from a bright red to a scarlet coloured heat.

In addition to the effect that may be produced by the presence of a portion of concrete carbon in occasioning the red-short quality of iron, more I am now inclined to suppose may be attributed to an excess of calcareous matter in the ore, or in the ashes or earthy matter of the fuel, which, when it exists to the extent of 4 or 5 per cent., and which is sometimes the case, cannot fail in impressing a peculiar character to the resulting pig iron, and which is afterwards more fully developed in the conversion of that pig iron into bar or malleable iron.

It has been of late years clearly established that the bar iron made from the iron ores of the Forest of Dean is more red-short than any other iron produced in England, those iron ores so predominating in calcareous matter, as to require not a lime-stone flux in the blast furnace, which is the case all England and Scotland over, but one as purely argillaceous and fusible as possible. We have only in this case to suppose that the excess of calcareous matter is metallized and unites to the iron in its metallic state, as calcium, to render it exceedingly probable that this may communicate the cause of the red-short in iron.

We have therefore two causes clearly ascertained in connexion with the opposite defects of hot-short and cold-short iron. In one case, viz., the use of the highly silicated scoriæ of the forge and mill in the blast furnace, (p. 14,) a decided cold-short iron is produced; and in the other case, viz., in the use of calcareous ores in the blast furnace, pig iron results, from which are made bars the most decidedly red-short in England.

In place therefore of seeking to account for the phenomena of cold and red-short by the presence of a salt or metal whose existence has not been ascertained, it would seem more rational to deduce these striking characteristics from the various earths which are united with the ores previously to their being smelted.

We have red-short iron resulting from an excess of lime in calcareous ores, and it seems a perfectly legitimate inference from the above premises respecting the silicated scoria, to derive the cause of the cold-short in iron, where such matters are not used, from an excess of silex in the ores whence the pig iron is derived.

The property of standing a high heat, attributed in the text to cold-short iron, must be understood of the foreign or charcoal bar iron in general use 40 years ago;—no such property belongs to the cold-short iron of the present time, which in heating is found to soften at a lower temperature, and is less capable of enduring the heat of the balling furnace than iron of a red-short quality.

Note D.

ON THE INFUSIBILITY OF MALLEABLE IRON.

Since this statement was written I have been in the habit of using more powerful furnaces, for experiments on these various subjects, and have found no difficulty in fusing the most perfect qualities of bar iron, such as charcoal iron horse nails, in 15 or 20 minutes.

Note E.

ON THE LOSS IN CONVERTING PIG TO BAR IRON.

At the time this paragraph was written 40 cwt. of pig iron was, at some places, required to make one ton of bar iron. Mr. Cort made 29.3.0.16 from 60 tons of government ballast, whereas such has been the gradual but certain progress of improvement in the process of puddling, that a ton of merchant iron is now made with from 26 to 27 cwt. of pig iron.

Hence also, and long after the period above alluded to, methods have been devised, (the description of which more properly belongs to the manufacture of bar iron, and therefore ought not to be anticipated in this place,) of using the whole or nearly the whole of the slag and cinders produced in the manufacture of bar iron, which at that time I represented as containing from 30 to 40 per cent. of iron; and which methods have since had the effect of lessening the consumption of iron ore in the production of bar iron nearly or fully 30 per cent.

NOTE F.

ON THE STATE IN WHICH CARBON EXISTS IN STEEL.

I have more than once intimated in the text, that the carbon in steel exists in a gaseous state; this opinion I have long considered the effort of a young mind eager to account for the whole phenomena before it, without that knowledge of the subject which long experience and observation confer. It was not long after its publication that I was led into a train of experiments by which cast steel of the best quality was made by the simple fusion of bar iron and common wood charcoal in close contact with the iron. It was discovered in the course of these experiments that the charcoal entered largely into combination with the pieces of iron, immediately in contact with it, constituting in the first instance a species of white cast iron unfit, in that state, for any useful steely purpose, but which acting as a flux to the more remote masses, brought the whole by a continuation of the heat and a perfect fusion, into one uniform state of cast steel.

The communication of carbon to bar iron in the process of cementation for the production of blistered steel, is somewhat different, and may in the first instance have led to the supposition of the carbon being imparted to it in a gaseous state: the process being clearly one proceeding from the surface of the bar surrounded by charcoal to the interior of the same, which could only become steelified by a transmission of carbon through the solid pores of the iron. In whatever state or form the carbon is at the period of its transmission into the substance of the iron, whether gaseous or concrete, there is no question but it exists in the iron in a solid state and forms part of that solid.

There are many other points connected with this subject, as to what constitutes the difference between cast iron and cast steel, and cast iron and steel made from bar iron, which will fall more properly to be noticed in my observations upon bar iron and steel.

In conclusion, I shall now only remark that I consider all sorts of pig iron equally crude and all containing carbon in the same state, but materially affected by the quantity taken up in the blast furnace. In this respect pig iron differs from bar iron; italso differs from bar iron in containing metalloids arising from the partial reduction, in smelting, of the earths which are united with the ores; and lastly, in the crystallization or arrangement of its parts in which it has obeyed the law of fluids entering into the solid state.