



Philosophical Magazine Series 1

Publication details, including instructions
for authors and subscription information:
<http://www.tandfonline.com/loi/tphm12>

XI. Observations on iron and steel

Joseph Collier

Published online: 04 Mar 2010.

To cite this article: Joseph Collier (1798) XI. Observations on
iron and steel , Philosophical Magazine Series 1, 1:1, 46-55, DOI:
[10.1080/14786447808676792](https://doi.org/10.1080/14786447808676792)

To link to this article: <http://dx.doi.org/10.1080/14786447808676792>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever

caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

place of the solid angles, and which are subject to another law of decrease, to be spoken of hereafter.

If the decrease of the laminæ of superposition took place according to a more rapid law; if each lamina for example had had on its circumference two, three, or four ranges of cubes less than the inferior range, the pyramids produced around the nucleus, by this decrease, being more lowered, and their adjacent faces being no longer on a level, the surface of the secondary solid would be composed of 24 isosceles triangles, all inclined one to the other. I call *decrease on the edges* that which takes place parallel to the edges of the nucleus, as in the preceding examples, to distinguish it from another kind of decrease which I shall speak of hereafter, and which takes place according to directions altogether different.

(To be continued.)

XI. *Observations on Iron and Steel.* By JOSEPH COLLIER.
From the Transactions of the Manchester Society.

[*With a Plate, No. III.*]

AFTER examining the works of different authors who have written on the subject of making iron and steel, I am persuaded that the accounts given by them of the necessary processes and operations are extremely imperfect. Chemists have examined and described the various compound minerals containing iron with great accuracy, but have been less attentive to their reduction. This observation more particularly applies to steel, of the making of which I have not seen any correct account. It is singular to observe how very imperfectly the cementation of iron has been described by men of great eminence in the science of chemistry. Fourcroy states the length of time necessary for the cementation
of

of iron to be about twelve hours ; but it is difficult to discover whether he alludes to cast or to bar steel : for he says, that short bars of iron are to be put into an earthen box with a cement, and closed up. Now steel is made from bars of iron of the usual length and thickness : but cast steel is made according to the process described by Fourcroy, with this essential difference—the operation is begun upon bar steel, and not bar iron.

Mr. Nicholson is equally unfortunate in the account given in his *Chemical Dictionary*. He says that the usual time required for the cementation of iron is from 6 to 10 hours, and cautions us against continuing the cementation too long ; whereas the operation, from the beginning to the end, requires 16 days at least. In other parts of the operation he is equally defective, confounding the making of bar with that of cast steel, and not fully describing either. In speaking of the uses of steel, or rather of what constitutes its superiority, Mr. Nicholson is also deficient. He observes that “ its most useful and advantageous property is that of becoming extremely hard when plunged into water.” He has here forgotten every thing respecting the temper and tempering of steel instruments, of which, however, he takes some notice in the same page. “ Plunging into water” requires a little explanation : for, if very hot steel be immersed in cold water without great caution, it will crack, nay sometimes break to pieces. It is however necessary to be done, in order to prevent the steel from growing soft, and returning to the state of malleable iron ; for, were it permitted to cool in the open air, the carbon which it holds in combination would be dissipated*. I shall at present confine my remarks to the operations performed on iron in Sheffield and its neighbourhood, from whence various communications have been transmitted to me by resident friends, and where I have myself seen the operations repeatedly performed. The iron

* It is the opinion of some metallurgists, that a partial abstraction of oxygen takes place, by plunging hot metal into cold water.

made in that part of Yorkshire is procured from ores found in the neighbourhood, which are of the argillaceous kind, but intermixed with a large proportion of foreign matter. These, however, are frequently combined with richer ores from Cumberland and other places. The ore is first roasted with cinders for three days in the open air, in order to expel the sulphureous or arsenical parts, and afterwards taken to the furnaces, some of which are constructed so that their internal cavity has the form of two four-sided pyramids joined base to base; but those most commonly used are of a conical form, from forty to fifty feet high. The furnace is charged at the top with equal parts of coal-cinder and lime-stone. The lime-stone acts as a flux, at the same time that it supplies a sufficient quantity of earthy matter, to be converted into scoriæ, which are necessary to defend the reduced metal from calcination, when it comes near the lower part of the furnace. The fire is lighted at the bottom; and the heat is excited by means of two pair of large bellows blowing alternately. The quantity of air generally thrown into the furnace is from 1000 to 1200 square feet in a minute. The air passes through a pipe, the diameter of which is from two inches and a quarter to two and three quarters wide. The compression of air which is necessary is equal to a column of water four feet and a half high. The ore melts as it passes through the fire, and is collected at the bottom, where it is maintained in a liquid state. The slag, which falls down with the fused metal, is let off by means of an opening in the side of the furnace, at the discretion of the workmen. When a sufficient quantity of regulus, or imperfectly reduced metal, is accumulated at the bottom of the furnace (which usually happens every eight hours), it is let off into moulds, to form it for the purposes intended, such as cannon or pig iron. — Crude iron is distinguished into white, black, and gray. The white is the least reduced, and more brittle than the other two; the black is that with which a large quantity of fuel has been used; and the gray is that
which

which has been reduced with a sufficient quantity of fuel, of which it contains a part in solution. The operation of refining crude iron consists in burning the combustible matter which it holds in solution; at the same time that the remaining iron is more perfectly reduced, and acquires a fibrous texture. For this purpose, the pigs of cast iron are taken to the forge, where they are first put into what is called the refinery; which is an open charcoal fire, urged by a pair of bellows, worked by water or a steam-engine; but the compression of air in the refinery ought to be less than that in the blast-furnace. After the metal is melted, it is let out of the fire by the workmen to discharge the scoriæ, and then returned and subjected to the blast as before. This operation is sometimes repeated two or three times before any appearance of malleability (or what the workmen call coming into nature) takes place; this they know by the metal's first assuming a granular appearance, the particles appearing to repel each other, or at least to have no signs of attraction. Soon afterwards they begin to adhere, the attraction increases very rapidly, and it is with great difficulty that the whole is prevented from running into one mass, which it is desirable to avoid, it being more convenient to stamp small pieces into thin cakes: this is done by putting the iron immediately under the forge-hammer, and beating it into pieces about an inch thick, which easily break from the rest during the operation. These small pieces are then collected and piled to the height of about ten inches upon circular stones, which are an inch thick and nine inches in diameter. They are afterwards put into a furnace, in which the fire is reverberated upon them until they are in a semi-fluid state. The workmen then take one out of the furnace, and draw it into a bar under the hammer; which being finished, they apply the bar to another of the piles of semi-fluid metal, to which it quickly cements, is taken again to the hammer, the bar first drawn serving as a handle, and drawn down as before. The imperfections in the bars are remedied by putting them

into another fire called the chafery, and again subjecting them to the action of the forge-hammer.

The above method is now most in use, and is called flourishing; but the iron made by this process is in no respect superior to that which I am going to describe. It is however not so expensive, and requires less labour.

The process for refining crude iron, which was most common previous to the introduction of flourishing, is as follows :

The pigs of cast iron are put into the refinery, as above, where they remain until they have acquired a consistence resembling paste, which happens in about two hours and a half. The iron is then taken out of the refinery, and laid upon a cast iron plate on the floor, and beaten by the workmen with hand-hammers, to knock off the cinders and other extraneous matters which adhere to the metal. It is afterwards taken to the forge hammer, and beaten first gently, till it has obtained a little tenacity; then the middle part of the piece is drawn into a bar about half an inch thick, three inches broad, and four feet long, leaving at each end a thick square lump of imperfect iron. In this form it is called ancony. It is now taken to the fire called the chafery, made of common coal; after which the two ends are drawn out into the form of the middle, and the operation is finished.

There is also a third method of rendering crude iron malleable, which, I think, promises to be abundantly more advantageous than either of the two former, as it will dispense both with the refinery and chafery; and nothing more will be necessary than a reverberating furnace, and a furnace to give the metal a malleable heat, about the middle of the operation. The large forge-hammer will also fall into dispute, but in its place must be substituted metal rollers of different capacities, which, like the forge-hammer, must be worked either by a water-wheel or a steam-engine.

It is by the operation of the forge-hammer or metal rollers,

rollers, that the iron is deprived of the remaining portion of impurity, and acquires a fibrous texture.

The iron made by the three foregoing processes is equally valuable, for by any of them the metal is rendered pure; but after those different operations are finished, it is the opinion of many of the most judicious workers in iron, that laying it in a damp place for some time improves its quality; and to this alone some attribute the superiority of foreign iron, more time elapsing between making and using the metal. To the latter part of this opinion I can by no means accede, as it is well known that the Swedish * ores contain much less heterogeneous matter than ours, and are generally much richer, as they usually yield about 70 *per quintal* of pure iron, whereas the average of ours is not more than 30 or 40 †: add to this, that the Swedish ores are smelted in wood fires, which gives the iron an additional superiority.

Iron instruments are case-hardened by heating them in a cinder or charcoal fire; but if the first be used, a quantity of old leather or bones must be burnt in the fire, to supply the metal with carbon. The fire must be urged by a pair of bellows to a sufficient degree of heat, and the whole operation is usually completed in an hour.

The process for case-hardening iron is in fact the same as for converting iron into steel, but not continued so long, as the surface only of the article is to be impregnated with carbon. Some attempts have been made to give cast iron, by case-hardening, the texture and ductility of steel; but they have not been very successful. Table and pen-knife blades have been made of it; and, when ground, have had a pretty good appearance; but the edges are not firm, and they soon lose their polish. Common table knives are frequently made of this metal. The cementation of iron converts it into

* Steel is commonly made of Swedish iron.

† The iron made from the ore found in the neighbourhood of Sheffield contains a great deal of phosphate of iron or siderite, which renders the metal brittle when cold.

steel, a substance intermediate between crude and malleable iron.

The furnaces for making steel are conical buildings; about the middle of which are two troughs of brick or fire-stone, which will hold about four tons of iron in the bar. At the bottom is a long grate for fire. The steel furnace, however, is not well adapted for description. I shall therefore avail myself of an accurate drawing, which was communicated to me by a gentleman conversant with the manufacture, and which is copied in the plate. A layer of charcoal-dust is put upon the bottom of the trough, and upon that a layer of bar iron, and so on alternately until the trough is full. It is then covered over with clay to keep out the air; which, if admitted, would effectually prevent the cementation. When the fire is put into the grate, the heat passes round by means of flues, made at intervals, by the sides of the trough. The fire is continued until the conversion is complete, which generally happens in about eight or ten days. There is a hole in the side, by which the workmen draw out a bar occasionally, to see how far the transmutation has proceeded. This they determine by the blisters upon the surface of the bars.

If they be not sufficiently changed, the hole is again closed carefully, to exclude the air; but if, on the contrary, the change be complete, the fire is extinguished, and the steel is left to cool for about eight days more, when the process for making blistered steel is finished. For small wares, the bars are drawn, under the tilt hammer, to about half an inch broad and $\frac{3}{16}$ of an inch thick. The change wrought on blistered steel by the tilt hammer, is nearly similar to that effected on iron from the refinery by the forge hammer. It is made of a more firm texture, and drawn into convenient forms for use. German steel is made by breaking the bars of blistered steel into small pieces, and then putting a number of them into a furnace; after which they are welded together and drawn to about eighteen inches long; then doubled and welded again, and finally drawn to the size and shape required

required for use. This is also called shear steel, and is superior in quality to the common tilted steel. Cast steel is also made from the common blistered steel. The bars are broken, and put into large crucibles with a flux. The crucible is then closed up with a lid of the same ware, and placed in a wind furnace. By the introduction of a greater or smaller quantity of flux, the metal is made harder or softer.

When the fusion is complete, the metal is cast into ingots, and then called ingot steel ; and that which afterwards undergoes the operation of tilting, is called tilted cast steel. The cast steel is the most valuable, as its texture is the most compact, and it admits of the finest polish. Sir T. Frankland has communicated a process, in the Transactions of the Royal Society *, for welding cast steel and malleable iron together; which, he says, is done by giving the iron a malleable, and the steel a white heat ; but, from the experiments which have been made at my request, it appears that it is only soft cast steel, little better than common steel, that will weld to iron : pure steel will not ; for, at the heat described by Sir T. the best cast steel either melts, or will not bear the hammer. It may here be observed, as was mentioned before, that steel is an intermediate state between crude and malleable iron, except in the circumstance of its reduction being complete ; for, according to the experiments of Reaumur and Bergman, steel contains more hydrogen gas than cast iron, but less than malleable iron ;—less plumbago than the first, but more than the latter ;—an equal portion of manganese with each ;—less siliceous earth than either ;—more iron than the first, but less than the second. Its fusibility is likewise intermediate between the bar iron and the crude. When steel has been gradually cooled from a state of ignition, it is malleable and soft, like bar iron ; but when ignited and plunged into cold water, it has the hardness and brittleness of crude iron. From the foregoing facts we are justified in drawing the same conclusions with Reaumur and

* Phil. Trans. 1795.

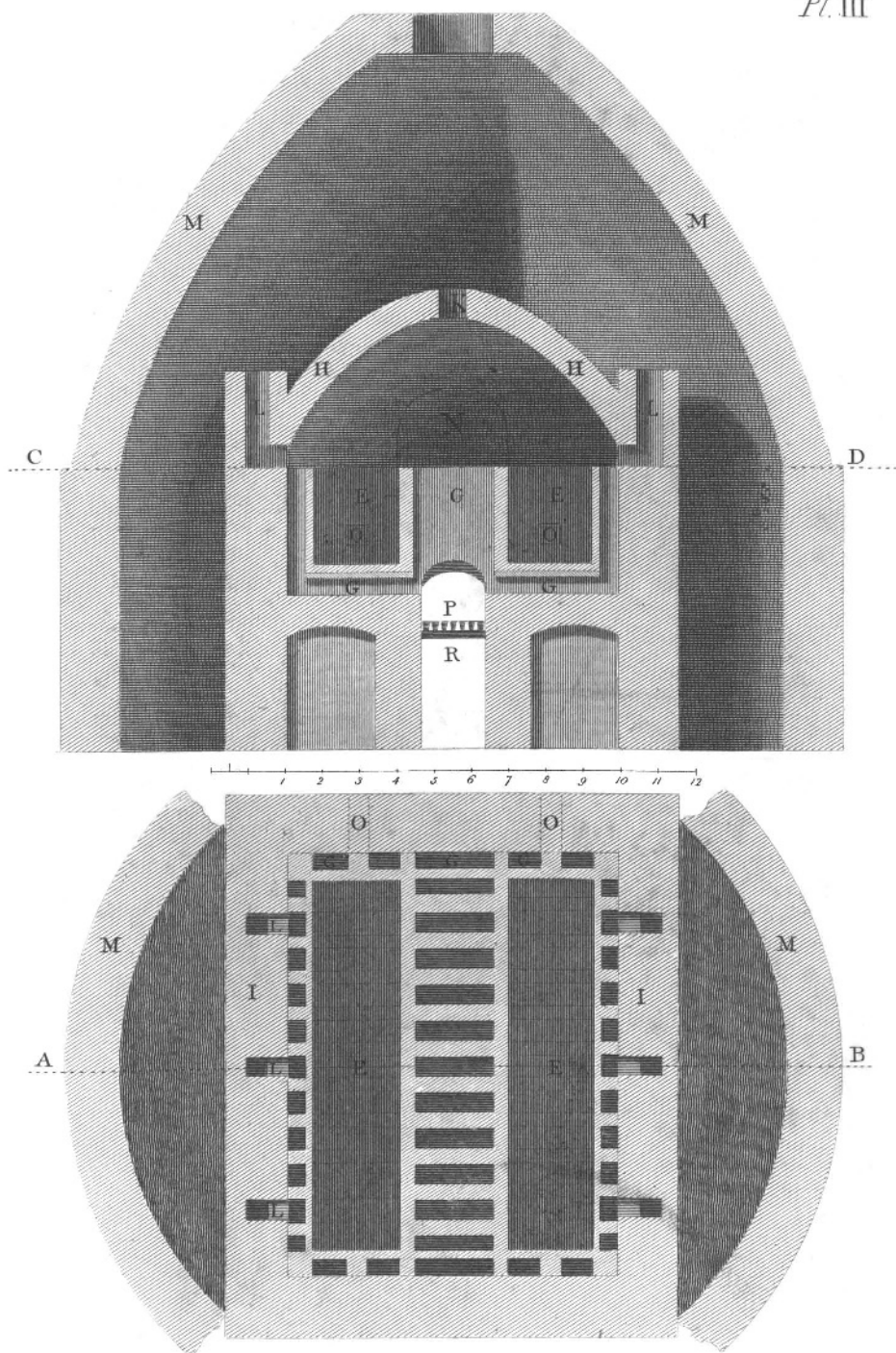
Bregman, but which have been more perfectly explained by Vandermonde, Berthollet, and Monge, that crude iron is a regulus, the reduction of which is not complete ; and which consequently will differ according as it approaches more or less to the metallic state. Forged iron, when previously well refined, is the purest metal ; for it is then the most malleable and the most ductile, its power of welding is the greatest, and it acquires the magnetic quality soonest. Steel consists of iron perfectly reduced and combined with charcoal ; and the various differences in blistered steel, made of the same metal, consist in the greater or less proportion of charcoal imbibed. Iron gains, by being converted into steel, about $\frac{1}{80}$ part of its weight. In order to harden steel, it must be put into a clean charcoal, coal or cinder fire, blown to a sufficient degree of heat by bellows. The workmen say, that neither iron nor steel will harden properly without a blast. When the fire is sufficiently hot, the instrument intended to be hardened must be put in, and a gradual blast from the bellows continued until the metal has acquired a regular red heat : it is then to be carefully quenched in cold water. If the steel be too hot when immersed in water, the grain will be of a rough and coarse texture ; but if of a proper degree of heat, it will be perfectly fine. Saws and some other articles are quenched in oil. Steel is tempered by again subjecting it to the action of the fire. The instrument to be tempered we will suppose to be a razor made of cast steel. First rub it upon a grit-stone until it is bright, then put the back upon the fire, and in a short time the edge will become of a light straw colour, whilst the back is blue. The straw colour denotes a proper temper, either for a razor, graver, or pen-knife. Spring knives require a dark brown ; scissars a light brown or straw colour ; forks or table-knives a blue. The blue colour marks the proper temper for swords, watch-springs, or any thing requiring elasticity. The springs for pen-knives are covered over with oil before they are exposed to the fire to temper.

Expla-

Explanation of the Plate.

Fig. 1 is a plan of the furnace, and fig. 2 is a section of it taken at the line A B. The plan is taken at the line C D. The same parts of the furnace are marked with the same letters in the plan and in the section. EE are the pots or troughs into which the bars of iron are laid to be converted. F is the fire-place; P the fire-bars; and R the ash-pit. GG, &c. are the flues. HH is an arch, the inside of the bottom of which corresponds with the line IIII, fig. 1, and the top of it is made in the form of a dome, having a hole in the centre at K, fig. 2. LL, &c. are six chimneys. MM is a dome similar to that of a glass-house, covering the whole. At N there is an arched opening, at which the materials are taken in and out of the furnace, and which is closely built up when the furnace is charged. At OO there are holes in each pot, through which the ends of three or four of the bars are made to project quite out of the furnace. These are for the purpose of being drawn out occasionally to see if the iron be sufficiently converted.

The pots are made of fire-tiles or fire-stone. The bottoms of them are made of two courses, each course being about the thickness of the single course which forms the outside of the pots. The insides of the pots are of one course, about double the thickness of the outside. The partitions of the flues are made of fire-brick, which are of different thicknesses, as represented in the plan, and by dotted lines in the bottom of the pots. These are for supporting the sides and bottoms of the pots, and for directing the flame equally round them. The great object is to communicate to the whole an equal degree of heat in every part. The fuel is put in at each end of the fire-place, and the fire is made the whole length of the pots, and kept up as equally as possible.



Engraved by W. Lowy.

Published June, 30th 1798, by W. Richardson, Cornhill.