MANUFACTURE

OF

STEEL

OVERMAN

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THE

MANUFACTURE OF STEEL:

CONTAINING

THE PRACTICE AND PRINCIPLES

OF

WORKING AND MAKING STEEL.

A HAND-BOOK

FOR

BLACKSMITHS AND WORKERS IN STEEL AND IRON, WAGON-MAKERS,
DIE-SINKERS, CUTLERS, AND MANUFACTURERS OF FILES
AND HARDWARE, OF STEEL AND IRON, AND
FOR MEN OF SCIENCE AND ART.

BY

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PREFACE.

The manufacture of steel is unnecessarily shrouded in mystery, which has been the cause of its being not more generally in application than it is at the present time. Steel is a superior metal for most purposes where metals are used, and its manufacture cannot be too much cultivated. A principal obstacle to its more general introduction is its high price; to effect a reduction in which, has been the aim of the author of this work.

We compare favourably in most branches of manufacture, and indeed eclipse other nations, except in the manufacture of steel. Yet we have materials in abundance, and of excellent quality for the purpose; and it needs but proper application to ensure success.

There is nothing particularly novel in this book, nor any new inventions recorded therein. I considered it sufficient for all practical purposes to record and explain what has been done, and confine the illustrations to such approved methods as are sure to succeed, assuming that improvements upon the known mode of manufacture are readily suggested to the minds of those who engage in it.

All I have endeavoured to accomplish has been, to develope the science of manufacturing steel, and explain the philosophy of the practical operations. All the facts recorded are with this view, as I am satisfied that, if our manufacturers understood the philosophy of the operation, there is no doubt they would soon accomplish much more than the best practical operator can perform without that knowledge.

A portion of the volume is devoted to the working of steel in the smith's forge, partly for the purpose of illustrating the principles involved, but chiefly to afford a safe guide to the blacksmith, who is always under the necessity of working more or less of this material.

In conclusion, I need only say that my aim has been to be of use, and to contribute my mite to the general prosperity of the country.

PHILADELPHIA, March 14, 1851.

MANUFACTURE OF STEEL.

CHAPTER I.

FORGING.

Degrees of heat.—In this chapter, we shall speak of the various degrees of heat required in the manufacture of steel. They are termed, by the blacksmith, the black heat; the red, or cherry-red heat; the bright red, or bright cherry-red; the white, and the welding heat. The first-named is the lowest heat; it is not visible in daylight, but shines in the dark with a brown colour. The second is, in daylight, a blood-red crimson. The third, a yellowish red, gives the scales, or hammer-slag on the iron, a black appearance. A white heat is that at which the scales and iron appear to be of the same colour; and the highest, or welding heat, is used for welding iron. The latter heat is very variable; for pure, fibrous iron sustains almost any degree of heat, so long as it is protected by a slag; while cold-short, or impure iron, bears but a comparatively low heat without being melted or burnt. That iron is—and for good reasons—considered the best, which bears the highest heat; the value or quality of iron varying according to the degree of heat it will sustain without injury.

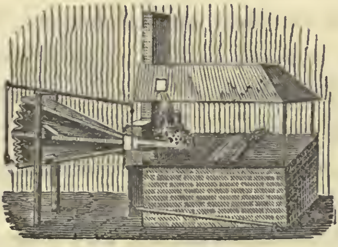
Steel does not bear the same degree of heat as iron without injury. The finest cast-steel will hardly sustain a bright red heat without falling to pieces; rendering it imprudent to heat it higher than a middling, or cherry-red heat. Blistered steel will resist a far higher degree of heat than cast-steel; and good shear-steel will endure a white heat without much injury. Natural and German steel can be heated to the welding heat of good iron.

Although very sensitive to heat, steel will bear much more forging than iron, if not previously injured by too great a heat. In forging steel, no heavy tools, or at least no heavy sledge, should be used; a good-sized hand-hammer, with a rapid succession of strokes, will be sufficient. This is, in fact, the best method of forging steel.

Overheating, either of iron or steel, is injurious, and should by all means be avoided; the lowest heat necessary for the work in hand, is the most advantageous. Steel or iron which has been overheated may sometimes be restored to utility, in a measure, by forging, or drawing. This, in the case of iron, often accomplishes the purpose intended; it will, however, improve burnt steel but little. If, therefore, iron requires care in heating, it is evident that steel requires much more.

Forge-fire. — The means employed for heating steel are the same as those used by the blacksmith for forging iron. The principles according to which a forge for heating steel is to be built, are those of fast work and a quick fire. In Fig. 1, a common blacksmith's forge is represented. The leather bellows are driven by hand, or, as here shown, by the foot and treadle. The bellows are double; that is, the whole is divided by a horizontal partition, which separates it into a working or under part, and a re-

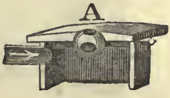
Fig. 1.



gulating or upper part. By lowering the under part, after having been raised, the valve in its bottom will be forced open by the pressure of the atmosphere, and the lower compartment will fill with air. On raising the bottom, the lower valve closes, and the air in the under part is compressed and forced through the valve in the partition, whence the weight of the top drives it through the *tuyere*, or nozzle. The pressure may be increased by putting weights upon the top. The bellows may be driven by machinery or power, where such can be procured, quite as well as by hand; but it is better, in such cases, to employ the fan-blast, as represented in Figs. 15 and 16. If the fan-blast can be obtained, it is preferable to the common bellows, as it is more uniform, and saves fuel; besides, its use improves the quality of the steel and iron.

The tuyere, or tue iron, is usually a simple block of cast-iron, as represented, of six or eight inches long and three inches square, with a tapered bore of one inch at the smaller, and three inches at the wider end. The narrow part, which is directed into the fire, can be made narrower by placing an iron ring, of more or less thickness, within the aperture. Tuyeres have been contrived of various forms; but probably none will be found superior to that above described. Hot-air tuyeres have been used, but are now generally abandoned. The water tuyere (Fig. 4) is, on account of its durability, very valuable; but it has the disadvantage of keeping the fire cold, which is injurious to both iron and steel, but particularly to the latter. Another tuyere, now coming very much into use, is the "rotary blacksmith's tuyere." This appears to be a very desirable addition to the forge, as it affords the facility of increasing the size of the aperture, and consequently the strength of the blast, at any moment, even while at work. Of this tuyere, (represented in Fig. 2,) E. Harris, of Springfield, Mass., is the patentee. The apertures are in a rotary, oblong ball, A, and are of various sizes; so that a larger or smaller one may be used by merely turning the ball. The whole is contained in a cast-iron box, closed on all sides. The great advantage of this tuyere consists in the fact that a small fire may be converted into a large one, or *vice versa*, by merely turning the hollow ball by means of an axle, which projects at one side of the box.

Fig. 2.

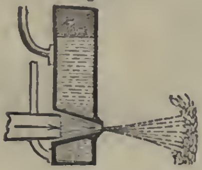


The form of the aperture of a tuyere is of considerable importance in the working of the fire. An almost cylindrical aperture, such as is represented in Fig. 3, throws the blast in a compact, close, and almost cylindrical current, into the fire; and furnishes the kind of blast required for welding, soldering, and small work, where the heat is to be concentrated upon a particular point. By the use of this tuyere, a great saving in fuel is effected. To make a cylindrical blast, the cylindrical part of the aperture should be at least as long as the diameter of the same is wide.

Fig. 3.

A tuyere of the form shown in Fig. 4 throws the blast over a large portion of the fire; it is useful for *heating*, but unsuitable for welding iron. The nozzle from the bellows, or the blast-pipe, is in all cases fitted closely into the tuyere, and surrounded by clay, or some other matter. A tuyere of the description shown in Fig. 3 makes a small, but intense heat; while one of the kind represented in Fig. 4 makes a larger fire, but lower heat.

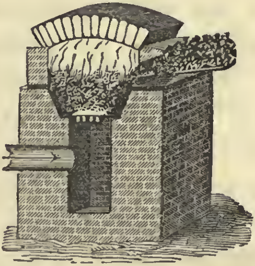
Fig. 4.



FORGE FOR HARD COAL.

In working hard, or anthracite coal, no horizontal tuyere, nor any of the description above referred to, can be used to advantage. A small grate is laid in the bottom of the fire-hearth, space being left below it for the reception of ashes and clinkers; the blast is then introduced under the grate. Such an arrangement may be made at any common forge-fire; but a more perfect forge is represented in Fig. 5. This is a brick hearth, about thirty inches high and three feet square, in the centre of which is a square pit, into which the blast-pipe is conducted. At a distance of six inches, or less, below the top of the brick-work, a cast-iron plate is inserted, in which is a square hole for the reception of the grate. A common stove-grate, four or five inches square, and fitting loosely into the cast-iron plate, is the kind generally used. A small opening, below the grate, leads into the ash-pit, in order to carry off the ashes and cinders. On the right and left of the fire, a wall of fire-brick is erected, six inches in

Fig. 5.



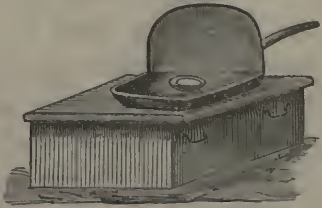
height, which support an arch, also of fire-brick. This arch is movable, and consists of an iron frame, into which the fire-brick are firmly wedged. In the wall on the right hand is an opening, into which an iron trough, in the form of a hopper, is inserted, for the purpose of heating the coal before it is put on the fire. Fresh hard coal, when thrown suddenly on a hot fire, is liable to crumble into small pieces; the heating prevents this, and keeps the fire open, and free from fine coal. The top of the hearth, or brick-pile, is covered by an iron plate. A fire of this kind is very advantageous for common smith-work; but a concentrated heat cannot be made in it.

The fire-hearth represented in Fig. 1 is commonly twelve or sixteen inches wide, and six inches deep. The tuyere dips a little into the fire. The hearth is built of brick or stone, thirty inches high, and is covered, in whole or in part, by an iron plate. At the left side, an iron trough for coal, and a similar one for water, are usually inserted. An iron coal-trough is advantageous in working bituminous, and also hard coal. The coal in the trough is soaked in water, which qualifies it for roasting or coking, and affords the additional advantage of more readily disengaging the sulphur of the coal. For charcoal, a water-trough only is necessary. Forge-fires for large work are generally very low — in some instances, but a few inches above the floor of the workshop. Over the fire is a light roof, or hood, of sheet-iron; or, over small fires, of boards. This hood gathers the smoke and gases of the fire, and conducts them to the chimney. The chimney should not be too small; for a great deal of cold air draws into it with the smoke, and diminishes, in proportion, its capacity for draught. The flues to the stack are usually in the highest part of the hood; but as this arrangement frequently leads to smoking, it is a good plan to have either an iron pipe or a brick channel leading from the upper flue down to the fire. The flue will then carry off all the gas and smoke from the fire, and also that from below the hood. This arrangement is indicated, in Fig. 1, by dotted lines.

Portable forges are of great utility in ship-building, on railroads, in laying gas and water-pipes, erecting steam-engines, and in many other branches of industry. Those most in use are called "truck-forges," and are generally mounted on two or four wheels. These portable forges are usually built entirely of cast-iron, and are supplied with a leather bellows, a vice, and a small anvil. They are used for sharpening chisels, bore-bits, picks, blasting tools, stone-drills, the heating of rivets, and similar work.

Such an apparatus, for small work, answers all the ordinary requisites of a smith's forge. In fig. 6, a portable forge is represented, such as is generally in use. The cast-iron fire-hearth is mounted on a box, or chest. The bellows are in the chest, and are protected by it. The tuyere is a concave disk, with six or seven apertures. The chest may be made of wood or iron, and be either mounted on wheels, or carried by hand. The advantage of the treadle in the hardening and tempering of tools may readily be perceived, as it leaves both hands free for operation; and such work is generally done single-handed.

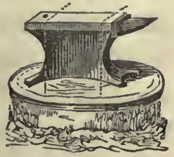
Fig. 6.



THE ANVIL.

Next in importance to the forge-fire, is the anvil of the smith. This is not only of interest as a tool of the trade; but it is also a particular object of our inquiry, because the steeling of the anvil is a matter of some importance. Anvils for heavy work are generally square blocks of iron, with steel faces. In many instances, however, it is merely a cast-iron block, with chilled face. The common smith's anvil is represented in fig. 7. It is made entirely of wrought-iron, and the upper part, or face, is covered with hardened steel. The making of an anvil is heavy work, as the whole of it is performed by hand. Anvils vary in weight from one hundred to over five hundred pounds. For their manufacture, two large fires are required. The principal portion, or core, of the anvil—a square block of iron—is heated to the welding-heat, at a certain point or corner, in one of the fires; and the piece of iron which is to form a projecting end is heated at another fire. When the core and corner have both reached the welding-heat, they are brought together upon an anvil, and joined by heavy swing-hammers. In this way the four corners of the base are welded to the body, in four heats. After this, the projection for the shank-hole, and lastly the beak, are welded to the core. The whole is then brought into proper shape, by paring and trimming, for the reception of

Fig. 7.



the face. The steel used for this purpose is, or ought to be, the best kind of shear-steel; blistered steel is, however, frequently substituted. The anvil and steel are heated in separate fires until they attain the proper temperature; the two sides which are to be welded are then sprinkled with calcined borax, and joined by quickly repeated blows of the hand-hammer. The steel generally used is half an inch thick; but if it be only a quarter of an inch in thickness, the difference is unimportant, if the steel be good. Steel of an inferior quality, if too thick, is apt to fly, or to crack in hardening.

The steeled anvil is next heated to redness, and brought under a fall of water, of at least the size of its face, and of three or four feet head. After hardening, it is smoothed upon a grindstone, and finally polished with emery. Small anvils, such as are used by silver-smiths, gold-beaters, &c., are polished with crocus, and have a mirror-like face.

The expensiveness of wrought-iron anvils has induced their manufacture, for particular purposes, of cast-iron. The common anvil, however, cannot be made of cast-iron; for the beak would not be strong enough. None but anvils with full square faces have been successfully made of cast-iron; these are either simply chilled by casting the faces in iron moulds, or the face is plated with cast-steel. Chilled cast-iron anvils are not much in use; they are too brittle, and the corners of the face will not stand. Cast-iron anvils with cast-steel faces, however, are a superior article, and in many respects preferable to wrought-iron; the face is harder and stronger, though the beaks will not last as long. For purposes where a good face is essential, as for saw-manufacturers, copper and tin-smiths, &c., the cast-iron anvil with cast-steel face will be found to answer every purpose.

The anvil is generally set upon the butt end of a large block of wood, oak being preferred. It is placed loosely upon it, being secured merely by a few spikes or wedges driven into the wood. Cutlers, file-makers, and those who manufacture small articles of steel, place their anvils upon blocks of stone, in order to make their foundation firm, prevent recoil, and give efficiency to light but quick blows of the hammer. In working soft metals, such as copper and its compounds, a layer of felt between the anvil and the block will be found of advantage.

TONGS

Form an important class of tools in the forge. There is so great a variety in their sizes and forms, that a description of the principal would occupy more space than we can devote to them. Still, there are but a few leading forms, the varieties of which arise either from fancy, or from the peculiar nature of certain work. The common or flat-bit tongs are represented in fig. 8, A; they are of various sizes, from one foot to five feet long, and from a half to ten pounds in weight. The fire-end is made more or less open, according to the thickness of the articles to be held with it. The bits, or lips, vary in width, and are often hollow, so as to fasten with more certainty to round iron and fagots. An oval ring, or coupler, is put upon the handles, or shank, to hold the tongs firmly to the work. Next in general utility to the flat-bit tongs, are the pincer-tongs, represented in

Fig. 8.

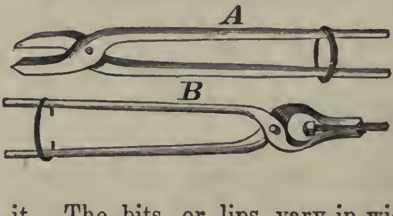
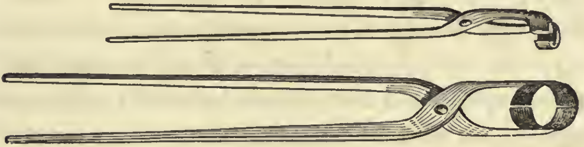


fig. 8, B. The swelling on the lips, or fire-end, is an advantageous arrangement, particularly where short pieces of round or square iron are to be forged. To this class of tongs belongs also that form in which the bits are round, as in the nail-tongs. Another useful variety is the crook-bit, shown in fig. 9; it serves particularly for small work in steel, because the rod may pass the nail. There are, besides these forms, basket-tongs, hoop-tongs, pliers, pincers, and numerous others.

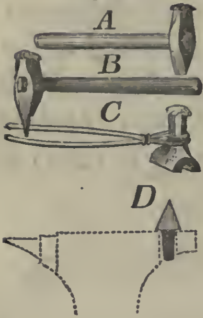
Fig. 9.



HAMMERS.

An item not less important in a smithy than tongs, are chisels, fig. 10, A; punches, B; swages, C; to which a bottom tool belongs, which is cut with its square tail, or shank, in the anvil. D, fig. 10, is a representation of anvil chisels. The above tools are either fitted to a handle which passes through the

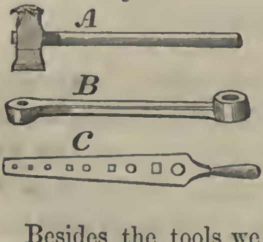
Fig. 10.



eye, as in A and B, fig. 10; or, as in heavy work, the handle consists of a twisted hazel-rod, wound around the tool, C. These tools are all faced with steel, and are, in fact, cheaper if made entirely of that metal. Natural steel is preferable for this purpose to any other. Tongs made of spring-steel are certainly more expensive at first, but are less costly in the end, than those of iron. Tools should never be heated red-hot, nor even allowed to become visibly hot; and if it should be necessary to bring tools in contact with heated iron, they should be repeatedly cooled, to prevent injury.

Tools which may be made of iron, but which are better of steel, or at least faced with steel, are the set-hammer, fig. 11, A; and the heading-tool. The latter may be a single tool, as in fig. 11, B; or a tool with many holes, C.

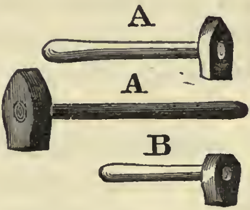
Fig. 11.



Besides the tools we have named, an almost endless variety is required in a blacksmith's shop, particularly where machine-work is forged. Forges for the manufacture of hardware, or where steel is principally worked, are generally limited to a certain kind of tools, which have been found by experience to be the best adapted to the purpose. Thus, in the axe-factory, hammer-tongs are requisite — an instrument which is rarely found in any other establishment.

Before leaving the consideration of forge-tools, we may make some additional remarks on the subject of hammers. The forms of this article are innumerable, each individual following the bent of his own fancy in constructing them. Undoubtedly, for certain occupations, a peculiar form is requisite; but there is no necessity for the endless variety of fanciful shapes the instrument is made to assume. The common hammer is shown in fig. 12; A, the eye or handle, being somewhat nearer to the pane, or narrow edge, than to the head. The pane is a little rounded, as is also the head; both are of steel, and hardened. The weight of the common hand-hammer of this form is from one to two pounds; of

Fig. 12.



the ordinary smith's sledge (fig. 12), from five to eight pounds. A heavy sledge weighs twelve or fifteen pounds, and a swing-sledge from twenty-five to thirty pounds. Some hammers have two flat heads, with the handle near one end; others have spherical, or egg-shaped heads; and others again have two flat panes set diagonally against the handle: these last are used in saw and hardware factories. Cutlers, and edged-tool makers generally, prefer the hammer with the handle at one end, or near the top, as in fig. 12, B.

FUEL.

The fuel used in forging steel is chiefly bituminous coal, which is preferable to any other. Where soft mineral coal cannot be obtained, charcoal is substituted. Anthracite is unfit for the purpose. A close fire is necessary, where the oxygen of the blast is consumed, or converted into carbonic acid, or carbonic oxide. Open fires, like those of charcoal and anthracite, are not well adapted for heating steel, because a great deal of air passes through them unburnt, which, in passing over the hot steel, deprives it, to some extent, of its carbon. Charcoal and anthracite fires require a roof or arch of fire-brick, as shown in fig. 5, in order to secure the proper comtion of the air. In a fire of bituminous coal, the roof may easily be formed of the coal itself. When damp, slack coal is thrown on the fire, in a layer of two or three inches thick, it will cake together, and, after the loose coal below it is burnt out, form a hollow fire like a bakeoven; the coke roof reflecting an immense heat upon the material below it. By no other means can a fire be made to possess so intense a heat as by the method we have described. In heating steel, particular attention should be paid to the purity of the coal, and to its freedom from sulphur. Fine coal, wet, is less injurious to steel than coarse dry coal of the same quality.

FLUX.

Sand or other material, sprinkled upon iron when near the welding heat, serves to form a flux, or fluid glass, with the iron. This flux surrounds the hot iron or steel, and protects it against the impurities of the fuel, removing, at the same time, the coating of dry scales from the heated metals, and greatly facilitating the operation of welding.

For welding steel to steel, and steel to iron, we have a variety of degrees of heat to deal with; and the flux which serves to protect good iron, is insufficient to protect cast-steel—just as, on the other hand, the flux which fits cast-steel for welding, would be useless on iron. Impure wrought-iron will form a slag of its own material; while good iron is protected, as we have intimated above, by sprinkling fine sand over it; but this method will not answer with steel, or where steel and iron are to be welded. The material used as a flux is to be applied shortly before the metal reaches the welding-heat, no matter how high or low that heat may be; it will melt on the surface of the hot iron or steel, and last long enough to be brought to the anvil for welding. The slag flows off, or is forced out, in bringing the two surfaces together, and pressing them into close contact. If steel or iron is heated in contact with air, it burns, and forms a film of infusible magnetic oxide, which is remarkably refractory on steel. If two surfaces are brought together which are partially covered with such infusible oxide, the metals cannot come fairly into contact, and of course the welding is imperfect; it cannot be sound. After the flux is strewn on the iron, it is necessary to turn the metal constantly in the fire, otherwise the flux will flow to the lowest parts, and finally be lost. A better method than that of sprinkling the sand on the hot iron is to roll the metal in the powdered flux, thus saving the latter, and keeping the fire more free from clinkers.

For welding iron, clean river-sand, or powdered sandstone, makes a good flux; but it does not answer for welding steel, or steel and iron. For this purpose, borax is generally used. The common borax in crystals, as it is sold in the drug-stores, is composed of nearly one-half water. On heating these crystals in an iron pot, they dissolve into a clear liquid; on further heating, the water is evaporated, and the residuum assumes the appearance of a spongy mass; and by the continued application of heat, this mass is converted into a clear glass. This glass is therefore calcined borax; it is entirely free from water, and not very liable to absorb it. It should be prepared and powdered in advance, and always be on hand for use. Borax, thus prepared, is sufficient in almost all cases; still, some workers in steel prefer a mixture of two parts borax with one of sal-ammonia, or three parts of the former with one of the latter article. This compound is preferable for welding iron and steel. Borax alone is rather too fluid for iron, where it is to be welded to steel; a more efficient flux for this purpose is well-dried and finely powdered white potters' clay — not common loam — which has been moistened with salt water, or brine.

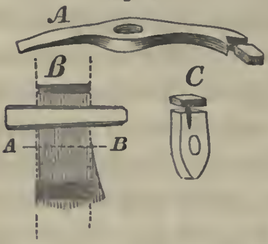
This clay makes a very fine flux and clean surface, to which steel readily adheres. There seems to be no apparent necessity for mixing sal-ammonia with borax in welding steel. It certainly makes a more fusible slag; but the chlorine of the ammonia, which combines with the slag—the ammonium being driven off—has a tendency to drive off the carbon from the steel, where it comes in contact with it, and convert such steel into iron. This conversion of the surface into iron does not facilitate welding, and leaves a vein of damask at the point of junction.

If pure borax is too refractory, as is the case with some of the best kinds of cast-steel, an excellent flux may be produced by melting potash, or pearlash, together with pure dried clay, three parts of the former and one of the latter, in an iron pot; adding to the fluid mass, gradually, an equal weight of calcined borax. This flux should be finely powdered, and used like the borax; it melts at a dark-brown heat, vitrifies the iron slag perfectly, and is not injurious to the steel. This metal rapidly deteriorates in quality if the atmosphere has access to it while hot; a suitable flux, therefore, which protects it, and at the same time purifies the surface, is all-important.

WELDING

Is that operation by which two pieces of iron or steel, or steel and iron, are heated, brought together, and intimately and permanently united under pressure, or, as is more generally the case, under repeated blows of the hammer; the junction being imperceptible. As the welding-heat of different materials greatly varies, it requires, in many instances, a skilful and dexterous workman to perform the operation successfully. The blacksmith is to watch the heat on the two pieces minutely, and, if they both have their proper heat and flux, he pulls them out of the fire, and quickly unites them. If the pieces are separate, or united but imperfectly, the smith incorporates both by his right hand and hammer; and if the work is heavy, a second hand, or helper, assists in striking with a more or less heavy hammer. To weld *natural* steel, or natural steel and iron, is not difficult; for it will bear almost as much heat as iron. Still, it should be kept off of the tuyere, and in the dark heat of the fire. If a small piece of steel is to be welded to a larger piece of iron, it is heated to a cherry-red, and the iron to a white heat, when they are temporarily united. The pieces, thus united, are next exposed to a white heat, and sprinkled with borax, (or, if German steel, with clay,) when the temperature is increased to a welding heat. If the steel is to be laid on a pick, crowbar, or any similar instrument, it is drawn into that form, or a triangular bit, in which it is to be welded to the iron, as shown in fig. 13, A. Here the steel forms the tongue to a split joint, and the welding is performed at the same heat, and in the same fire. In a similar manner, chisels, hammers, panes, hatchets, axes, &c., are steeled. If shear-steel is to be welded in this way to iron, more attention and experience is requisite than for the welding of natural steel; and the iron is drawn out to a greater length, so as to overlap and cover the steel more perfectly. Cast-steel requires still more caution, because it sustains still less heat; and the iron must either overlap the steel entirely, and afterwards be cut or ground off; or the steel and iron should be heated in separate fires, in which case the butt-joint or scarf is preferable.

Fig. 13.



In many instances, the edge which is to be steeled is made at first narrower than it is intended to be when finished, and is afterwards drawn out when the welding has been completed. This method is adopted in the making of an axe. In fig. 13, B, is a representation of this process. The first operation is to bend a flat bar of iron, nearly as broad as the iron around the eye, and a little thicker. The eye is temporarily formed around a mandril, and the iron welded in the line A B, leaving two tails for the edges. The eye is then nearly perfected, using the mandril from both sides, so as to make it narrower in the middle than at the ends, which aids in securing the axe more firmly to the handle, and prevents its flying off, or slipping backward and forward. The head or poll of the axe is then laid on with steel of an inferior kind, and a slip of shear or cast-steel is laid between the two tails which are to form the edge. All three are then welded together, and drawn out, so as to form the broad side of the axe, which is now trimmed or pared with chisels, and hammered at a low heat to smooth it; after which it is hardened, ground, and polished.

Where the iron and steel are very thin, as in steeling shovels, the steel is laid between two thicknesses, and the whole welded and drawn out together.

The butt-joint is used in welding a piece of steel to a flat surface, such as the face of an anvil, or the head of a hammer. In such cases, the piece of steel is forged to its proper shape before it is cut off from the bar, and fastened to the iron by notches, or by the drawn-up corners of the hammer-mould. It is then cut from the bar, and is ready to be welded. A more perfect method is to cut both surfaces coarsely with a rasp-like chisel, and fasten them together with a strap of wire; this makes a better weld, particularly where the steel will not bear strong heat. Still another method is to nail the steel to the iron, as shown in fig. 13, C. A pin or spike is made of the steel by drawing it out in a thick round form, with a head as large and thick as is necessary to form the face. A corresponding hole is made in the iron mould, and the steel firmly spiked to it. The pieces, in this way temporarily united, are welded in one heat.

Where large objects are to be faced with steel, such as anvils, beak-irons, and the like, two fires are required, that the iron and steel may be heated separately. If this cannot be conveniently done, the iron is first heated to a brisk white heat, and the cold steel is placed behind it, with a view of shielding it from the direct action of the fire. When the steel has in this way attained the welding-heat, the iron is ready, and the two may be united. When iron and steel are put at the same time into the fire, in a cold state, the steel will be burned and spoiled before the iron is ready. Steel is so easily injured by heat, that the greatest care is requisite in exposing it to the action of fire. One of the most difficult operations in steel, on account of its peculiar liability to injury, is the making of wire draw-plates. The process is most successfully performed by the French manufacturers. In this country and England, wire draw-plates are made by welding a plate of shear-steel to a plate of iron. In France and Germany, draw-plates are made by forming a crucible of the iron plate in drawing up the edges. In the cavity thus formed, hardened fragments of crude steel, white plate-iron, cast-steel, or the hardest natural steel, are driven in. The whole is then heated to the melting point of steel, and suffered to cool slowly. This melted steel forms a uniformly sound coating upon the iron. The face of the iron, before the steel is driven in, is well cleaned with a file, and of course a flux of borax applied.

Flat edged tools, which are covered with a thin plate of steel on one side, such as carpenters' chisels, plane-irons, adzes, and instruments which require tenacity as well as hardness, are made by taking steel and iron, of a greater thickness than they are intended to be when finished, and drawing them out together, after welding, to the requisite dimensions. In a cast-steel factory, such chisels may be made by polishing the iron on that side where it is to be laid with steel, and, subjecting it to a gentle heat, the steel and iron may be firmly united by casting the former upon the latter. Both metals are here also to be drawn out together.

The scarf-joint is but little used for welding iron and steel. If a rod of steel is to be welded to iron, as in stone-drills and similar tools, a cleft, or the split-joint, is preferred. The steel rod is then pointed or drawn out into a chisel, and the iron rod cleft to receive it.

BLISTERED STEEL.

In the blacksmith's shop, blistered steel is more used than any other description. It certainly costs less at first, and is to some extent improved by forging, or welding it to iron; but when its inferior quality is considered, and the labour necessarily expended on many tools of common use, such as pick-axes and mattocks, it is evident that the difference in the cost of the steel will effect but a slight reduction in the price of the tool; while its real value may be much enhanced by the use of a superior quality of steel.

The price of common blistered steel is about five cents per pound; and of good shear or cast-steel, sixteen cents. Now, as a pick scarcely requires a quarter of a pound of steel, it is evident that the difference in the expense is not quite three cents. Cast and shear-steel are both made of blistered steel; but the blistered steel commonly sold will not make good shear, and is certainly unfit for cast, steel. Good blistered steel — by which we mean steel made from good iron — cannot be sold at five cents per pound. Even if made of common charcoal bar-iron, it can scarcely be sold at that price. Swedish common bar-iron commands almost as high a price as our ordinary blistered steel. Good cast-steel is made of a superior quality of Swedish iron, which costs nine cents a pound. Forging and hammering by a low heat will improve steel remarkably; but this improvement is scarcely perceptible, so far as tenacity is concerned.

SHEAR-STEEL.

The most suitable steel for welding with iron, is the shear, or double shear-steel; it will stand the fire better than cast steel, and, if of good quality, is but slightly inferior to it in hardness. The variation in quality is, however, very considerable, and great care is necessary in its manufacture. Edge-tools of a superior description are manufactured from shear-steel; which, if good, possesses the requisites of durability and tenacity.

CAST-STEEL.

In the manufacture of articles composed of steel and iron, cast-steel is but seldom used; yet, there is a description of cast-steel made expressly for welding purposes, denominated welding cast-steel. It is frequently used in the manufacture of axes; and some of the best now in use are made of this steel. It does not, however, although superior to shear-steel, assume the delicate edge and hardness of the best cast-steel. Very hard and fine varieties of cast-steel are but seldom, and then with extreme difficulty, welded to iron. In the manufacture of tools requiring the use of cast-steel, such as cold-chisels, boring-bits, and tools for the turning and planing of metal, solid bars of cast-steel are employed; this being, in many respects, the most economical method.

WELDING STEEL.

There is no difficulty experienced in welding together two pieces of either the natural, German, blister, or shear-steel; but, with cast-steel, the case is somewhat different. The first varieties of steel may be either welded one to the other, or two pieces of the same kind be welded together, in the usual way; the only requisites being, a good forge, and the use of a flux of dry, pure clay. Steel of an inferior quality, may, by the use of a gentle heat, be drawn into small rods; then fagotted, welded, and made into bars of any required weight and size. Good bituminous coal is almost indispensable for this purpose: forge-hammers are not necessary, the common sledge-hammer being sufficiently effective.

Two pieces of cast-steel can be welded together, if proper care be used in the performance of the operation. When two bars are to be welded lengthwise, they should be so tapered as to form a scarf-joint, and the scales on the tapered faces of the bars removed by the use of a file; the faces of the bars may then be roughened like a rasp, and covered with a paste, of borax-glass, or calcined borax; after which the bars may be finally bound together by iron wire. In this condition the weld may be exposed to the action of a fire which is nearly at a welding heat, and contains a sufficient quantity of ignited coal, to render the use of a blast almost unnecessary. When the steel has been softened to such an extent, that an impression can be made on its surface by an iron poker, and the borax has become perfectly fluid, the bars may be cautiously removed from the fire to an anvil, previously heated, and there hammered gently with a small hand-hammer. The iron wires, being at each end of the scarf, may be removed after the first heat. If the first heat does not prove sufficient, it may be again applied, with the same precautions. Small rods of steel undergo a similar process in welding, with the exception, that but little pains is taken to roughen the connecting faces of the rods; they are merely filed, before being joined together, and the powdered borax applied to the joint when the rods are sufficiently hot to melt it.

The East Indians weld their wootz, by a process similar to that just described. They taper their rods, file and roughen them, then bind them together with wire, and apply the borax when they are hot.

A subject of some interest, and certainly of great importance, is the welding of steel to cast-iron. This may readily be effected if the steel be clean, a little heated, and protected by a flux of calcined borax. The cast-iron, of course, is to be very hot, if the objects are small; or the steel is to be heated to a high degree. The chief difficulty in this operation consists in the hardening of the steel so welded to the cast-iron; for, in chilling the hot steel and iron together, the latter will either become brittle, and crack, or cause the steel to fly. If strong and pure grey cast-iron be used, this is not so apt to occur. Perhaps the best iron for this purpose is the Pittsburgh dark-grey charcoal pig. The best kind of cast-steel is that which hardens by the lowest heat. If grey, strong cast-iron is not overheated, it loses, on cooling, but little of its strength, and is not very subject to hardening. Cast-iron is similar, in this respect, to steel. A good tempering of the cast-iron, after hardening, as steel is tempered, will restore, in a great measure, its lost tenacity.

TEST OF THE QUALITY OF STEEL.

The indications by which we distinguish good from bad steel are difficult to describe. Blistered steel, when the blisters are uniform in size, may generally be considered as of the best quality. Where there are but few blisters, and those of an irregular size, we should pronounce the steel of an inferior description. Natural steel, German steel, and shear and cast-steel, are always bad if single sparkling crystals show themselves in a fresh fracture. Generally speaking, any sparkling steel is bad; it is merely hard, impure iron. Good hardened steel, on fracture, presents a dead silvery appearance, and is of a uniformly white colour; in soft shear-steel, the fracture has a bluish tint; and in soft cast-steel, it is of a greyish hue. In German and natural steel, the fracture has a soft bright grey tint, often inclined to fracture in the centre of the bar.

THE HARDENING OF STEEL

Is an operation which requires the exercise of some judgment. The usual method is to heat the steel to a certain point, and then plunge it suddenly into cold water, tempering it afterwards. This method is undoubtedly the correct one; but the degree of heat to which steel is to be exposed before cooling, is a matter of vast importance. Some steel — the natural, for instance — will bear a strong white heat, and a plunge into cold water, before it assumes its greatest hardness. Other steel, particularly fine cast-steel, will not bear more than a brown or cherry-red heat; beyond that point it burns, and becomes brittle in hardening. It may safely be concluded, that steel which does not bear heat in forging, will not bear it in hardening. The heat at which steel falls to pieces, or melts, is too high for hardening, as steel hardened in such heat will fly or crack. The alterations manifest in steel after hardening, as compared with annealed steel, are the following: — Its volume is a little increased; the black scales which adhere to its surface fly off, and the surface appears clean, and of the colour and lustre of iron; the fracture is brighter, and crystals are visible. Good steel, as we have said before, is silver-white, and is so hard that it will scratch pane-glass, and even a file. The cohesion, relative and absolute, is increased if the heat has not been too high before cooling. These are the chief characteristics of good steel, when hardened.

The phenomenon of hardening by sudden cooling is not peculiar to steel; it belongs to all the alloys of metals, but is perhaps more characteristic of iron. There is not a bar of puddled iron in market which does not show all the phenomena of hardening and tempering as clearly as they are perceived in steel. Most of the charcoal wrought-iron, particularly the hot-blast, shows the same phenomena. There is no difference in kind, but in degree.

None but the best and purest charcoal wrought-iron is uninjured after cooling. It is a true test of the quality of pure fibrous iron, if a bar, heated to the welding-heat, and suddenly plunged in cold water, does not harden or become brittle. Most of the bar-iron, on subjection to such a process, becomes as brittle as glass, and presents the appearance of an accumulation of crystals, without apparent connection. Such iron may be made more fibrous and strong by being fagoted, welded, and drawn.

The assertion of some writers and artisans that any iron which hardens by cooling is to be considered steel, is unfounded in reality; for every variety of iron in the market has this property. It is the tenacity and fine grain, or rather absence of grain, which distinguishes hardened steel from hardened iron. Bar-iron, hardened, does not derive much strength from tempering; while steel, on the other hand, does so to a high degree.

While it is true that bar and wrought-iron are very sensitive to the process of cooling, it is so in a far higher degree with cast-iron. This description of metal, if suddenly chilled, becomes, in most cases, so highly excited as to crack, or fly. The hardest cast-iron, if pure, may be converted into malleable iron, almost equal to wrought, by judicious tempering. Such tempered cast-iron, however, cannot be welded; it becomes brittle again if heated, and cooled in the air. Slow tempering, however, will restore such re-hardened cast-iron to its malleable condition. The best and purest varieties of cast-iron become so excessively hard on refrigeration, that the finest cast-steel, in its hardest condition, can be scratched by it; but this hardened cast-iron is very brittle in its smallest particles, and flies to pieces when in large masses.

It is not possible to give any distinguishing mark between steel, wrought-iron, and cast-iron. A chemical test is even inadmissible. As a general feature, however, we may say, that cast-iron cannot be forged or welded, or at least very imperfectly; that wrought-iron feels softer under the hammer than steel, in forging; and that both impure wrought and cast-iron become very brittle in hardening. The united hardness and tenacity of steel are its characteristics. Good cast-steel, or any other variety, if not freshly annealed or hardened, and if free from fissures, will emit a sonorous silvery tone when a suspended bar is struck. Iron, particularly if good, emits a dull, leaden sound; while cast-iron gives out a tone like that of a cracked instrument.

Steel is superior to wrought or cast-iron in all the characteristic qualities of that metal; it is stronger, tougher, harder, and more elastic than either cast or wrought-iron: indeed, it is iron in its highest perfection.

TEST OF STEEL.

The surest test of the quality of steel is to draw a rod into a tapered point, harden it by a gentle heat, and break off pieces from the point. The degree of resistance to the hammer, which of course should be a very small one, is the test of the value of the steel. The best steel is that which, under this treatment, is found to be the toughest and strongest.

THE EXPANSION

Of hardened steel is frequently the cause of great inconvenience to the workman. Steel welded to iron invariably draws the edge around, if it should be on but one side of the edge. It is also liable to become brittle when laid upon iron. These difficulties may be obviated by making the steel side convex, or taking as little iron as possible. Files are never straight if made of natural steel, because that is in most cases but a mixture of iron and steel. In all cases where exactness after hardening is essential, the best kind of cast-steel is to be used; neither blistered nor shear-steel can be trusted. The better the steel, the greater is its expansion in hardening. This expansion is in some measure reduced in tempering the steel, but not to the size in which it was received from the tilt. The expansion is greater where the steel has been heated to a high degree before refrigeration, which may in some measure account for the brittleness of the metal when overheated. It is an important matter, in working steel, to keep it moving in the fire; otherwise, on that side where the blast acts, it will lose its carbon, and will not shrink so much in hardening as those portions which have been protected. A good method of protecting steel is to keep a film of calcined borax, or any other flux, around it while in the fire, or to cover it with a paste, as is done in hardening files and mint-stamps.

REFRIGERATING FLUIDS.

In hardening steel, the hardness is derived, not so much from the degree of heat to which the metal is subjected, as the degree of cold of the cooling fluid, and the manner in which the cooling is performed. Steel must be heated to a certain degree, to assume its greatest hardness; if heated below that point, it will not become hard, no matter what kind of cooling fluid we employ, or in what manner we refrigerate. If the proper degree of heat be obtained, it is in our power to make the steel more or less hard, by choosing more or less cold water, or other fluid, for chilling it. Many plans of refrigeration, and many refrigerating fluids, have been advised for hardening; but the most of them are of no practical utility. Pure well-water, taken fresh from the well, is the best element to cool in; and it should be renewed at each operation. Well-water is everywhere, and at almost all seasons, of the same temperature; and the smith should use this for hardening the steel, to ensure success. Hard well or spring-water is preferable to that of a softer quality, and should, if possible, be obtained. Steel treated in this way assumes its greatest degree of hardness, and may afterwards be tempered to any extent.

The manner of cooling is of some importance. If hot steel is held quietly in cold water, it will not become as hard as may be desirable, because the steam formed on the hot surface will prevent its rapid cooling. A motion backward and forward, or up and down in the water, greatly increases the hardness. For hardening large objects, a current or fall of water is indispensable.

The different degrees of heat required for hardening steel, accordingly as that steel is of good quality, or has been more or less worked, or is welded to iron, or is in large or small pieces, makes it exceedingly difficult, and indeed practically impossible, to employ hardening and tempering fluids at the same time. The surest method is to impart to the steel, in the operation of hardening, the greatest degree of hardness of which it is susceptible, and temper it afterwards.

HARDENING FILES.

This process is one which has been brought to a high degree of perfection, and the experience gained in it has been advantageously applied in other branches of manufacture. A file, after being cut, is dipped in a fluid of a cream-like consistence. This fluid is composed of a saturated solution of common salt in water, thickened by flour or meal of peas or beans. This paste melts into a fluid slag, and surrounds the file, protecting it against the influence of the fire and air. The file is uniformly heated in a common smith's forge, or in a small reverberatory furnace, and plunged vertically (except half-round and fancy files, which have a more or less horizontal inclination) into cold spring-water. Saw-files, and sculptors' files which are of iron, are hardened by using animal-charcoal powder with the flour paste, or using it and salt water only. Coal for this purpose is made by putting leather, tanners' scraps, or horns and hoofs, in a tight iron pot, and exposing the whole to a cherry-red heat. The spongy, black, and shining coal is then to be finely ground for use.

Rubbing a hot file, or any piece of hot steel, with a piece of charred leather, hoof, or horn, is not of much use; the glassy coating imparted by the salt is requisite to success. After files are hardened, they are brushed over with water and powdered charcoal, by which they become perfectly clear and metallic. After washing them repeatedly in fresh water to extract the salt, they are dipped in lime-water, dried by the fire, and finally, while still warm, placed in a mixture of olive oil and turpentine.

HARDENING OF NEEDLES, ETC.

These are hardened in quantities of twenty-five pounds, which are heated together, and plunged in cold water, but so that almost each needle is separated from its fellow. Cutlery, such as knife-blades and similar articles, are held by the tangs, either in pairs or singly, heated to a cherry-red in the common forge, and plunged into cold water up to the tang. Sunk steel dies and mint-stamps are heated to the proper degree, and hardened under a current of fresh cold water, which is made to issue from a basin with great rapidity.

THE MAKING OF STEEL DIES

For stamping coins or medals, for impressing bank-note plates, and copper cylinders for calico printing, is an art of much importance. It requires considerable skill, time and expense, to make such dies; all of which may be lost by imperfect material, or mismanagement in hardening or tempering. The first requisite to success is the selection of the steel. Cast-steel is in all cases the best; and it should be cast-steel which has been manufactured at a low heat, well-cemented, and made of the best materials. All steel, without an exception, contains veins of unequal hardness. Natural steel is the worst in this respect; blistered and shear are not much better; and even the best cast-steel is not exempt from this characteristic. These veins are generally the cause of cracks. The steel, before it is selected for these operations, is carefully washed over with dilute nitric acid, or aquafortis, which causes the damask veins or spots to appear at the surface. Steel for dies should be entirely free of such veins, and more particularly of cracks and ash-holes; for detecting which latter, a lens is required.

In cautiously and slowly tempering steel, the hard veins and spots may be concealed, especially if it has been tempered in charcoal; but they will appear again in heating and forging the steel. These veins are less apparent in hardened steel, and would, in fact, be of but little consequence to the engraver, were it not for their greater liability to crack and fly than uniformly grained steel. Very much depends upon the die-sinker; he can spoil the best steel by faulty work; that is, by overheating, or heating too often. Steel generally, and particularly this kind of steel, ought to be forged by the lowest possible heat—as little as it can be done with, and no more. After the steel has been selected and forged into rolls, or dies of the desired form, it is annealed. The common way of annealing is to imbed the steel in coarse charcoal powder, in a crucible or iron pot, heat it to a cherry-red heat, and let the fire slowly go out, while the steel is in it. Animal coal is frequently substituted for charcoal, or mixed with it; but one is as good as the other: the time which the steel remains in the fire is generally too short for the mixture to act upon it. This annealing is of the utmost consequence in the subsequent engraving operation, and also in hardening, and ought to be extended to the proper period; six, or even twelve hours, are not sufficient to anneal steel to perfection.

A low heat for twenty-four hours, or even twice that time, is not too much.

When dies are engraved, they are next hardened; but as the face of the engraving is to be faithfully preserved, it is protected by being covered over with a mixture of lamp-black and linseed oil. The whole is then imbedded in charcoal powder, in a pot, as in annealing, and finally plunged into cold spring-water, where it is rapidly moved about; or it may be cooled under a current of water.

As such dies will not safely bear twice hardening, the heat by which that particular kind of steel assumes its greatest hardness is to be ascertained by experiments upon a piece cut from the bar; the die is then subjected to that heat. Dies and heavy bodies of steel are naturally exposed to cracks in hardening, resulting from its expansion. The interior of a body of steel cannot shrink as much as the exterior, because it is protected by the surface steel. Nor can the hardening be of the same degree in the interior as at the surface.

For the reasons we have given, we may conclude that all round bodies of steel are more or less fractured at the periphery; and experience, under all circumstances, will prove the correctness of this conclusion.

To prevent breakage as the result of these cracks, steel is to be tempered as soon as possible after hardening, taking care that no impurities of any kind are in the water, which might fill the invisible crevices. Round bodies, such as dies and similar articles, may be tempered by fitting a wrought-iron ring around them, first heating the ring to redness, and inserting the die or other object in it; the ring, in cooling, will firmly compress the die, and secure it against subsequent flying. When the die thus inserted receives its proper temper, which is indicated by the colour, it is thrown into cold water, or water of 60° or 80°, and cooled. After tempering, the die is boiled in water for some hours, and suffered to cool slowly in the water. This process increases its tenacity considerably, and makes the hardening and strain more uniform throughout the body of the steel.

The liability of dies and other engraved steel instruments to break in hardening, or oftentimes hours after hardening, is rather a serious matter; for it may cause great loss to an artist. Every kind of steel is not liable to shrinkage, and consequently less liable to breaking. Steel containing much carbon is more liable to crack than where it is of a less carboniferous quality. The practice of imbedding steel in animal or wood-charcoal, is therefore not judicious when steel is saturated with carbon, as is the case with the not-welding cast-steel. Steel with hard and soft spots or veins is also more liable to breakage than uniform steel. The latter steel generally contains less carbon than other steel of the same hardness; slow tempering in hard charcoal will make it more uniform, and be a guard against cracks. Crude German steel does not shrink, and, if moderately heated and hardened, will not crack; but if heated to such an extent as to acquire its full degree of hardness, it becomes very brittle. The steel made of this crude material shrinks and cracks, though not so much as cast-steel; still, it never assumes that uniform hardness and tenacity which characterize the last-named variety.

A number of plans have been devised to avert the danger of breaking dies, matrices and die-rollers, in hardening them; but there is nothing better or more safe than slow and careful annealing, gentle heat in hardening, clear hard spring-water, and time and patience in tempering. The roller-dies for bank-note plates, and copper calico-printing rollers — an invention of the late Jacob Perkins, of Massachusetts — are hardened in this simple manner, the often very delicate engraving being protected by a chalk paste, which admirably answers the purpose. Other means of protection, such as plunging the heated steel in oil, hot or cold, or in melted lead, or a composition of metals, are uncertain in their results, and liable to failure; because, even if the oil, metals and heat are always the same, the steel is not—one kind of steel, or a particular kind of work, acquiring more hardness by the same treatment than another.

HARDENING BY COMPRESSION.

Among the various methods of hardening is that in spring-water, the most simple and most safe; but there are some small articles to which we cannot give their highest degree of hardness and tenacity in this way. These are engravers' tools, surgical instruments, &c., which may be hardened to a high degree by being hammered with a very small hammer, well polished, on a hard, polished anvil. Delicate instruments assume by this practice a high degree of hardness, and a finer edge and more elasticity than can be given to them by any other mode of hardening. The conical holes in the wire draw-plate are hardened in the same way.

ANNEALING.

Of steel is a necessary operation in all cases where filing or engraving is to be done. The steel, as it comes from the anvil, is too hard for the file and the chisel, and must be softened or annealed before it is ready for the engraver. The common method of annealing is to heat the steel to a gentle redness off the tuyere, and leave it in the ashes of the hearth until cold. The slower this operation is performed, the more uniform and soft will the steel be. Tempering in a pot, imbedded in sand or chalk, or any dry powder, is preferable to the open fire. Some authorities recommend pastes and powders of various compositions for annealing; but all such preparations are fallacious. Nothing more is requisite than heat, and the exclusion of atmospheric air or oxygen.

TEMPERING.

Steel properly hardened, is as hard as its peculiar quality permits it to become. In this state it is generally too brittle to be of any practical use, and it is necessary to temper it before it is exposed to any strain on its tenacity. Small tools are generally tempered after hardening, by covering the surface with a film of tallow or oil, then heating the steel until the oil diffuses a black smoke, or burns, or ceases to burn, and then plunging it in cold water. Picks, mattocks, blasting tools, and similar implements, are tempered by heating the heavy part from behind the edge or point, driving the heat towards the point. One side of the edge being ground white, shows the tempering colours; and when the proper colour is arrived at, the steel is cooled just at the point, but not the heavy iron behind it. Many mechanics harden and temper their common tools in the same heat, by merely dipping the hot point or edge in cold water; the heat of the heavier parts is then transmitted to the hardened edge, after it is removed from the cold water. When the proper colour is gained, which is ascertained by scratches of a dull file, the tool is cooled by dipping it in water. This latter process requires some experience, or the steel is apt to become either too hard or too soft, and require renewed hardening; which, of course, is injurious to the steel.

Instruments which are designed to be very perfect, are polished all over, and then heated to the tempering colour. Small articles, such as knife-blades, are set in large numbers with their tangs in a heavy steel or iron plate; that plate is then heated, and, when the proper colour is on the blades, each is singly plunged into cold water. Needles are tempered in masses, by burning oil upon them. Saw-blades, and large articles generally, are tempered in hot sand; the sand being heated to a certain point, which is tested by the thermometer. Sometimes this precaution is not taken; and the course then is to watch the articles until they obtain the requisite colour, when they are hardened in either air or water.

The colours to which steel can be tempered may be approximately stated thus: The hardest articles, which do not require much strength, should assume a faint yellow; surgical instruments, razors, and engravers' tools, a pale straw-colour; knives, cold chisels, and bore-bits, yellow; chisels, shears, hammers, anvils, and some varieties of saw-blades, dark yellow; axes, plane-irons, carpenters' tools generally, and most edged tools, brownish purple; table-knives, weapons, and scissors, purple; watch-springs, saws, and augers, light blue; common saws, heavy watch-springs, carriage-springs, and springs generally, blue; articles which require strength, but in which hardness is a secondary consideration, dark blue. Beyond dark blue the colour is black, and the steel is perfectly soft.

These colours are only approximating the subject; for the various kinds of steel will show a different degree of hardness in being tempered to the same colour. The naturally soft steel should have a shade or two less temper than that of the hardest description.

Many propositions have been made by scientific men to harden steel in fusible metal compositions, to avoid tempering; or to temper the steel in such metals; or to temper in a bath of lead heated to a certain degree, measured by the thermometer, &c. All these things are very well as scientific recommendations, and we shall speak of them in another place. They are of little practical value, however; for it is not the absolute degree of heat in hardening, or the difference in heat and cold, or the degree of the tempering bath, which decides the superiority or inferiority of hardened instruments of steel. The quality and description of the steel, the manner and mode of working it, the form and the fuel, are matters which influence the degree of heat in hardening, and also in tempering. In all cases of this kind, the simplest way of working is the best; the skill and dexterity of the worker in steel is a better guarantee of success than all the artificial compositions of cooling and tempering mediums. A good, skilful workman knows by the bearing of his steel under the hammer what degree of heat is most suitable for the kind of steel under his management, and will harden and temper according to his own convictions.

DAMASCUS STEEL.

To imitate or make Damascus steel in the forge by welding together steel and iron which has been bound in fagots, or any other form composed of thin rods, is an experiment generally attended with but ill success. The quality of steel, as we shall explain hereafter, depends so much upon the quality of the ore and iron from which it is made, as not to offer any hope of success in the attempt to make good steel in the forge. Damascus gun-barrels are made by welding strips of iron and steel together; but in hardening such compositions, the advantages are small in respect to tenacity, and the loss is considerable in hardness.

Gun-barrels, which are of course not hardened, are certainly superior when made in this way to those forged in any other manner; but this is not the case with edged instruments. A kind of Damascus steel for weapons is still imitated by some French cutlers;

but it is so expensive a process, and the blades are so slightly, if at all, superior to those of the ordinary manufacture, that this is more of a curiosity than anything else.

CASE-HARDENING

Is that process by which the surface of iron is converted into steel. This is a very useful art, and deserves to be more cultivated than it is at present. In this process, the surface of iron may be made harder than the hardest steel, and still retain all its malleability. Steel, when hardened, is brittle, and tools or keys of steel are liable to break. If case-hardened, however, they combine all the advantages of steel and iron.

The articles to be case-hardened are to be well polished; and if the iron is not quite sound, or shows ash-holes, it is hammered over and polished again—the finer the polish, the better. The articles are then imbedded in coarse charcoal powder, in a wrought-iron box, or pipe, which should be air-tight. A pipe is preferable to a box, because it can be turned, and the heat applied to it more uniformly. The whole is then exposed for twenty-four hours to a gentle cherry-red heat, in the flue of a steam-boiler, or in some other place where the heat is uniformly kept up. This makes a very hard surface, and, on large objects, one-eighth of an inch in depth may be thus obtained. If so much time cannot be given to the operation, and no deep hardening is required, the articles are imbedded in animal charcoal, or in a mixture of animal and wood coal; four or five hours' heat will make a good surface of steel. If a single article, a small key, or any other tool, is to be hardened, the coal must be finely pulverized, and mixed into a paste with a saturated solution of salt; with this paste the iron is well covered and dried. Over the paste is laid a coating of clay, moistened with salt water, which is also gently dried. The whole is now exposed to a gradually increased heat, up to a bright red, but not beyond it. This will give a fine surface to small objects. In all cases, the article is plunged in cold water when heated the proper time, and up to the proper degree.

A quick mode of case-hardening small objects is that by prussiate of potash. The iron is well polished, and heated to a dark-red heat; it is then rolled in a box containing powder of the yellow prussiate of potash, or sprinkled with it; the powder will melt on the surface, and the iron is then heated to a bright-red, and plunged in cold water. The powder of the prussiate is obtained by exposing the crystals to a gentle heat in an open iron box, or pot, for the purpose of evaporating the water contained in them; the remainder is a white powder. Some persons recommend the mixing of one-third camphor with the prussiate. As the camphor melts at a lower heat than the prussiate, and causes it also to melt, the whole operation can be performed at a lower heat, which is certainly an improvement. Calcined borax has also been proposed to be mixed with the prussiate; but we do not know with what effect it operates. To mix prussiate in clay, as recommended by some, is not of much use, as it requires too much labour to put the clay around the article; in these cases, the above recipe of coal, salt and clay, is all-sufficient.

In the operation of case-hardening there is not the slightest difficulty; any degree of hardness may be given, and almost any depth. The addition of salt, bone-ashes or bone-black, animal charcoal, hoof, horn or leather, to the charcoal powder, will regulate the degree of hardness; and the time of its exposure to the action of heat must be governed by the depth of steel required.

While the performance of the operation is simple, it is not so easy to select the proper kind of iron. If the iron is of coarse fibre, the hardened and polished surface will be unsound; if it is impure, it will be brittle after being hardened. The surest way is to select a very fine, close-grained iron, heat a piece of it a little beyond the heat by which it is to be hardened, and plunge it into cold water. If it retains its fibre and malleability, and is free from ash-holes, it may be selected as fit for the purpose.

Edges, however hard they may be, are never good if made of case-hardened iron; it is not in the nature of the materials, nor of the process, to produce such a result.

The most expeditious method of case-hardening is to imbed the article in borings of grey cast-iron, in a sheet-iron box, which may be open at the top, and covered with fine dry sand. These borings are a better conductor of heat than charcoal, and the article is therefore very soon covered with a coating of steel. A very little salt may be added to the borings; or a mixture of borings, charcoal, bone-coal, animal coal, scraps of horn, hides, leather, and other materials of the kind, may be used to advantage.

CHAPTER II.

VARIETIES OF STEEL.

Among the numerous kinds of steel, we recognize but few which are at present current. These are blistered steel, shear-steel, cast-steel, and German steel; the other varieties are simply modifications of these. The first is almost the only quality at present manufactured in the United States; a small portion of cast-steel is made, but so small as to be scarcely worth mentioning. About eight thousand tons of iron are annually converted into steel, in this country; of which about five hundred tons are melted into cast-steel, and the rest is principally used as blistered steel for springs and saws, and consumed by the manufacturers themselves. German steel also was formerly manufactured, particularly in New Jersey and some parts of Pennsylvania; but we are not aware that this is now the case. Little of the American steel is brought into market.

There are some kinds of steel which have but an historic interest for us — such as the Asiatic Damascus steel, Indian wootz, and similar varieties—which, as belonging to the manufacture, and therefore deserving of notice, we shall mention in subsequent pages. Such steel, however, is not found in our market as merchandise.

WOOTZ.

The most ancient steel historically known appears to be the Indian cast-steel, or "Wootz." The ancient Egyptians imported steel from Asia and Bombay, via Persia — the great high roads of the Indian trade. At the time of the invasion of India by Alexander the Great, when the Greeks made their weapons of bronze, wootz was manufactured in India. English travellers in modern times have been very inquisitive as to the mode of manufacturing wootz among the Asiatics, and also as to the material from which it is made. They have succeeded very well; but the operation is of such a nature, that we cannot derive much practical benefit from it.

Wootz is made of magnetic iron ore, such as we have in great abundance in the States of New York, New Jersey, and Pennsylvania. This ore, which is naturally mixed with quartz, and which appears to be very impure — for nearly half of it is quartz — is finely pulverized, and the impurities winnowed away. The fine ore is then moistened with water and formed into cakes, to prevent its running down through the hot coal in the smelting furnace. The furnace is of the form of one of our cupolas, about four feet high, and two feet wide at the bottom by one at the top. The furnace is charged with charcoal, and thoroughly heated. The breast or front opening, which is about a foot wide, is then closed and dried, and a certain quantity of ore is laid upon the hot coal, at the top of the furnace. The furnace is kept filled with fresh coal, and the blast applied. This is made by two goat-skins, which, being worked alternately by hand, make a uniform blast. The nozzles are of bamboo sticks, fastened to the neck of the skin; the tail, and a similar bamboo, forming the valve, which is shut and opened by hand. The tuyere is made of clay.

From three to four hours generally finishes the blast. The breast-wall is then broken open, and the iron from the interior of the furnace removed. The metal, then in the form of a cake, is beaten down with wooden mallets, and cut so as to show the interior, but not broken; in which form it is ready for the market. The ore yields about fifteen per cent.

of iron. It is from the iron thus obtained that the wootz, or Indian steel, is made. This iron is cut into small pieces, and charged with about ten per cent. of dry wood in crucibles. The crucibles are made of fire-clay, mixed with the charred husks of rice. One pound of iron is generally a charge for a crucible: it is covered with a couple of green leaves, and a layer of fire-clay rammed on closely. This crucible, when charged, is gently dried to expel all the water and hydrogen. From twenty to twenty-four of such crucibles are then built, in the form of an arch, into a small furnace, and covered by charcoal all around, when fire is applied, and this at last urged by blast. Two or two and a half hours of blast generally finish the work; the crucibles are then removed from the fire, and allowed to cool. When cold, the crucibles are broken up, and the steel is found in the bottom, in the form of a cake. Good cakes show a radial crystallization on the upper surface, and are free from holes and blisters. An imperfect fusion shows a rough surface, or honeycomb appearance, with lumps of malleable iron. In this form the steel is brought into market, and corrected, in re-melting the cakes, by fusing many together, and running them into ingots like common cast-steel. It is said that wootz which has been re-melted in this way is superior for the manufacture of cutlery to any cast-steel.

In this process of converting iron-ore, first into iron, and then into steel, we find all the elements of our present mode of doing the same business. The blast-furnace of the Asiatics is, on a small scale, our present blast-furnace; though, owing to their imperfect operation, the ore which yields them but fifteen per cent. of iron would, in our hands, yield at least sixty or seventy per cent. Instead of using, as they probably do, twenty tons of fuel, we use but two tons for the same quantity of iron. The Asiatic mode of converting iron into steel is the mode we follow at the present day; the only difference being that we divide the operation into cementing and melting, while they perform both in the same heat. It is not the place here to inquire what is the preferable mode of manufacturing steel; but we shall consider the subject thoroughly in some of our subsequent pages.

DAMASCUS STEEL—DAMASCUS BLADES.

These are terms applied to a kind of steel which shows a variegated, watery appearance, on the polished surface. It is originally from Asia, and the scimitars, or swords, chiefly from Damascus, where the art of manufacturing blades appears to be best understood. The excellent quality of this cutlery, particularly scimitars, has long been proverbial; no other steel has been found to equal it in tenacity and hardness. The process by which this steel is worked is not known; it is a secret faithfully preserved among those who are engaged in the manufacture. European artisans and scientific men have endeavoured to imitate the Asiatic damask, but with ill success; the form and appearance of the steel has been imitated, but its quality has never been equalled. French manufacturers, particularly, have wasted a great deal of time and means in such attempts. The probable cause of the superior quality of this steel is in the raw material, the ore; and it may in some measure be attributable to the skill of the artisan who manufactures the blades. It has been ascertained that the ingots of wootz of which the oriental Damascus is made come from Golconda; and it is therefore probable that it is manufactured in the same manner as the Indian wootz before described. This supposition is strengthened by the great value of the blades, and the peculiarities of the wootz.

Alexander Burnes, in his journey to Cabool, tells us that a scimitar was shown him in that city which was valued at five thousand rupees, and two others at fifteen hundred each. The first was forged in Ispahan, in the time of Abbas the Great. The peculiar value of this weapon consisted in its uniform damask; the "water" could be traced upon it, like a skein of silk, the entire length of the blade. Had this "water" been interrupted by a curve or cross, the blade would have been of little value. One of the cheaper weapons was also of Persian make; its water did not run straight, parallel with the blade, but was waved like a watered silk fabric. It had belonged to Nadir Shah. The third scimitar was a Khorassan blade; there were neither straight nor waved lines in it, but it was mottled with black spots. All three blades were strongly curved, but the first more so than the others. They tinkled like a bell, and were said to improve by age. How very interesting these accidental remarks of the traveller are in respect to the manufacture of steel generally, we shall show hereafter.

Imitations of Damascus steel are made daily, and have been made for the last fifty years; and there is no doubt some good has resulted from these experiments. The real value of the imitations, however, is quite limited, and we shall say but little about it. Damask steel has been made and is made of such perfectly developed veins, by welding together bundles of small slips of steel and iron, or steel of different kinds, that all imaginable figures which can be delineated by hand have been imitated. The smooth water, the waved water, a torsion of the damask, and the spotted damask, have all been produced; names, letters, inscriptions, leaves and flowers, have been represented; but all these pretty things do not make Damascus blades of equal quality with those of Asiatic manufacture. It appears the Persians do not use so much skill in forging, but depend upon the elements. Recent experiments have shown that when blades are cooled slowly, as by swinging them in the air, a damask is produced on steel highly charged with carbon. This, however, is nothing new; for the next best blades to those of oriental manufacture —the blades of Solingen—have been hardened or tempered in that way for centuries. It is certainly the most perfect mode of hardening steel, where tenacity also is desirable.

It is said that one hundred parts of soft iron, and two parts of lamp-black, melted together, make a fine steel, of great strength. It is also said that equal parts of cast and wrought-iron turnings make a fine steel, of damask quality, which is superior for arms and edged tools. There is no doubt that, by such means as the foregoing, an imitation of the appearance of damask steel may be effected; but it will depend entirely on the quality of the steel, the iron, the cast-iron, the lamp-black, or the crucibles, whether the resemblance will extend to the *quality* of the steel. Impure materials will, under all circumstances, make bad steel; and if we have good, pure iron, we can make good steel in a cheaper way than that proposed.

Some experiments have been made by melting together cast-iron, carbon and alumina, so that the molten iron contained aluminum. A portion of this aluminous iron was melted together with blistered steel, and the result was a steel very much like the wootz; it showed damask very distinctly. Other manufacturers than those who made the experiments, however, assert that aluminum is no necessary part of Damascus steel.

The damask veins may be made to appear on the surface of polished steel by washing it with a thin solution of sulphuric or muriatic acid, which will dissolve the softer parts of the steel first, or those parts which contain least carbon; after which the steel is washed in fresh water, and oiled, or waxed. We do not know whether or not the orientals bring out their damask in a similar way; but are inclined to believe that they do not. In some parts of Europe — Spain, Portugal, and portions of Italy—steel is buried under ground, often for months together, to improve its quality. May not this be the manner in which the orientals etch their blades?

CHAPTER III.

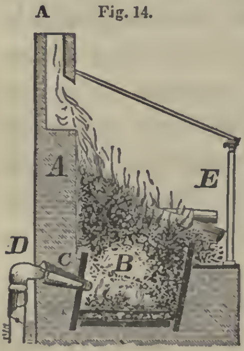
GERMAN STEEL—NATURAL STEEL.

In a few places, such as the east of Europe, and in Russia, steel is made in wolfs, or blue-ovens; a kind of high furnace, or blast-furnace, in which a certain quantity of ore is melted; the iron gathers in the hearth, and is then broken out and cut to pieces, by which the iron and steel are separated. It is thus a similar process to that followed by the Asiatics in making wootz, except that the apparatus is larger, and more iron is made at a time. This process is of little practical value, and is possessed of merely an historic interest.

German steel derives its name, not from being of a peculiar quality, though that is the case, but from the manner in which it is manufactured. It is always made of pig or plate iron, in forges where charcoal is used for fuel. Natural steel may be made of grey pig-iron, or of white plate-iron; the latter is the cheapest method, and produces the best steel. As we cannot make that peculiar white plate-iron, which the Germans call steel-iron, and which is made from the sparry carbonate of iron as its ore, because we have no such ore, we shall not say much about the manufacture of steel from such peculiar ore

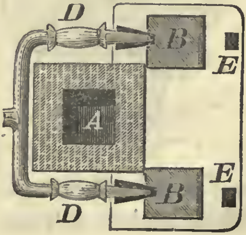
The fires or forges used for making this kind of steel are the common forge-fires of the smithy, generally known as the charcoal forge-fires. They resemble the bloomery fires, the only difference being in some minor points of dimension. In fig. 14, such a forge-fire is represented, in a section through its tuyere. The chief object here is a stack or chimney, A, which is from twenty to forty feet high, and of the width inside of two feet or more, so as to absorb all the heat and smoke from the fire. B is the hearth or forge-fire, the dimensions of which vary according to the quality of the crude iron, the quality of steel to be made, the kind of charcoal used, the description of blast, and the peculiarities of the workman. We shall allude to these dimensions hereafter. This

Fig. 14.



hearth forms a square, or often an oblong, basin. The four sides are cast-iron plates; in many cases, however, they are made of stones, or fire-brick. The bottom is formed of sandstone; and it depends very much upon the composition of this sandstone, of what quality the steel will be. C is the tuyere of copper, which may be replaced by iron; but a water tuyere, as is used in the iron forge, will not do here. D is the blast-pipe and nozzle; the latter is to be moveable, and is therefore connected with the main-pipe. Hot blast cannot be applied here as is done in making iron. The blast-pipe, which is five or six inches wide, and made of tin-plate or sheet-iron, is provided with a throttle valve, so as to regulate the blast at pleasure, according to the requirements of the work. E is merely a column of iron, wood, or stone, designed to support a sheet-iron hood, or roof, which is to protect the workman, and carry off the heat. The chimney, foundations, and walls, may be built of either brick or stone, as most convenient.

Fig. 15.



In fig. 15 the same forge-fire is represented from above. It is here assumed that two fires are at the same stack; if necessary, more than two may be erected to one chimney. This figure requires but little explanation. A is the chimney, B B the fire-hearths; in fact, the references used in fig. 14 denote the same objects here.

THE BLAST

Is made by strong blacksmiths' bellows, of which there should be two pair, driven by water-power, or any other force; or the bellows may be of wood, in the form of the common leather bellows, or either wooden or iron cylinders. A powerful blast is not so requisite here as in making wrought-iron. The best blast for the purpose would be a good fan, such as is now generally in use.

Fig. 16.

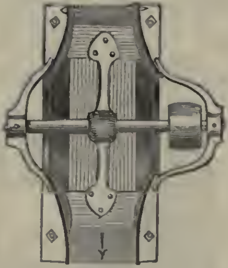


Fig. 17

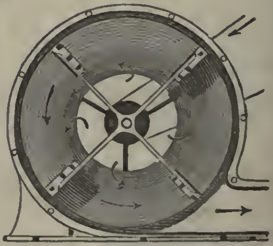


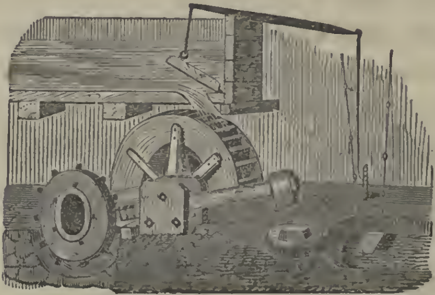
Fig. 16 represents a fan of the improved form, which makes at least twice the pressure of the old fan; the engraving shows a horizontal section through the centre shaft of the vanes. Fig. 17 is a vertical section of the fan. The shaft is made of steel, the four vanes of copper, and the cross arms which carry the vanes are of brass or wrought-iron. The four vanes are enclosed in, and fastened to, two rings of sheet-copper, which form with the vanes a round box, open at the periphery and at the centres. The air enters at the centre, and is expelled at the periphery. This round box, which is composed of the axle, the cross, the four vanes, and the two sides in one piece, moves in a cast-iron case of the form of the common fans. The blast is driven out at some convenient place in the circumference of the outer or stationary case; it makes no difference where, or at what place in the periphery, this is done. The inner case fits as closely as possible with its rims to the cast-iron case. The two cases are bored and turned on the lathe, where they meet in the centre.

FORGE-HAMMERS.

Besides forge-fires, there are to be hammers or tilts, for forging and refining natural steel. Up to the present period, we have had no better machinery than the old, well-known tail-hammer; that is, a tilt which is chiefly built of wood, and where the moving power is attached to the tail-end of the hammer-helve. For a series of years, improvements in the old form of construction have been proposed and executed, but with ill success; there is hardly anything known that can be considered an improvement on this primitive mode.

Fig. 18 shows a side view of a common tilt, as it is used in this country, England, Germany, &c. There are often slight deviations in the form, but in the main it is everywhere the same. This figure also explains itself; it shows the hammer, whose helve, of dry white oak or hickory, is from six to seven feet long, according to the weight of the hammer. The hammer-head should be of wrought-iron, and its face

Fig. 18.



plated with one inch thick of cast-steel, well hardened and polished.

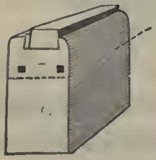
For the forging of scythes, files, and other small articles, the hammer-head is of about fifty pounds in weight; for drawing loups and refining, the weight is increased to two hundred pounds. The head is secured to the helve by wooden wedges, into which wedges of iron are driven. The eye of the helve is tapered on both sides, like an axe, which prevents its flying off. The wooden wedges are used for the protection of the helve and head. At the tail-end, the helve is provided with a strong iron ring, or hoop, firmly fastened to the helve. This hoop (sometimes there are more than one) holds a flat steel bar, which rests upon the helve, and upon which the cams or wipers strike. Below the helve, at the tail, is another iron or steel plate, held by the hoops, which strikes upon a piece of timber so laid as to spring back when pressed down by the hammer. This wooden spring is provided with a steel or iron plate, upon which the tail end of the hammer strikes.

The practice, in lifting the hammer, is not to raise it slowly, according to the speed of gravitation, but to strike the tail of the hammer with great speed, and fling the hammer so that the wiper merely touches the tail. The hammer, in being moved with great velocity, touches the spring-timber under the tail, and the head is forced down by this recoil upon the hot steel on the anvil. The lift of these hammers is in most cases but a few inches; of the heaviest, but eight or ten inches. The force is chiefly produced by recoil. The speed of these hammers is unusually great, the heaviest kind making from two hundred to two hundred and fifty strokes per minute. Small hammers, for forging thin or small articles, make from four to five hundred strokes in the same time.

THE FACES

Of the hammers are from five to nine inches long, and from one and a half to two and a half inches wide The anvil is in most instances made of wrought-iron; and a hardened steel plate, a little wider than the face of the hammer, is dovetailed and wedged in, as represented in fig. 19. The anvil may also be made of cast-iron, and the cast-steel welded to it when casting the block; an operation now very well performed in a factory in Trenton, N. J. The anvil is fastened by wedges in a heavy wooden log, which extends eight feet or more under

Fig. 19.



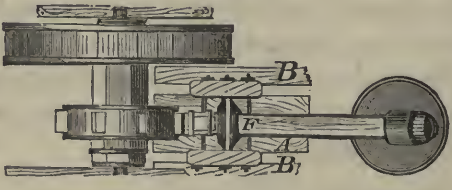
ground; so deep, that the earth is sufficiently solid to resist the further depression of the log. If the ground should be too loose, swampy or sandy, piles should be driven, and the anvil-log set upon them. The anvil-log is frequently three feet or more in diameter, taking the butt-end uppermost, and is provided on both ends with strong iron hoops, which prevent its splitting. The position of the anvil-log is a serious affair in erecting a hammer; if not well supported below, it will sink; and a rock foundation is equally bad, for on it the log is crushed. To protect the wood, and afford stability to the anvil, the vertical log is provided with a cast-iron crown, or chabote, which weighs from one to three tons. This chabote is fastened upon the log, and the anvil is set in a square hole on its upper face. This iron block receives the momentum of the strokes, and protects the anvil-log against sinking and crushing. Stone foundations for the anvil are expensive and insecure.

THE PILLARS,

Or housings in which the fulcrum of the hammer is fixed, are in most cases made of good hard wood. There are also cast-iron frames for this purpose; but, considering the first cost of such iron frames, and their short durability, there is nothing gained in using that metal for these standards. We will not, therefore, further allude to iron standards, but proceed to describe the construction of those which are made of wood.

The two pillars of the housing are made of good white oak, eleven or twelve feet long, ten or twelve inches thick, and about twenty-four inches wide. In case such heavy timber cannot be had, two sticks are bolted together by iron screw-bolts. About three or four feet of the two pillars are above ground. The part below ground is provided with cross timbers, as shown in fig. 20, which is a view of the hammer from above. The timbers, A, BB, are from five to six or more feet long, and are fastened to the pillars by screw-bolts, which are from eighteen inches to two feet apart. Below the surface of the earth, the cross-timbers are securely held down by heavy blocks of stone, and firmly walled into the ground,

Fig. 20.



so as to prevent all possible motion of the timbers. This stone-work can scarcely be too heavy. Above ground, the space between the pillars is open, to receive the fulcrum of the hammer. The fulcrum, F, which is fastened to the hammer-helve by wedges, is made of cast-iron with chilled points, or of wrought-iron with steel points. In the wooden pillars, two cast-iron plates of hard metal are inserted, with some half a dozen holes to receive the points of the fulcrum. These plates are from two to three inches thick, eight wide, and sixteen inches long. They are inserted in the wood so as to be moveable; for the adjustment of the hammer and anvil faces is regulated by the shifting of these plates. Wooden wedges are used for fastening these blocks, as iron screw-bolts do not resist the raking force of the hammer. In making these plates large, so as almost to cover the interior of the pillars, and providing them with a sufficient number of screws, we no doubt gain an advantage; they are certainly preferable to the small plates. There is no need of large holes for the screw-bolts, if the plates are provided with various centre-holes. The pillars above ground are held together by three iron bolts, which serve in the mean time to hold the pillars close in the points of the fulcrum.

Hammers are generally worked by water-power, partly because the speed necessarily varies, and such variation can be most conveniently regulated by a small water-wheel — partly also because the first outlay is generally less for a water-wheel than for a steam-engine — but chiefly, because the running cost is lower by the water-wheel.

The tap-ring is invariably a cast-iron hoop, of six or eight inches wide and three or four inches thick, in which there are from eight to twenty-four wipers. The cams, or wipers, are either of cast-iron, wrought-iron, or (if small) of steel, wedged by wood into the square holes of the ring. The ring is to be of at least four feet diameter; it may even be larger. Small tap-rings are very injurious to the hammer and its frame.

The shaft is sometimes of wood; but cast-iron is the best. It may be made hollow, to increase its strength with the same weight. The water-wheel, which is on the same shaft with the tap-ring, is either of wood or iron, but is to be strong in both cases, as the reaction upon the wheel from the hammer would soon shake it to pieces, if not well braced. The water-wheel is in most cases seven or eight feet in diameter, seldom more than nine or less than five feet. The size of the water-wheel depends partly on the head of water, but chiefly on its quantity. If there is an abundance of water, the pressure is principally relied on; where economy is to be exercised, the weight gives the power; but in most cases both weight and pressure are used. Where steel is drawn, or hardware manufactured by force-hammers, the speed of the driving-power must be absolutely in the command of the workman, as it is impossible to work thin steel to advantage with a uniform rate of speed. Drawing steel rods, and similar work, may be done, after some experience; but the forging of scythes, sickles, and such light articles, cannot be done, with a due regard to excellence, by a uniform speed of the hammer.

For the reasons we have given, a wheel for a steel-hammer should always have a head of five or six feet of water, which is led in such a manner upon a breast-wheel that it may be used either by weight or by pressure. A wheel of seven feet diameter should work by ten revolutions, and must be capable of making twenty-five. This will give, with a tapring of four feet diameter, and sixteen wipers, from one hundred and sixty to four hundred strokes, which difference is required for small hammers and light work. For large hammers, the extremes need not be so great. Each hammer should have its own independent speed; for it is the varying heat and thickness of the work which renders the variation in speed necessary; and this differs at each hammer.

These irregularities in speed cause, of course, a great loss of power, either of water or steam; and in consequence of this loss, a great many attempts have been made to connect a series of hammers with one stationary power, and regulate the speed by belts and drums. In the New England States, these attempts, in some instances, have been successful; but in Europe they have generally failed. The cause of failure is the inability to produce a sudden change of speed in the belt.

The arrangement we have described is by no means the most perfect; but it is approved and simple, and the best adapted to show the principles involved. The sudden jerks given by the hammer to the shaft and wheel render it necessary to make both as strong as if of one piece. Heavy masses are well applied; but it is ill policy to go beyond the necessary weight. The momentum of the wheel and shaft is then an obstacle to sudden changes of speed, which are always necessary.

If a wheel of seven feet makes twenty-five revolutions, and the cam-ring is four feet, it will impart a speed of five feet per second to the wipers. The speed of the hammer-head is to be greater than that of gravitation in the first second, or sixteen feet. If the fulcrum is set one distance from the tail, and three distances to the head, the next wiper will catch the tail before the head is on the anvil, if there are but six inches stroke. The fulcrum is to be at one for the tail and four to the head, which will give sufficient speed and recoil.

Force-hammers of a great variety of forms are in use, in this country as well as in Europe; but, of all the variety, there is none better adapted for forging steel and hardware than the tail-hammer we have described.

MAKING STEEL.

The operation of making natural steel is very similar to that of making charcoal blooms of pig iron. On melting grey pig or mottled iron in the charcoal forge, it frequently happens that a part of the iron is naturally ready for forging, while the other portion is at the bottom, in a liquid state. The portion of the charge which is soonest ready is a mixture of crude steel and fibrous iron, and may be said to be spring-steel.

In all our remarks on natural or German steel, we wish it to be understood that we speak but with reference to cold-blast charcoal pig-iron. Hot-blast, anthracite, or coke-iron, will never make an article that can with propriety be called steel, or answer the uses of that metal.

We have said that in melting grey pig or mottled iron, we frequently find a description of natural steel. This may be of a tolerably good quality, but it is never suitable for edged tools, or for any purpose where strength is required. If such lumps of steel are from good, strong pig-iron—that is, iron which makes a strong bar-iron, and is smelted of pure ore, such as magnetic and specular ore—they are of use for common blacksmiths' purposes, and particularly for springs and agricultural implements. They are drawn out into square or flat bars, of one inch square, or less, and then fagoted and welded, by which the steel is greatly improved. If it should be hard and show no fibres after the first refining, it may be piled once more, when it will become still more uniform.

The steel made in this way is, in reality, not steel; it is simply a kind of hard wrought-iron, which is brittle or tenacious according to the quality of the pig-iron from which it is obtained. This is the most simple form, the first step in the approach to the making of steel. A hard, brittle wrought-iron, made directly from the ore, no matter how good that ore may be, is never more than a brittle, impure, cold-short bar iron.

The foregoing process of making steel is the result of imperfect work in the forge, which never ought to happen. If the pig-iron is of such a quality as to be suitable for steel, it is better to rebuild the fire, and prepare it for the work of a few days, or a regular course of steel-making.

When steel is to be made of Nos. 1 or 2 pig-iron, the common charcoal forge in which bar-iron is refined, is altered so as to adapt it to the making of steel. The principle which governs in the manufacture of natural steel is, the regulation of the refining process in such a manner as to delay the completion of the refining, and still expose the iron to a high heat. The pig is melted opposite the tuyere, instead of above it, as in making iron; or, if very grey pig, it is melted above the blast. The principal requisite, however, is a hot fire, that the iron may be melted down as speedily as possible.

The fluid pig-iron is in this way brought below the tuyere, where it is worked gently by hot tools to prevent its boiling. If the iron boils below the tuyere, it will not make steel, but short iron; the Swedish bars are made in that way. The iron should never be allowed to boil; and if it chills on the bottom, and is very hot, it is brought opposite to or above the tuyere, but so far off as not to be touched by the blast. The principal difference in making iron and steel is, that iron is to be worked diligently, and is never worked too much; while in making steel, the work must be regulated by a practised judgment. Steel must be protected against the blast; still, the fire and iron are to be very hot, and uniformly hot. It is never broken up by a bar; but the cake of iron retain the form it receives on melting and flowing into the hearth; the blast being so directed as to heat it uniformly.

The practice of making steel is somewhat different if the pig-iron should be No. 2, or white iron. We have little or no ore which will make a good white iron for steel. The only useful ore which we know of is the Missouri iron mountain ore — a particularly good quality of per-oxyde — or the specular ore of Lake Superior, of which we know but little. There are other good ores in New Jersey, viz., the Andover specular ore; but this is not used at present, although in the last century steel was made from it. Such white iron — that is, No. 2 iron, or that made by a heavy burden in the blast-furnace — is melted entirely above the tuyere, in the strongest heat and a strong blast. By the time such iron arrives at the bottom of the hearth, it is almost converted into steel. A low heat and weak blast will make iron instead of steel. In this instance, the pig-iron is selected with particular reference to steel. Open or mottled No. 2 is reserved for wrought iron; and only the close, compact, crystallized, clean pigs are selected for steel. The pigs or plates for steel are not to be cast in chills, nor in damp sand; they are cast in heavy pigs, either in dry sand, or, what is better, in charcoal-dust. If, during the melting-in of this pig-iron, some of it is converted into fibrous iron, it does not matter; it may be reconverted into steel by giving a strong blast, and keeping such blast off the iron; it will then once more dissolve and unite with the crude iron, or steel.

FLUXES.

In all cases, the addition of fluxes to the melted iron, such as hammer-slag or scales, cinders of former heats, iron-ore, and similar matter, is to be avoided. Though such fluxes may be good in making iron, they are worse than useless in manufacturing steel. A fluid cinder should always be around the cake of iron, or steel; if the fire works too dry, it is better to throw some fine fire-clay, or fine white sand, on the cake, to make cinder. Anything else, no matter what its name may be, is injurious to the steel, and should be most carefully avoided.

PIG-IRON,

No. 3, or white iron with much carbon, of a quality suited to the manufacture of steel, is not made in this country. We have no ore for making such iron. White iron highly carbonized, as it is frequently made in blast-furnaces when the operations are disordered, is the least useful for steel. We know of but the black magnetic and specular ores, in this country, which are of any use for the manufacture of natural steel. These ores are to be smelted by charcoal and cold-blast, and the blast-furnace should not be overburdened, or the product will be cold-short wrought-iron, and not steel.

The method of working Nos. 1 and 2 pig-iron differs essentially from that pursued in working No. 3. The dimensions of the fire-hearth and arrangement of the blast are also very different; so that Nos. 1 and 2 cannot be worked in a hearth intended for No. 3. As, however, we have no No. 3 pig-iron which is suitable for the manufacture of steel, we shall confine our remarks to Nos. 1 and 2.

THE MAKING

Of steel requires great heat. For this reason, the fire is made more flat; the bottom is raised, and the tuyere not dipped so much as in making iron. Grey iron admits of more dip of the blast than mottled or white pig. When working the latter, the wind is to be kept off the bottom, or the steel cakes altogether too fast. Grey pig requires less blast than mottled; white iron should have a strong blast, and the highest possible degree of heat. Grey iron made from the same ore as the white, will make a better steel than the latter; but it requires more labour and attention than to work white iron.

Under all conditions, a high heat is desirable; but as grey pig works rather slowly, the heat is diminished; this often arises from the quality of the product. The heat and blast should be uniform, as well during the melting, as after the metal has caked in the bottom. The tuyere or nozzles are sometimes shifted; but this is an imperfect way of mending matters, and the necessity for it should be avoided. Two nozzles, and a broad half-round or oval tuyere, will be found of great advantage. A round tuyere, with one round nozzle, is not adapted to the purpose, and should not be admitted into a forge for the manufacture of steel.

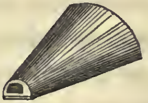
The more the iron is inclined to give up its carbon, which is always the case with the best and purest kinds of iron, the more should the work be hurried, and the higher should be the heat. The bottom of the fire is to be clean and dry, every drop of cinder tapped off, and every particle of scoria removed, before the iron is melted down. This is a standing rule, which must be rigorously adhered to in all cases; but more particularly with white and good pig than with grey or bad iron.

Pig-iron which is grey, or which works too slowly, may be improved by melting it down, and gradually introducing small quantities of good, pure scrap-iron, cut up finely, and freed from rust or scales. These scraps are to be of old iron, or old steel; fresh scraps are not of much use. The scraps dissolve in the fluid iron, and are put into it quite hot, almost at a welding heat, to prevent the cooling of the mass. Impure or rusty scrap-iron, and cold water, are to be avoided; they make the iron boil, and give it a fibrous quality. By avoiding what we have designated, the heat may be increased without any fear that the iron will boil; it will assume a pasty, thick appearance, and soon become strong enough to be shingled. Reducing the blast, diminishing the heat, or turning the blast upon the melted iron to accelerate the process, are bad practices; they either make cold-short and brittle or fibrous iron.

FORM AND DIMENSIONS OF HEARTH.

The form and dimensions of an approved hearth for converting grey pig-iron into steel are as follows (we refer to fig. 14): The square fire-hearth is thirty-four or thirty-six inches wide from the tuyere to the opposite side. The cast-iron plate at the tuyere is at an inclination of about 10° or 12° to the hearth, which is about one and a half inch on twelve inches high. The opposite plate is as much inclined out of the hearth, to permit a more easy access to the loup of steel. The timp-plate, or that plate nearest the workman, which is the front part of the drawing, is vertical, but is a few inches higher than the other three plates. Its opposite plate is thirty inches distant. In the timp-plate is a round hole of two or three inches diameter, for letting out cinder and scoria. A copper tuyere, very much tapered, as represented in fig. 21, is inclined about 12° into the fire, and projects about four inches into the

Fig. 21.



hearth; at its narrowest end, it is one and a half by half an inch wide. The distance of the tuyere from the timp-plate is twenty inches, and from the back plate ten inches. The cast-iron plates around the fire are from one and a half to two and a half inches thick; and as they are always covered with charcoal dust, or braize, there is not much danger of their burning out. The height of the tuyere above the bottom is five inches—never more than six. The height above the tuyere is variable; it may be four or five inches, for very hard coal: fine coal, or soft coal, make nine or ten inches necessary, at least at the timp and opposite the tuyere. The bottom, one of the most important portions of the fire, is a sandstone slab of two or three inches thick; it rests upon an iron base, but better upon sand. This bottom is better if in one piece, but may answer if of several pieces. On the quality of these stones the success of the operation mainly depends. Coarse sandstones, in which much iron, lime and magnesia are found, are not good; they will make iron, but no steel. Stones in which there is lime are also unsuitable. A fine-grained, slaty sandstone, in which there is much clay, and which does not effervesce with acids, is the best for the purpose. Fire-brick are not good; they do not last, and cause great waste in iron. If the stones for the bottom are of the right sort, the work progresses faster, and the steel is better. Good stones will last eight or twelve heats; bad ones often but one or two. If the stones are gently dried and heated before they are put in the hearth, they last much longer; two or four weeks should be allowed for drying. The advantage of having the bottom in one piece consists in the fact that it will last longer, and that the work-bars are not retarded in passing over the crevices, as in a hearth composed of several pieces. The crevices between the stones, where a single slab of sufficient size cannot be obtained, are filled with fire-clay, or fire-proof sand; clay is preferable to sand.

MANIPULATION.

A fire-hearth prepared in the above manner is covered on the inside with a layer of clean charcoal dust, which is well-rammed in, partly to protect the iron sides, and partly to have a non-conductor of heat between the melted or hot steel, and the cast-iron plates. The bottom stone is left bare, or only covered with some fine charcoal. The hearth is then filled with charcoal, and the fire gently urged by the blast. Upon the dust of the far-off plate, some pieces of steel from the last heat may be laid, partly to secure the dust, and partly to re-heat these pieces for subsequent drawing.

When the fire is well burnt through, and every part of it warm, the pig-iron, about one hundred and fifty pounds, is laid opposite the tuyere, upon the charcoal, so that it may be uniformly heated, without melting. At this stage of the operation, a little hammer-slag, or fine cinder, is strewn over the fire, so as to make a slight film or covering of cinder over the bottom, by which the bottom is protected, and the heat augmented.

During the heating of the pig-iron, the pieces of steel from the last heat are brought above the tuyere, and heated for shingling and drawing. In the meantime, a piece of pig-iron, weighing about twenty pounds, is placed in such a position opposite the tuyere, but out of the blast, as to cause it to melt rapidly. The fire is constantly fed with fresh coal. Water on the coal is to be avoided. At this stage of the process, all the blast is given which the bellows will make; for the fire cannot be too hot; the iron must become perfectly liquid before it reaches the bottom. If the iron is grey, and the trial by crowbar shows it to be thin, the blast may be slackened; but if it is not quite grey, and there should be any doubt as to its fusibility, the blast may be urged on.

The iron in this condition is stirred by means of a small crowbar; but as soon as it assumes a thick, paste-like appearance, a second piece of cast-iron, of say thirty pounds in weight, should be rapidly melted in; this will make the iron in the bottom quite fluid again, even if it has become chilled or stiff. The working in the bottom is now continued until the iron becomes pasty, or stiff; and if it works too slowly, some fine iron scraps, which have been previously heated above the tuyere, may be added. The cinder in the bottom, if there should be any, is to be let out each time the mass feels stiff, and is ready for another melting; there is no necessity for cinder in the bottom at this period of the process.

Care should be taken that the metal in the bottom does not harden, and assume the appearance of wrought-iron, as in such case the stones are injured, and it is absolutely impossible to make steel. Should this hardening take place, the fire must be strenuously urged by the blast, and another portion of pig-iron, of thirtv or fifty pounds in weight, melted down. Each addition of pig-iron is intended and expected to make the whole mass in the bottom liquid again; if it does not, there is something wrong.

Grey pig-iron, after having melted and reached the bottom, is inclined to boil upon the slightest stirring. If it contains much carbon, there is no harm done by a little boiling; but if the crude iron is mottled, it is advisable to avoid the ebullition of the fluid mass. Boiling may be prevented or stopped by an increase of heat and a suspension of work, and also by keeping the bottom free from slag, or cinder. Iron which is inclined to boil should be melted by daylight, and the bottom kept clear of cinder. During the melting, the blast must be kept off its surface. Some stirring in the hot mass is always necessary, in order to bring it to a uniform quality. The pig-iron is melted in successive portions, until the whole of it is down. The last or two last melts do not generally restore the whole of the steel cake in the bottom of the hearth to a fluid state; they are apt to cut into the centre, and spread over the surface of it. This should be avoided by all means; for the raw iron will penetrate between the bottom and the mass of steel, forming new cast-iron in the lower part, and wrought-iron of the upper part of the loup. The rule to be strictly adhered to in working the fire is, to melt the crude iron down in small portions, and let the next melt always cover the cake; otherwise the blast will convert into wrought-iron those portions which are uncovered. The last melts of pig-iron are performed as quickly as possible, under the influence of a strong blast; for if the steel cake is exposed too long to the blast, most of it will be converted into iron. It depends very much on the dexterity of the workman whether, of the same materials, he makes good steel, inferior steel, or iron. Low heat and slow work invariably make fibrous or hard cold-short iron; too great heat and too much blast generally make a very hard, but brittle steel. All water, cold or wet bars, damp coal, and slag to accelerate the process, are to be avoided if a good steel is desired.

The termination of the process is shown when the surface of the cake begins to give indications of conversion. The surface is then scraped off the cake with a crowbar, and held before the tuyere. If it resists a high welding heat, it is time to stop the blast.

Hot steel is always of a darker colour than fibrous iron in the same heat; and an experienced workman can perceive, by this difference, when the cake is ready. If the scale scraped off the cake melts before the hot fire at the tuyere, it is evident that the mass is not yet done; the scale must neither melt, burn, nor turn white, like iron. The cake, when well done, feels slippery to the touch of a bar; if it feels soft, it is not yet ready; and if it feels rough, it is time to stop the blast, as that roughness is an indication that the mass is about to be converted into iron. After stopping the blast, coal and coal-dust are removed to the hearth by a scraper, the steel cake cleared of cinder and dust, and then permitted to remain for a while to cool, before it is taken out. When red-hot yet, or so far cooled as to be strong enough to be lifted without breaking, a sharp flat crowbar is driven through the tap-hole in the timp-plate, and the cako is lifted off the bottom. Should it adhere to the bottom, or to the tuyere-plate, as will sometimes happen, the crowbar is driven in by the force of a sledge-hammer.

THE CAKE

Is almost of a round form; it is brought to tho tilt, and cut into six or eight segments, which are of course in the form of a triangle. It is natural to expect that the circumference of the cake will be more of the nature of iron than of steel, and the internal part inclines more to cast-iron than to either steel or fibrous iron. The triangles, whose base is formed by the periphery of the cake, and which are drawn out into squaro or flat bars while the melting of crude iron is going on, make bars whose ends are inclined, the one to wrought-iron, and the other to cast-iron, while the middle portion is the best part of the steel. These bars are generally forged into a square form, if uniformly hard steel is required; if spring-steel is the object, flat bars may be preferable. As soon as the bars are drawn, they are thrown into cold water, to be chilled and afterwards broken. This hardening of the crude steel is by some persons thought necessary for the purpose of observing the fracture, and classifying the steel accordingly. But it is not strictly necessary, and is certainly very injurious to the steel, particularly if it should be deficient in carbon. A far better method is, to cut or shear the bar of crude steel into three lengths, and call these Nos. 1, 2 and 3 steel. A good forgeman knows perfectly well, while he is drawing the bars, whether he has fibrous iron, cold-short iron, or steel. The hammer-man's judgment is sufficient, and the danger of hardening the bars may and should be avoided.

When the cake is permitted to get too hard, before another portion of pig-iron is melted in, by scraps or by blast, no steel can be expected; the cake will consist principally of iron. If the cake should be too soft or cold when a fresh melt comes down, cold-short iron or bad steel is the result. If the process is not conducted with the requisite experience, it may happen that the steel cake will be crude at the seam, and fibrous in the centre.

EXPENSE OF THE PROCESS.

The manufacture of steel in this way is not a very cheap operation. To make a ton, from good pig-iron, requires at least four hundred bushels of charcoal; if the iron should be of an inferior quality, a still greater consumption of coal is necessary. Soft charcoal is preferable to hard coal in this, as in every other part of the process of manufacturing steel. The loss on iron is seldom less than thirty or thirty-three per cent.; the very best pig-iron never, under any circumstances, yields more than seventy-five per cent. of crude steel.

One fire, supplied with two hands, may refine and draw, in the course of a week, from a ton to a ton and a half of steel. The yield of a fire may be augmented by using wrought-iron scraps freely; two, or even three tons per week, may be thus produced; but this requires good pig-iron, good scraps, and good workmen. Scraps of puddled iron, no matter of what kind, are useless; they should be of the very best and purest charcoal iron, large quantities of which may be had at the charcoal forges, or at the gun factories.

THE GERMAN METHOD

Of making steel is to use cast-iron derived from the smelting of carbonate of iron, or sparry ore. We cannot make steel in that way, and are compelled to use grey or mottled iron for the purpose. The process in use in Sweden and Northern Germany was formerly practised in this country. The art among the Germans is highly cultivated, and is practised in a variety of forms, with a view to vary the quality and quantity. The processes are also, of course, modified by the peculiarities of the material and the workmen. On account of their many advantages, the Germans are enabled to make cheaper natural steel than we can. It is not of much use to describe their manipulation, for we can neither imitate nor improve upon it; and to describe it merely for the purpose of showing the principle, would be a waste of time.

The heavy expenses attending the manufacture of steel have given rise to numerous attempts at improvement; but, thus far, very little has been accomplished. The necessity of using a stone bottom, and the further necessity of cooling the fire almost every day to put in a new bottom, are great obstacles in the way of cheapness; and frequent schemes have been devised to avoid them, but in vain. In those countries where iron or coal bottoms are used, as in Styria and Carinthia, the work is carried on only in the day-time. This certainly involves a great expense in coal and labour, but it seems to be necessary and unavoidable. If the manufacture of natural steel could be carried on without intermission, by day and night, as is the operation of making iron, it certainly would not cost any more to manufacture the former than the latter metal—perhaps even less. To the accomplishment of this end, however, there seem to be at present insuperable obstacles; and we must trust to time and further experience to simplify and cheapen the process.

MAKING STEEL IN A PUDDLING FURNACE.

Some years ago we noticed a process of making steel in a puddling furnace; it was made of very good steel-iron, puddled by dry wood. The product looked like steel; but it was no more steel than strong cold-short iron ever will be. In the following pages we shall endeavour to show that any use of the puddling furnace in making steel is wrong in the principle; *good* steel can never be made in that way, or by any such means.

REFINING OF STEEL.

Natural steel obtained in the way described is not marketable, or ready for use. Before it is exposed to sale, it is refined or tilted; the bars, either flat or square, as they come from the forge, are sent to the tilt. This consists of a force-hammer, or hammers, of from one hundred to two hundred and fifty pounds in weight, and a series of forge-fires. A forge-fire is similar to a common blacksmith's forge, and the refining is done by bituminous or mineral coal. It is also sometimes done by charcoal; but mineral coal is preferred.

The steel to be refined is broken into convenient lengths of twelve or fifteen inches, and piled or fagoted so as to make a fagot of fifty pounds. The bottom and top of the pile are to be in one length; the interior may be composed of short pieces. A fagot is taken in a pair of strong basket-tongs, and heated in a fire to redness; if it is found to be open, the red-hot pile is gently pressed together by a hand-hammer. When close, it is taken to another fire, where it receives the welding heat. Before and during its exposure to the welding heat, the pile is sprinkled over with burnt and finely-ground clay, partly to protect it against the blast, and partly to remove the dry film of scales, which are generally more refractory on steel than on iron. When sufficiently heated at one end, the fagot is brought to the hammer, and that end is welded. The tongs are now fastened to the welded end, which is generally drawn down to one and a quarter or one and a half inch square, and the other end of the fagot brought into the fire, welded, and drawn.

If the steel is to be refined again, the bar is cut into two or more pieces, and again welded and drawn out. This process is repeated, or may be repeated, four or five times in succession; and the steel is then called two, three, or five times refined steel.

THE REFINING FIRES

Are not different from a common smith's forge, except that they are larger and lower. Where charcoal is used, and of course where anthracite is to be used, the fire is provided with a long arch of fire-brick, of about two feet span, and one foot high above the tuyere. Bituminous coal, which contains so much bitumen as to cake, forms an arch over the fire by itself, and a brick arch is therefore unnecessary. No injury to the steel need be apprehended from the use of any of the varieties of fuel we have named; still, it is advisable to drive off the bitumen of the mineral coal before any steel is brought into contact with it. These fires are frequently provided with two or three tuyeres in a horizontal line, to make a continuous fire for long fagots.

The refiner, or tilter, can accomplish a great deal in making the steel uniform; but he cannot be expected to improve a defective quality of material. By making the bars small and flat, and assorting them well, a superior article may be made of good raw steel. A great deal depends upon piling the bars and forming the fagot. The labourer who performs that work should understand the nature of the steel by its fracture, and pile accordingly. Hard steel should be piled next to that which is soft, and inferior steel between that which is of a better quality. Notwithstanding all the attention we give it, it is impossible to make a bar uniform in itself, and uniform with another. We not unfrequently find spring-steel, shear-steel, mill-steel, mint-steel, and other varieties, in the same bar. The bars are therefore all thrown in cold water, hardened and broken, and, according to the fracture, assorted for market, where it is known under different brands, or signs, which are burned upon the kegs in which it is transported.

The steel made in this way is certainly far from being perfect; but still, for the manufacture of some articles, it is admirably suited, and is even superior, for such purposes, to the best cast-steel. For instance, swords are made of it which cannot be imitated by a prime article of cast or shear-steel. For almost all other manufactures, however, this natural steel is inferior to good shear or cast-steel, on account of its irregularity. This irregularity has given rise to many attempts at improvement, and the steel has been re-melted, in the hope of converting it into cast-steel; but it is of so refractory a nature, that the best crucible will not melt it, at least not to advantage. An attempt has also been made to use this natural steel, instead of iron, for cementing in the converting furnace; but the experiment was not fully successful — the steel was found to be inferior, for that purpose, to good soft iron.

CHAPTER IV.

AMERICAN AND ENGLISH METHOD OF MAKING STEEL.

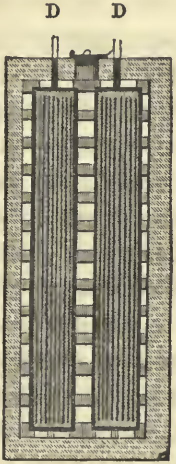
BLISTERED STEEL.

THE amount of steel annually manufactured in England is twenty-five thousand tons; one-half of the iron consumed in this manufacture is imported from Sweden and other parts of the continent of Europe, while the remainder is obtained at their own charcoal forges. The best steel is made of Swedish Danemora iron; but not more than twelve or fifteen hundred tons of this iron are imported, as its price ranges above one hundred and eighty dollars per ton. The remainder of the foreign iron used is common Swedish, Norwegian, Russian, German and Madras iron. It is generally in the form of hoops, or bars, of a half to five-eighths of an inch thick, and from two to four inches wide. We shall now proceed to describe the making of steel in Sheffield.

The first operation in this branch of the manufacture is to range the iron bars in the "converting furnace." In fig. 22 is a section vertically through the chimney, representing the cementation boxes, fire-grate, and the arch over the boxes. Fig. 23 is a horizontal section of the boxes and flues. In each, the same references show the same objects. The whole of the converting furnace has the appearance of a glasshouse. The grate, A, divides the interior of the furnace into two equal parts, each containing a cementation box. There are some furnaces which

Fig. 22.

Fig. 23.



have but one box; but they are not found so advantageous as double furnaces, owing to their greater consumption of fuel. The fire-grate, A, is over the whole length of the furnace; but its breadth varies according to the fuel used — inferior fuel requiring a greater breadth than that of a better quality. The object here is not so much the intensity as the bulk of the heat; and it is accomplished by the slow consumption of a heavy body of fuel. A grate of two feet in width for bituminous, and three for anthracite coal, may be considered as sufficient. The fire passes entirely around the cement-boxes, BB, and finally escapes at C, where a succession of draft-holes is left in the arch. These draft-holes are so arranged as to admit of being either partially or entirely shut. In case the heat is stronger on one end than at the other, it is to be regulated by pening or closing these flues. If the heat should be found too great towards the close of the operation, it may of course be promptly regulated in the same manner. The flues between the boxes are six by eighteen, and the others six by eight inches. The firing is done at both small ends of the furnace; for the grate is long, and cannot be conveniently reached from one side. At one of the smaller ends of the furnace are two small orifices, DD, for drawing out the proof-bars. On the same side with the proof or tap-holes, which serve also as charging-doors, is the door F, through which the workman enters in filling and emptying the cementation-boxes. In many furnaces there are, besides the above apertures, two doors for the charging and discharging of the steel; these are above the troughs.

The external dimensions of the conversion furnace are fifteen or sixteen feet in width, by twenty-four feet long; and the conical chimney is from forty to fifty feet high. The exterior or rough wall is built of common brick, or stone; the interior, of fire-brick. In case the walls cannot be supported by heavy masonry on the outside, the furnaces are to be kept together by wrought-iron binders. The first plan is, however, the best of the two. The fire-brick arch, or top of the interior of the furnace, is as flat as possible—just high enough to admit the steel-maker. Heavy walls and brick-work are of advantage in the converting operation.

THE TWO CHESTS,

Or cementing-boxes, are in most cases twenty feet long each, though sometimes they are but ten or fifteen feet in length. They are occasionally three feet high, and of the same width; but this is a disadvantage, as it requires an unusually attentive and skilful workman to manage such large chests. The lower and smaller they are, the easier is the work, and the more uniform is the quality of the steel. On the other hand, there is a proportionately greater consumption of coal in small than in large boxes.

The boxes are made of sandstone slabs, the joints of which rest upon, and are covered by, the tongues which form the flues. These slabs are of tabular sandstone, which naturally exfoliates or splits into thicknesses of one or two inches—the proper size for the slabs. These should be in one way as high as the intended height of the box, or as wide as the bottom; the other dimension is less definite, and may be arranged so as to have the joints properly covered. The tongues which form the flues are small, and take as little off the heating surface as possible, merely sufficient to secure the permanency of the box. A new box is heated very gently for the first few days, so as to produce the gradual expulsion of the water of the stones; the heat should not be higher than the boiling-heat of water. The slabs are cemented together by fire-clay; in fact, the joints of the whole interior are so united. Small boxes are often set without heads; but it is preferable to have flues on both ends, as well as along the sides.

CHARGING OF THE BOXES.

The boxes are charged with iron in the following manner: On the bottom of each trough is placed a layer of coarsely-powdered charcoal, about two inches thick. Upon this layer of charcoal, or cement, a layer of iron bars is laid edgwise, leaving a space of an inch at each side, and also between each bar a space equal to the thickness of the bar. The bars are to be within a couple of inches of the length of the box; but in case they are too short, small pieces may be used to make them of the requisite length. Above the first layer of iron, a layer of cement is spread, of half or three-quarters of an inch thick, and upon this another layer of bars with spaces, as in the first layer. The spaces between the bars are closely filled-in with charcoal powder, or cement; care must be exercised to have every crevice well filled with cement. The bars are never allowed to touch each other or the trough. The boxes are filled to within six inches of the top, and this space is filled with the refuse cement of former operations. Finally, a layer of fine sand or mud is spread over this last cement. The material used for this purpose in Sheffield consists of the sand worn off of grindstones, which is a mixture of particles of iron, fine quartz, and a little clay or lime. This is called in Sheffield "wheelswarf," and makes a very close and compact cement, almost impervious to water and air.

THE CEMENT

Consists of ground charcoal, made from hard wood, sometimes mixed with soot, or of soot only. This charcoal powder is intimately mixed with one-eighth or one-tenth of its weight of wood-ashes, and a little common salt. Good steel is made without ashes or salt, by using simply charcoal powder; but the general practice is to use a cement of the kind above described.

WORKING OF A CONVERTING FURNACE.

When the boxes are well packed and covered, fire is kindled, and very gradually raised. For the first twenty-four hours the heat is merely sufficient to expel the moisture in the boxes, cement, and cover. A rapid heat will injure the stone slabs or bricks of which the chests are made. The fire is gradually increased so as to raise the heat a little every day; and at the end of six days, if it is designed to make spring-steel, the bars are ready to be drawn. Shear-steel requires eight days, and cast-steel from ten to twelve days, to be sufficiently cemented, or carbonized. Two days, and often a much longer time, are required to cool the furnace; after which the workmen enter it and discharge the steel bars. Twelve tons of steel are generally made in a double furnace. In a single furnace, or where there is but one chest, only six or eight tons are made at a time. For the purpose of enabling the workmen to charge and discharge the chests, iron plates are laid over the fire-brick arches, on which they stand.

THE DEGREE OF CEMENTATION

Is a nice point to determine, and cannot be decided by the length of time for which the iron has been exposed to the cementing process; practice must be had, and is always depended upon in well-regulated establishments. Experience teaches us that steel for coach-springs requires a low degree of conversion; after this comes blistered steel for common use; then, shear-steel, steel for cutlery, and steel for files. Cast-steel requires a higher degree of conversion than any other. Some steel, such as cast-steel for bits, is frequently returned to the box two or three times, and is then called twice or thrice-converted steel. The point where to stop cementation is decided by the steel-maker in drawing and trying the trial-rod, or rods. The trial-rods are somewhat longer than the others; they reach at one end through the thickness of the slabs of which the chest is formed, and may be drawn out from between the other bars by a pair of tongs. The bar itself may be but three or four feet long. The trial-holes, marked in the cuts D D, are called "tap-holes;" they are but a few inches wide, and are closed around the trial-rods by clay or wheelswharf;

they are almost in the centre of the chest. An experienced steel-maker uses but one trial-rod, though some persons think it necessary to have two or three bars. If a trial-rod has been once drawn, it cannot be returned to the box; it is then broken, and from its appearance on fracture the quality of the steel is adjudged. The fire is cautiously kept so low, that the highly converted steel at the bottom of the box does not melt. If it happens that it does melt in the box, it is generally converted into cast-iron, and is useless for steel. The success of this converting operation depends, therefore, in a great measure, indeed almost entirely, on the knowledge and sagacity of the steel-maker. On his care and judgment the avoidance of losses mainly depends. Too much stress cannot be laid upon this point.

GAIN IN WEIGHT.

The bars in the process of conversion gain about a half to three-fourths of one per cent. in weight. They are entirely covered with blisters, whence the name "blistered steel" is derived. The steel is very irregular in the different layers of the box, as also in each bar. The fracture of a bar is very crystalline, its colour a bright silvery white, and the tables of the crystals are lustrous like brilliants. The central crystals are always smaller than those near the surface of the bar.

TILTING.

Blistered steel is hardly fit for any purpose, no matter how simple or coarse the article made of it may be. Its blisters and fissures make it unfit for the manufacture of tools, until it is re-heated and tilted. The first operation of this kind of refining makes common steel; the second makes shear-steel, and steel for cutlery. Very little steel is exposed to three welding-heats, as each heat adds to its tenacity and strength, but, if carried too far, will reduce some of it to iron.

THE REFINING FIRES

Are like a blacksmith's forge-hearth; the fire is, however, of a larger size. Soft or bituminous coal is used for welding the bundles of steel. This coal is converted into a coke, and forms an arch over the fire, giving the appearance of a bakeoven. Neither charcoal nor anthracite has this effect.

The forge-fires are supplied with air by cylinder blast-machines, or by common bellows, placed above the head, and worked by a crank which is driven either by water or steam-power. The air is conveyed in copper or tin pipes to the tuyere. The blistered steel is cut or broken into lengths of twelve or eighteen inches, and four of such lengths are piled along with a fifth of double length. This longer bar is placed in the middle, between the others, and forms the handle to the pile. This pile, or fagot, is held together by being bound with a small steel rod. It is carried to the fire, and a good welding heat given to it. While in the fire, it is occasionally sprinkled with sand, to form a protecting slag against the impurities of the coal. The fagot, when of a cherry-red heat, is carried from the fire to the tilt, and notched down — that is, hammered down in a rough manner — so as to unite the bars together, and close up every internal flaw and fissure.

In the first heat, the fagot is merely welded in a rough manner; after which the bindings are knocked off, and the pile is again re-heated. In the second heat, the welded bars are drawn out into a uniform rod of the thickness required, which is generally an inch or an inch and a half square, and twice or three times the length of the original fagot. The bars of the first heat, which are common steel, are piled again to form shear-steel. Five or six of such bars are piled and held together by a slender band of steel, as before, when they are once more exposed to a welding heat in the first forge-fire, and welded imperfectly, or soaked, to cement the bars together. This fagot, which also is supplied with a long bar for a handle, is then carried to a larger fire, in which it receives a thorough welding heat, and is then tilted at the heaviest hammer of the establishment, called the "shear-hammer." In this heat a bar of two or two and a half inches square is drawn out; and if steel of more than two heats, or "double shear," is required, it is cut in two, doubled, welded together, and drawn out again.

Blistered steel, repeatedly re-heated and drawn out, assumes a very uniform, fine grain; it loses all its flaws, fissures and blisters, and is by far more tenacious than any other steel; it is also less affected by heat than cast-steel. When rendered compact by welding and hammering, this steel is also susceptible of a very fine polish, in which respect it is but little inferior to cast-steel. It is therefore a superior steel for cutlery, and unites a fine, close texture, with great tenacity.

Shear-steel has not derived its name from being particularly useful in making scissors. In days gone by, there were a large kind of shears in use for dressing woollen cloth; they were formed like those in use for shearing sheep, being four or five feet long, with blades of twelve or eighteen inches in length, by eight to twelve inches wide. The refined blistered steel was particularly adapted to make the edge and spring of these shears.

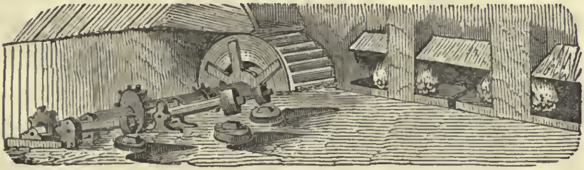
THE TILTS,

Or hammers, are very much the same as those described in the last chapter for tilting natural steel. The heaviest hammer—the shear-hammer—varies in weight from two hundred to four hundred pounds. In Sheffield, the principal and cheapest mart for the manufacture of steel, the hammers are driven by a small water-wheel, upon whose prolonged axis are one or more iron rings, which contain the wipers, or cams. In the periphery of the cam-ring, or wiper wheel, there are from twelve to eighteen cams, which strike the tail of the hammer in rapid succession, by which the hammer-head is raised and suffered to fall on the steel. To increase the effect of the hammer, a spring is placed under its tail, so as to work the hammer partly by weight, and partly by recoil.

Large tilts make two hundred, smaller ones four hundred, strokes per minute. The majority of the hammer frames in Sheffield are of wood, which in fact is the most suitable material for tilts. In some establishments, more than one hammer is on one wheel-shaft. The anvils are placed upon a stone foundation, and these stones upon a grate of wood-piles. The surface of the anvils is almost level with the floor of the tilt-house, and the workman sits down in a fosse, or pit, with his face towards the hammer. The smaller rods are tilted sitting, the larger ones standing. At the lighter tilts, the hammer-man or tilter sits on a swinging seat, suspended from the roof of the building. While thus suspended, he takes one end of the bundle of rods between his legs, and by the motion of his body gives to the rods a rapid backward and forward motion under the hammer. Each tilter has two boys in attendance, to furnish him with hot rods, and take away those which are sufficiently hammered. The rods are heated to a higher or lower degree, but, after the welding is done, not higher than a cherry-red. Small rods of good steel, which very soon cool after being brought upon tho anvil, speedily become red again under the rapid blows of the hammer.

Tilting is a very important process in the manufacture of steel; and none but very skilful and industrious men will make good hands at the tilt. In fig. 24, as will be seen at a glance, a tilt-house is

Fig. 24.



represented. The faces of the hammer-head, as well as the anvil, are of the best cast-steel, well hardened and polished. Each hammer has a blast-pipe conducted to it, which ends in a nozzle, from which a stream of air is constantly blowing upon the anvil, to keep it free from dust and scales. This cleanliness is necessary to impart a good polish to the steel bars.

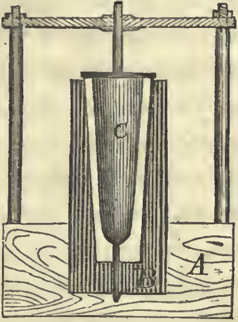
CAST-STEEL

Is made by melting blistered steel in crucibles. The converted steel is broken into convenient pieces for charging it in the narrowest space possible. A portion of carbon is always dissipated in this process; therefore, the most highly carbonized bars of the blistered steel are selected to be transformed into cast-steel. The highly converted steel is known by its larger crystals and brighter lustre, in a newly-made fracture, than in the other bars. These broken pieces of blistered steel are charged in crucibles made of the best Stourbridge fire-clay.

THE MAKING OF CRUCIBLES,

Or melting-pots, is an important branch in this department of the art. They are from eighteen to twenty inches high, and of a sugar-loaf shape. The clay is, as we have said, of the best Stourbridge, worked to a high degree of uniformity and smoothness. To give it this uniformity, the clay is first moistened with water, and well puddled; it is then spread on a smooth floor underneath the casting-house, and worked by bare feet; this requires the uninterrupted work of two men for six hours. In some establishments, the clay is mixed with finely-pulverized coke, or finely-ground cement of old crucibles, or a portion of black lead; and sometimes it is mixed with the whole of these ingredients. Up to the present time, every attempt has failed to substitute machinery for manual labour in mixing the clay; it would seem that there is an efficacy in the human hand, or, in this case, in the foot, which no machinery has been found or can be expected to possess.

Fig. 25.



The crucibles are moulded in a cast-iron mould, as in fig. 25. A is a solid block of wood, in which the outer part of the iron mould, B, closely fits, but still so loose as to be easily lifted out of its place. This iron mould is well bored out on the turning lathe, and polished. The core of the mould, C, is also of cast-iron, well turned. It has two guide-pins, one above and one below. In the space between the core of the mould and the case, a lump of clay is laid on the bottom, just sufficient to fill the space and make a crucible. When the proper size of a lump has been found by experiment, it is weighed, and its weight made the standard for future operations, thus securing uniformity in the crucibles. A dried and baked Sheffield crucible weighs from twenty-five to thirty pounds, and will contain forty pounds of broken steel.

Crucible-making is the most tedious and expensive branch in the manufacture of cast-steel. The best

Sheffield crucibles do not last longer than three heats, or one day.

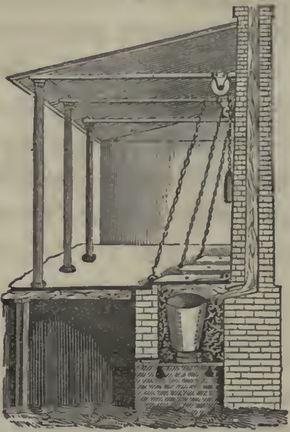
The core, C, is pressed down upon the lumps of clay in the mould, by which they are forced upwards and fill the upper part of the mould. In this way, the lower portion of the crucible receives the necessary degree of compactness. The hole in the bottom of the crucible, caused by the guide-pin, is stopped up with clay before the vessel is taken out of the mould. When the core is removed, and the bottom hole stopped, the mould, B, is lifted out of the wooden block, and reversed upon a board. If the clay is of the right texture and well worked, the withdrawal of the core and the crucible is easy enough; but if the clay is a little too damp, it will adhere to the iron, and is with difficulty loosened. If the clay should be too dry, on the other hand, the crucibles are very apt to crack, or to become porous. With the proper degree of moisture, the crucibles are easily removed from the mould. The adhesion of imperfectly prepared clay to the mould may be prevented, to some extent, by rubbing the mould with coke-dust, or laying sheets of paper or muslin in it; but these expedients are troublesome, and the necessity for them should be avoided.

The crucibles, after being moulded, are placed in drying-stoves, where they are slowly dried by a liberal access of atmospheric air, gently heated. They are here dried hard, but not baked. The day before they are intended to be used, the crucibles are set upon an annealing grate, made of fire-clay, where they are covered with the refuse coke from the air-furnaces; they are here baked, if it can be called baking, for one day.

THE CAST-HOUSE

Has a great resemblance to a brass foundry. There are a dozen or more air-furnaces in one or two ranges, their tops being on a level with the undermined floor of the building, as shown in fig. 26. It is very convenient to have the top of the furnaces level with the floor, as it gives the workman a better chance of lifting the crucible with the melted metal. The ash-pits are below the floor, in a subterranean vaulted passage, from which the grates derive a supply of cool air, which favours the rapid combustion of the fuel. The crucibles are made and dried in these vaults. The pit of the air-furnace is a square cavity; if intended but for one crucible, it is twelve inches square—if for two, it is twelve by eighteen inches. The crucibles being six inches wide at the

Fig. 26.



top, there is a space of three inches all around. The depth of the fire-pit, from the top of the grate-bars to the floor, is twenty-four or twenty-six inches. The flue leading from the furnace to the stack is three and a half by six inches in a single, and three and a half by nine inches in a double furnace. The crucible stands on a sole-piece of two or three inches high; this may be either a piece of fire-brick, a lump of fire-clay, or the bottom of an old crucible. The in-walls of the furnaces are made originally of fire-brick, but are repaired with mud, taken from the roads where a certain kind of quartz, called "ganister," is used in macadamizing. The grate-bars are square bars of wrought-iron, seven-eighths or one inch in thickness, and are loose, so as to admit of being pulled out if necessary.

A very hard shingling coke is used in these furnaces, broken to the size of an egg. The grate is supplied with air by natural draught, which is very strong in these furnaces, as there is an almost vertical ascent of the burnt gases.

A crucible full of metal requires four hours for melting, and three heats are made in a day. The first operation is to put the fresh crucibles upon their stand, and kindle a small fire around them; or, as is generally the case, to put the crucible upon its sole-piece in the gently heated furnace. The crucibles are generally taken from the annealing fire, and, while still warm, set in the furnace. The heat upon the crucible is gradually but slowly raised, by charging more coke, until it assumes a white heat, which operation requires more than an hour's time. When the crucible is hot, and of course glazed, the furnace top-plate — a sort of iron trap-door — is raised, and a tapered sheet-iron pipe is inserted into the hot pot. Through this pipe the pieces of blistered steel are gently lowered into the bottom of the crucible. The pots are usually of the capacity of thirty pounds, though a large sized pot will readily contain forty pounds of pieces.

A cover made of pot-clay, which fits the crucible, is now laid upon it, fresh coke given to the fire, and the heat gradually raised to the melting point of steel. This operation requires from one to two hours; and in the mean time the furnace is frequently opened, and fresh coke charged, so that the fuel may be higher than the top of the crucible. Before the steel is melted, the lid is removed, and a little bottle-glass, or pounded blast-furnace slag, is thrown in. This will form a vitreous cover on the surface of the melted steel, and exclude the access and influence of atmospheric air, in case the cover of the crucible is not sufficiently tight for that purpose. A great deal of fresh air draws in at the furnace door, even if it fits well.

After the fusion of the steel, the crucible is still kept standing in the fire, to fuse it perfectly, and give time for the interchange of atoms in the fluid mass. As the melting process is chiefly for the purpose of making a uniform grain, those portions of the steel which have more carbon than others, have to dispose of a portion of it, and thus equalize the whole mass. When sufficiently fused, the crucible is lifted from the fire to the floor, when the cover is removed, and the scoria taken off by an iron rod, with a scraper attached to it.

The tongs with which the crucible is lifted are provided at their fire-end with arched claws, like basket tongs, to fit the circle of the crucible. The workmen, in getting ready for casting, cover their hands, arms and legs with coarse bagging, formed into narrow sacks, which they saturate with water before putting on; they are thus protected against the intense heat. When all are ready, one smelter grasps the pot in the furnace, and conveys it to a certain spot on the floor. Other hands are ready to take off the cover, remove the scoria, and carry the crucible to the mould, into which it is cast as quickly as possible. The smelter in the meanwhile gets his furnace ready for the returning crucible; for there may be coke on the sole-piece, and, if so, it is necessary that it should be removed.

As soon as the crucible is emptied, it is returned to the furnace, and the fire put in a condition to make another heat. The operation is now somewhat shorter, but very much like the first.

THE MOULD

Is a hollow cast-iron prism, in two halves; it is either a square or an octagon — the latter for round steel. Steel designed to be rolled in sheets, for saws, &c., is cast in flat moulds. The two halves of the mould, while casting, are held together by hooks; and it is set vertically in a narrow pit, so as to project but little above the floor of the building. The mould is well polished on the inside, and, shortly before casting, is covered with a film of oil and finely-ground charcoal. It is perhaps three times the weight of the cast, and about three feet long. The upper end of the mould, into which the fluid steel is poured, is open, and of a bell-mouthed shape. Fig. 27 is a section of the mould. The pouring of the hot steel into the mould requires some dexterity and skill, if we expect to make a sound and uniform bar. The liquid metal is cast down in the centre of the hollow mould, so that none of it shall touch the mould before it reaches the bottom. There are also larger moulds than those we have described, which take more than the contents of one crucible at a time, and

Fig. 27.

in which steel bars of two hundred pounds are frequently cast.

When the ingots are cold, the moulds are opened, and the steel removed and brought to the tilt, where it is treated like other steel.

Cast-steel is much harder under the tilt than any other steel, and, what makes it still worse, it will bear but a low degree of cherry-red heat before it becomes brittle, and falls to pieces under the hammer. Nor will it bear piling and welding like other steel, but in this respect very closely resembles cast-iron. Another characteristic of cast-steel is, that it is always more highly carburetted than other varieties, in order to make it fusible. Steel which contains but little carbon requires too high a heat to be melted to advantage in crucibles.

AMERICAN STEEL

Is manufactured in a manner similar to the foregoing described processes. There are some slight variations in the converting furnaces; but they are not of sufficient distinctness and importance to warrant us in giving a particular description of the process. We shall allude to this in the next chapter. There is but little cast-steel at present manufactured in this country. Indeed, what has been done may be looked upon more in the light of experiments, of an undecided nature, than as a regular and systematic course of manufacture. The apparatus does not differ in any respect from that described in this chapter, as we may show hereafter.

CHAPTER V.

GENERAL REMARKS ON MAKING STEEL.

WOOTZ.

To make wootz, or Damascus steel, in the United States, is out of the question. Even if we had the materials, which we certainly have not, and if we could pay an exorbitant price for such steel, there would still be no inducement for its manufacture among us. The steel used in the United States is intended for the arts of peace; and for such purposes, cast-steel, and shear or blistered steel, are all-sufficient. Wootz, and similar kinds of steel, are undoubtedly superior for instruments of war, and the finer descriptions of cutlery; but these advantages do not make up for the expensive and tedious process of manufacture, and must for ever prevent its introduction among us. We need therefore say no more on the subject.

GERMAN STEEL

Is at present not manufactured in the United States, and will not probably again be attempted, because the particular kind of ore from which the Germans make their cheapest and best steel has never yet been found in such a quantity and of such a quality as to warrant the erection of steel-works. The fact that we have no spathic carbonate of iron, or sparry ore, however, does not, in our opinion, furnish a good ground for excluding the manufacture of German steel. There are localities where it might be carried on successfully. There is an abundance of pure and rich iron ore scattered over nearly all of the States; and, though every ore, even if pure, will not make good steel, still there are many deposites of rich ore which are in every way suited for the manufacture of natural steel. A great difficulty in the way of our advancement in this manufacture is the high price of labour, which renders us unable to compete with foreign manufacturers. Another difficulty is found in the fact that our operatives are not skilled in the manufacture. For the last thirty years, the aim of the iron manufacturers has been to increase the quantity, with, in most instances, an entire disregard of quality. Now, as the first requisite in the manufacture of steel is a superior quality of iron, it is not surprising that we encounter difficulties in the process. As the majority of our native workmen may be considered as belonging to the English school of operatives, and as the tendency of England has been to make cheap iron for export, we naturally fall into the same practice.

German or Swedish working cannot succeed here, because our material and our social relations are so widely different from theirs, that their mode of operations is altogether unsuited to us. If we would succeed in this important branch of industry, we must cultivate our own resources, augment our knowledge of materials and the mode of working them, and raise a set of native hands, who shall take a proper interest in the successful prosecution of their art.

FIRST ELEMENT.

In making steel, the first and most important element is the iron-ore. To be sure, steel may be made of almost any kind of ore; but it would be found, in the end, that the product would cost more than it would come to. Bog ore, the common impure hematites, the compact carbonates and hematites of the coal formation, the clay ores and red iron-stones, tho impure magnetic ores, and all our sparry ores, will make steel; but the steel will never be of a good quality, and will always be expensive. There are no doubt many heavy deposites of very pure and rich iron-ore, particularly the rich ores of Vermont, Connecticut, New York, and New Jersey; the beautiful hematites and pipe-ores of Pennsylvania; and the rich ore-beds of Ohio, Tennessee, and Alabama; but it is questionable whether natural steel can be made successfully even of any of these ores. They are adapted to make blister, shear, and cast-steel, and many of them will make a pure iron for conversion into steel; but here their usefulness may be said to cease. Magnetic ore and pipe-ore, even if of the best quality, cannot profitably be converted into natural steel.

We come now to the only ores which can with profit be used for the manufacture of natural steel, and which fortunately are found in great perfection and abundance. These aro the ore of the Missouri iron-mountain, and the recently discovered deposites near Lake Superior. There are also fine specular ores in Pennsylvania and New Jersey; but tho amount is more limited than in the above localities, and the ore is not of so pure a quality. An iron-ore to be converted into natural steel should be cheap and pure — either a carbonate or a per-oxide — to be profitable.

The conversion of cast-iron into steel has been before described; it is by no means difficult if the pig-iron is suitable; but, should the iron be impure, it is a tedious operation. Proper attention must be paid, in making natural steel, to the conversion of the ore into crude iron. The usual method of conducting a blast-furnace will not answer in this case. Crude iron for steel requires a very regular and not too heavy blast, a wide hearth, and steep boshes. The charges of the blast-furnace ought to be entirely without lime, or at least with as little lime as possible; and for the same reason, any ore containing lime is to be rejected. Hot-blast is to be avoided by all means; it should never be used where good wrought-iron is made, and is utterly unsuitable for steel. Charcoal is the best fuel for the blast-furnace; it should be of pine, coarse and well charred. All brands and pieces of uncharred wood must be carefully rejected.

A leading object in making cast-iron for natural steel is to purify it of all admixtures but of carbon; and for this reason particular attention must be paid to the operation. The ore is therefore to be pure, clean and dry, and, if not a per-oxide, well roasted by charcoal or wood. Fluxes should be avoided, if possible; the iron oxide or manganese itself is to be the flux; the cinder is then of a brownish colour and glassy fracture. The hearth-stones are to be of fine-grained sandstone, with a liberal admixture of clay.

Another important object in the operation is to flux the impurities of the ore by spending or wasting some of the iron in the ore; for this purpose, a cheap ore is necessary. So long as we insist upon having thirty-nine out of the forty parts of iron which an ore may contain, there is no possibility of obtaining an iron which is suitable for making steel. We require not only a pure iron, but also an iron which contains carbon, if we would make good steel; and to secure such iron, we have to charge a liberal quantity of charcoal along with the ore, being careful not to raise the heat in the furnace so high as to cause impurities in the iron. In short, a low heat, and an abundance of coal and good ore, will produce a superior steel; it is idle to hope for it in any other way.

Our deposites of rich pure ore are of so great an extent, and in such abundance, that a ton of the material costs a mere trifle; and if charcoal or wood can be had equally low, the place for a steel-works is indicated. Steel does not cost so much in the article of labour, as for materials; where the latter are expensive, the steel of course is so; but where materials are abundant and of good quality, there is no impediment to carrying on the business successfully and profitably. As we have already said, the present mode of conducting blast-furnaces will not produce iron sufficiently good for conversion into steel; and we have indicated the faults in the system.

BLISTERED STEEL.

In making blistered or cast-steel, there is little or no difficulty; the mechanical operations of conversion, melting and tilting, are well performed by our workmen, and it is unnecessary to make any further remarks upon them. But here, as in the case of the natural steel, the difficulties in the manufacture arise from the quality of the iron used in conversion, and not from any want of skill in manipulation.

The American steel at present in the market shows that we have the means of making good steel, but that there is some deficiency in the quality of that produced. In Pittsburgh some very excellent spring-steel is made; indeed, it is superior for springs to any of the imported article. In Philadelphia, large quantities of converted steel are worked into saw-blades of excellent quality. All this steel, amounting to near seven thousand tons annually, is made of iron which is smelted from hematite and pipe-ores. There is frequently some iron among that to be converted which would make fine shear or cast-steel; but, as it is not of a uniform quality, it cannot be depended upon. This irregularity, which is a chief objection to this otherwise superior iron, is a serious and apparently insuperable impediment to the progress of the steel factories.

Cast-steel is manufactured in New Jersey, and also in Pittsburgh, at the present time. We know little of the progress of those establishments, however, and suppose they suffer under the general complaint—imperfect iron. As it is of vital importance to the prosperity of steel-works to have good iron, it may be the better plan for us to define, first, what is good iron, and then show precisely how it should be made.

GOOD IRON FOR CONVERSION

Is *pure* iron, no matter whether strong or weak. The strongest kind of iron is generally the least valuable for this purpose. Fibrous iron is usually inferior to short iron; but the rule is not to be implicitly relied on. Iron may be fibrous, and still be pure, though there is little of it known which is of this character. Colour, strength and hardness are not unerring guides in arriving at a decision as to the fitness of iron for making steel. Bright iron, of a brilliant lustre, may contain phosphorus, silicon, or some other matter which renders it unfit for steel. The strongest fibrous iron generally contains more silex than other pure kinds of iron; chemically pure iron is also fibrous, but it is weak. Iron may be hard, and yet make a superior steel; but this is not often the case.

The safest method of ascertaining the quality of iron for conversion is by actual trial; but this is an expensive experiment when the iron proves bad, as a single trial in a converting furnace of but one box requires from six to ten tons of metal. It is practically impossible to obtain iron that is perfectly pure; but the nearer we arrive at that standard, and the less foreign admixture there is, the more suitable is the iron for conversion.

A good plan for ascertaining the purity of iron is to submit it to chemical analysis. Iron may contain carbon to any extent; but if it contain more than one-two-thousandth part of silex or silicon, phosphorus, sulphur, calcium or lime, copper, tin, or arsenic, it will never make first-rate steel. The quality or value of the iron in this case is in an inverse ratio to the amount of impurities it contains.

An analysis of wrought-iron is not easily made, when the object is to find very small quantities of foreign substances; it requires a skilful manipulator, and good apparatus and re-agents. It may not be improper here to refer to Professor James Booth, of Philadelphia, as in every way qualified to make the necessary tests.

We have said that for conversion we need pure iron, no matter how it looks, or how weak or strong it may be. Such iron, however, is not so easily made. The first step towards success is pure, rich iron-ore, no matter of what kind. Magnetic ore is generally preferred; but this is on account of its being usually richer and more free from impurities, and those of such a nature as to be got rid of in the refining process. There is no essential difference between the ores which makes one more qualified than the other. The process in the blast-furnace is of the same nature as that described in the foregoing pages for making natural steel. For this purpose we require a pure grey or mottled pig. We may then sum up thus: The blast-furnace is to be charged with well-prepared ore, little limestone, less coal as above, an excess of ore, cold blast, and regular working.

MAKING OF THE IRON FOR CONVERSION.

Grey pig-iron of the kind we have described is boiled in the forge-fire; that is, it is not passed through a run-out fire, as is now frequently done at our forges. It is charged to the fire, and melted down a whole heat at once. This grey iron, when melted, is or ought to be perfectly fluid; and by directing the blast upon it, with continual stirring, it is brought to boiling. It works rather slowly by this method; but it is the proper way to make good iron. The process can be accelerated by throwing scales, or rich magnetic ore into the fluid iron; but here speed is obtained at the expense of quality; for, unless the magnetic ore is freed of every particle of impurity by washing, the iron will be inferior to that produced by the slower method. Anything, no matter what, thrown into the iron to make it work faster, is injurious, and seriously degrades the quality of the metal.

The liquid mass is kept boiling under continual stirring until the iron crystallizes into lumps, which are brought before the tuyere, and, under the influence of a strong heat, welded together. A large quantity of cinder is kept all the time in the hearth, which is occasionally tapped, particularly when the iron is about to be welded and shingled.

It is useless to think of making good steel-iron of white plate-iron, or iron which does not boil. If the crude iron is pure and of the best kind, it still requires time, skill, and labour to reduce the amount of impurities to such an extent as to make good iron. As the purest iron is never too pure, there is no limit to the qualitative improvement of this description of iron.

The puddling process is not so far perfected as to enable us by its use to make good steel-iron; our knowledge of the operation is entirely insufficient for this purpose. There is no other method at present known to us but the charcoal-forge, good pig-iron, plenty of coal, and careful and competent men to conduct the operations.

The description given in Chapter IV. of the apparatus and manipulation for converting and melting steel are sufficient for all practical purposes; but we will here allude to some leading principles which it is important to know. A remarkable feature in the nature of steel is, that it continues to be steel until it is melted, when it turns into white cast-iron; and this is true of all the varieties of steel. A knowledge of this fact is important in constructing converting furnaces; they should be so constructed as to give a uniform heat over the whole interior, that one part of the chest might not become hotter than another. The strength of cast-steel would be no greater than that of white cast-iron, if it were melted in an apparatus where it could absorb impurities. The iron in the converting-box is in contact with foreign matters which are injurious to steel; and if the converted iron melts in such a box, its fitness for steel is generally destroyed. If iron could be cemented to any degree we chose, it would gradually be converted into a fine grey cast-iron, in which form it would absorb little or none of the cement. The combination takes place only when the iron is in a molten state.

THE CEMENT

Consists principally of charcoal; and there is sufficient evidence that pure charcoal will make the best steel. All descriptions of iron, however, are not similarly composed; and as carbon alone does not make the very best steel, there is a necessity for a compound cement. The charcoal is used in the form of a coarse powder, the grains of the size of blasting powder; it is sifted, and the fine dust, a great deal of which is made in pounding the coal, is thrown away. Sometimes the charcoal is cut by a sharp knife, set in a machine similar to a straw-cutter. Charcoal made from the harder woods, such as white-oak and black-jack, hickory, dogwood, sugar maple, &c., give us the greatest quantity of cement, and of the best kind. The addition of refuse tobacco, such as is thrown away by segar manufacturers, may prove of advantage to the cement. An addition of ten or fifteen per cent. of pure lampblack is also an improvement, but rather expensive. In the Western States, or the bituminous coal region, lampblack may be made cheaply; but if not of the purest kind of coal, it will injure the steel. Sulphurous coal, therefore, should not be used. Anthracite powder, coke powder, and black lead or plumbago, are inadmissible, either pure or in admixture with charcoal. The cement generally in use is composed of charcoal mixed with one-tenth part of good wood-ashes, and about one-thirtieth of common salt. The whole of it is then moistened and well mixed. Some establishments vary the cement slightly, but the majority use the proportions above given.

For some descriptions of iron, charcoal alone makes the best cement. In such cases, the wood of the gum, poplar, sassafras, &c., which make but little ashes, should be charred. Charcoal made from pine is to be rejected, as it is too soon exhausted. Some metallurgists have tried and recommended the addition of borax, prussiate of potash, horn, bones, vinegar, manganese, sal-ammonia, and a variety of other things; but none of these admixtures have any beneficial effect upon the steel.

Experiments have been tried with a view of making steel by conducting carburetted hydrogen gas between bars of hot iron; or leading carbonic oxide gas to it; or cementing with diamond powder, and similar projects. These experiments, however, have all proved abortive; bad iron cannot be converted into good steel, under any circumstances; and it is certain that charcoal powder is at least equal to diamond powder, or anything else that has been tried up to the present time.

The size, form and material of the converting-chest has some influence on the quality of the steel made. For spring-steel, the boxes may be three feet high and three feet wide; such a box will take a charge thirty inches high. The chest, however, had better be not more than thirty inches each way; this size will consume a little more fuel than the other, but that loss is richly made up in the superior quality of the product. In wide and high chests, particularly the latter, the central bars are never so well cemented as they should be, while the extreme bars absorb too much carbon. As a general rule, American converting-chests are not wider than thirty inches; while in Europe we frequently find them of the larger size mentioned.

The length of the boxes is unlimited, except by the strength of the furnaces. Long boxes require to be well secured by iron binders; of course, with shorter boxes, this is not so important. In this country we find no boxes less than twelve feet long, and they do not often extend beyond twenty. The grate is somewhat troublesome to manage in long furnaces; but this is not of much consequence. The size of the grate is of some importance in the result;

it is better in all instances to have it too large than too small. A grate two feet wide by thirty inches deep is a good size for bituminous coal, with thirty inch boxes. For wood or anthracite coal, the grate should be four feet wide. In this case the boxes will be rather far apart, because the bottom of each box is to rest on solid masonry, and there will consequently be a considerable loss of heat. To avoid this loss, we put another box in the open space, thus making three boxes in the furnace. The middle box is to rest upon a series of fire-brick arches, which are sprung upon the tongues; and as these arches are higher than those tongues, the middle box will be

Fig. 28.

higher than the other two, and the whole will assume the arrangement represented in fig. 28.

The flues around the boxes are to be of uniform size, and so arranged as to make an equal heat all over the furnace. If, after the first trial, it is found that the boxes work hotter in one place than in another, the flues in the hottest parts are to be made narrower. The arch is to be as flat as possible, and at least nine inches thick. The spring or height of the arch will depend upon the resistance of the rough walls of the furnace; if these are secure, and the furnace well provided with iron binders, the arch may be very flat. The flues are generally in the centre of the arch; but should the furnace work hotter in the centre than on the sides, some flues may be opened at the sides, where it is found to work too cold. In some instances the boxes have no flues at the ends; this is allowable where spring-steel only is made; but for shear or cast steel it is an ill-advised economy, as the ends of the bars are always better cemented when the fire plays freely at the ends of the chests.

THE KIND OR QUALITY OF MATERIAL

Used for chests is not only of importance so far as durability is concerned, but it is also of influence in the quality of the product. In this country, and also on the continent of Europe, the boxes are made of fire-brick; but in England they are not unfrequently made of sandstone slabs. The first consideration is the durability of the boxes, and the absence of fissures in the material. Pure clay is the best material, so far as its influence upon the quality of the steel is concerned; but it is liable to cracks and fissures, and its expansion and contraction are too great to admit of durability. The addition of fire-sand to the clay renders the latter much more durable; but the steel is injured just in proportion to the amount of sand in the admixture. Good fire-brick is perhaps the best material for chests; and here Pittsburgh has a decided advantage in its Johnstown brick. A similar brick, known as the Mount Savage fire-brick, is obtained from Cumberland county, Maryland. The clay for these bricks is not at present, but ought to be, formed into slabs of a sufficient length to cover a flue, and of half the height of the box, and then burned. Such slabs would be very durable, and the material is decidedly favourable to the quality of steel.

Sandstone slabs of good quality may be found in the anthracite coal region; but they would cost quite as much as fire-brick. It is possible that the Maryland soapstone can be used to advantage; but, considering that a good fire-brick chest may last for many years, it is scarcely advisable to risk the experiment for the sake of the trifling saving which might perhaps be effected.

In the Western States, particularly in the coal-fields — the only localities where steel can be made to advantage in the West — there is no alternative but to use good fire-brick, that in which clay predominates. Slabs of freestone may be had in that region of all sizes and compositions; but the stones of the bituminous coal-fields are very liable to break when heated, and never bear alternations of temperature without injury.

The thickness of the sides of the chest is generally two inches, which is quite sufficient; but a greater thickness does no other harm than that it requires the use of more fuel.

A NEW BOX

Should be gently dried and heated up to its normal heat, and then slowly cooled, before any iron is charged. This is necessary to open those fissures which may be invisible in the bricks or joints. At each heat, before any iron or cement is charged, the box is to be carefully examined, and the smallest crevice or joint cautiously filled with a fire-clay which is chiefly composed of finely-ground and well-burnt fire-brick. The most diminutive opening in a box may cause great loss by burning a portion of the iron, and rendering it unfit for steel or any other purpose. Care must also be taken to prevent any iron, such as binders, wedges, plates, &c., from coming in contact with the chest, as it injures the fire-brick.

FORM OF IRON.

It is not only the quality of iron which has influence upon the manufacture of steel; a great deal depends also upon the form in which it is used. Iron which has become rusty from exposure to the atmosphere is to be cleaned of its oxide, and not used until that is done. The iron bars for conversion, too, should be as free from scales or hammer-slag as possible; on this account, hammered iron is preferable to that which has been rolled. Rust or hammer-slag forms a coating of very close and compact carburet of iron, through which the carbon cannot penetrate. All coarse fibrous iron, even if of good quality, should be rejected, as it makes imperfect steel; the same may be said of iron which is unsound, splintery, and scaly. The *size* of the iron, also, is a matter of some importance. Swedish and German iron for conversion is usually of the thickness of a common horse-shoe or wagon-tire. In Pittsburgh, rolled bars of four or four and a half inches are generally used. In Philadelphia, we see slabs for cementation of about two feet long, five or six inches wide, and three-fourths of an inch thick.

Bars for blistered steel, shear-steel, and all those kinds of steel which are not melted, but simply tilted or rolled, should not be thicker than half an inch, or even less. The difference in a thick bar, between the exterior and interior parts, is too great to be removed by simply tilting or rolling them. Bars which are designed for cast, spring, or coarse blistered steel, may be three-fourths of an inch; but they should be longer exposed to the heat, and, in the case of cast-steel, the conversion should be two or three times repeated.

Shear-steel, to be profitably manufactured, requires thin and small bars, which need but little refining to be uniform. The inducements to use heavy iron are a saving of time and fuel. A box which will take seven tons of wagon-tire size will take but six tons of horse-shoe bars; while at the same time it will contain ten tons of four inches by three-fourths of an inch. Very small iron is too unprofitable in the blistering process, even if of greater advantage in refining. The bars should be always at least two or three inches shorter than the boxes, as iron expands more by heat than brick, and an iron bar of twenty feet in length will gain two and a half inches by the time it is red-hot.

There is a point also in the size of the furnace, at which it is found that the iron works most advantageously. Small iron and small furnaces work faster and more uniformly than large iron and large furnaces; the only disadvantage being that they use more fuel. Where fuel is cheap, and where shear-steel is to be made, or steel refined in any form, it is more profitable to use small iron and small furnaces; for it saves labour in tilting and re-heating. Furnaces so large, and iron so heavy, as to require more than ten days for conversion, are not profitable; because the charcoal cement works but for a certain time in a certain heat, and all additional time and heat is useless waste. Bars which require more carbon than can be given to them in a week's time, like those for cast-steel, had better be converted a second time with fresh cement.

THE FIRING OF A FURNACE

Is to be conducted with intelligence, particularly at a large establishment. Too rapid firing not only injures the furnace and boxes, but exhausts the cement before the iron is sufficiently heated to absorb the carbon thus liberated. The cement or charcoal is a very bad conductor of heat; and the heat of the most intense fire would scarcely reach the centre of the box before that of a more moderate character. Two or three days are required before a cherry or bright-red heat is given to the boxes; and after this it is gradually increased to a white heat, which is kept up regularly and constantly without diminution until the operation is finished.

Small furnaces require four or five days and nights —large ones, from that to ten days. The kind of fuel has some influence on the time of conversion.

Anthracite appears to be the best fuel; and bituminous coal is superior to wood.

A good steel-maker knows pretty nearly when a heat is done, if he is acquainted with his materials. To assist his judgment, the trial-bars are drawn when he thinks the process has been completed. These bars may be either of the whole length of the box, or but two or three feet long; the iron is to be of the same quality as the other iron in the box. The breakage of the bar will of course show whether the whole of the metal has been converted into steel, or whether a core of iron is left in the centre. If the latter should be the case, the heat is continued until another trial shows a sufficiency of carbon throughout the bar. Spring-steel may be good enough for the purposes for which it is used, even if it has an iron core in the centre; but the other varieties of steel, such as that for saw-blades, shear-steel, mill-steel, &c., are of but little value unless thoroughly cemented. Blistered steel, to be suitable for conversion into cast-steel, must have an abundant supply of carbon.

CLOSING OF A HEAT.

When the conversion is sufficiently advanced, the furnace doors are closed, the chimney-top and the flues in the arch stopped up, and the furnace left to cool, which will require from two to five days, or half as long as the conversion. If the furnace is cold, or so far cooled as to admit of the entrance of a man, the doors and flues are reopened, and the workmen remove the converted bars. The size and form of the blisters on the surface show very nearly the kind of iron used, and the quality of the steel made from it. The best steel shows small blisters of uniform size; coarse and imperfect iron shows both small and large blisters in great profusion; a sound iron has but few blisters, and those of a large size; coarse fibrous or puddled iron shows hardly any blisters. Blistered steel, on coming from the chest, if well converted, is very brittle; if strong, it generally contains iron; but there is no rule to be depended on: short iron makes short steel, even if imperfectly converted. The produce of a box, if designed for cast-steel or refining, is assorted according to the size of its crystals in the fracture, and laid by for either the one or the other purpose.

THE TILTING OF STEEL,

As described in Chapter IV., has been sufficiently explained, and requires no addition here. Steel for springs and saw-blades, if made directly from blistered steel, is rolled like sheet-iron, and not subjected to tilting or refining. A few remarks, however, are needed in reference to the chemical characteristics of cast-steel.

CAST-STEEL.

In former years, many experiments were made by Europeans, and in America also, to make cast-steel in a more simple way, with the hope of avoiding the converting process. It was thought that cast-steel could be made directly from the iron, without resorting to the use of blistered steel. These experiments, however, have utterly failed, and are now scarcely thought of. We will enumerate some of them as a matter of curiosity: The melting of wrought-iron together with carbon, or lampblack; the melting of protoxide of iron with lampblack; protoxide of iron and grey cast-iron; and the melting of pure wrought-iron. These experiments were so erroneous in principle, that success can hardly have been expected. Even if this were not so, the practical difficulties are so great, as to render success almost impossible. If too much carbon were used, the product would be cast-iron; if too little carbon, we should have wrought-iron; and if the admixture were precisely correct, the burning of a part of the carbon, which would be almost unavoidable, would destroy or injure the steel.

The inexperience of some metallurgists, inducing them to pronounce hard brittle wrought-iron to be steel, has been the cause of many errors. Some of these learned men insisted upon making good steel by melting grey and white cast-iron together, or, as before remarked, grey cast-iron and wrought-iron; or carbon, plumbago, or diamond dust, together with wrought-iron. All these and numerous other experiments show that the nature of steel never was understood by these men. They assumed that any iron combined with a certain amount of carbon would make steel, which is not true. They did not discriminate between pure and impure wrought-iron — did not know that most iron is too impure ever to make steel. How absurd to recommend the melting of volatile carbon and refractory wrought-iron together! Even if the iron is of pure quality, it is almost impossible to guess the exact quantity of carbon; and, further, the danger of burning the carbon before it comes in contact with the hot iron, as we have said, is almost unavoidable.

The expense of conversion is too small to permit us to think of such projects. Blistered or converted steel is sold at an advance of but one cent per pound upon the cost of iron; and in this advance are comprised the profits of the steel-burner and the merchant. Who would think of cutting wrought-iron into small fragments, or converting it into borings or filings, for the munificent profit of one cent per pound! Even if this could be done, which we positively deny, what would be the gain? It certainly requires less time and fuel to melt blistered steel, than would be consumed in melting iron and carbon together. However allowable such experiments might be in Europe, where fuel is high and labour cheap, they are both unnecessary and unadvisable here, where fuel is abundant, and labour comparatively scarce and high.

ALLOYS OF STEEL.

Experiments which tend to form a better quality of the steel in the process of manufacture have also been made, but with little success. Alloys of steel and other metals have been made by melting them together; but none except the alloy of steel and silver ever came into practical use. This was composed of steel and one five-hundredth part of silver, and was for a time known as silver-steel of superior quality. It has probably fallen into disuse, as we do not hear of it at the present day. Other alloys than those of the precious metals deteriorate the value of steel, and there is some doubt as to the beneficial effect of silver. On the whole, we may conclude that there is no advantage in forming any alloy of steel; it increases the expense, without any corresponding improvement.

SELECTION OF THE CONVERTED BARS.

In making cast-steel, the most important object is the selection of the converted bars. The fragments of steel to be charged and melted together in the crucible are to be uniformly and highly cemented, and free from any iron cores. Not only is a highly finished cementation necessary, but all the blistered fragments should be of the same iron, and of the same heat of conversion. For cast-steel, the most highly cemented bars or parts of bars are selected, so as to have some excess of carbon, because a portion of it is lost in melting. The uniform grain, and consequently uniform hardness, of good cast-steel is entirely dependent upon a proper selection of the blistered steel which is subjected to the melting process, The throwing together of heterogeneous fragments of steel is often the cause of imperfect results. German or natural steel, or blistered steel made of imperfect iron, is never suitable to make good and uniform cast-steel. A perfectly fluid state of the steel in the crucible is absolutely necessary, and this is to be further assisted by stirring the liquid mass repeatedly before casting. This is done with a rod of good iron; impure or puddled iron is inadmissible for this purpose. The melting of the steel is expedited by selecting the most highly cemented bars, or subjecting the bars to be melted to two or three conversions. Such steel will not be injured by losing a little carbon, and this in burning will raise the heat in the crucible. Where there is sufficient carbon, some pure black manganese is laid in the bottom of the crucible. The manganese, in being reduced to protoxide, combines with such silex and alumina as may be freed from the iron, and forms a slag which strongly resists the tendency of the carbon to decompose. The oxygen liberated from the manganese serves to increase the heat in the pot. Nothing but pure black manganese is admissible; any foreign matter will injure the steel. The manganese should be subjected to a careful chemical analysis before it is employed.

THE FORM OF THE AIR FURNACES

For melting steel has been already described; they are much better adapted to the purpose than those of any other form. A sort of reverberatory furnace has been proposed and tried; but it has not been found of much advantage. The square form is decidedly in advance of the round form of the fire-pit. In the Eastern and Middle States, anthracite is the best fuel for these furnaces, and is successfully employed in Jersey City, in the steel-works of the Adirondac Company. In the Western States, coke is used; and its excellence depends upon the hardness and purity of the coke. The fuel should be dry and warm before it is used, as, if not so, the pots are in danger of breaking. Charcoal is a very good fuel, but it is entirely too expensive. There is not much profit or economy in double furnaces, or furnaces having two pots.

POTS.

Of the material of which pots are composed, and of the manner of making them, we have spoken elsewhere; we will therefore make but a few additional remarks on their form and composition.

It has been said that a mixture of plumbago and clay forms the best material for the construction of these pots; but in practice we do not find this to be the case. Pounded coke, anthracite or charcoal, are also added; but with little advantage. The best crucibles, on many accounts, are those made of pure fire-clay; and the only objection to them is that they are liable to breakage, from their inability to resist a sudden change of heat. The addition of old pot-sand and a little coke-dust diminishes the brittleness, and is therefore of great advantage. Instead of coke-powder, the powder of burned or charred anthracite — such as has passed through a blast-furnace, or the heat of a re-heating furnace in a rolling mill — may with a good effect be substituted for common coke-dust. These ingredients should be perfectly mixed, and subjected to strong pressure in the pot-press.

A saving in fuel may be effected by making the pots of a conical form; but, on the other hand, they do not last so well if too much tapered, and the quality of the steel is also injured. The cylindrical form is the best for quality and durability; but these are obtained at a greater expense of fuel. Pots are generally of three and a half to four inches diameter at the bottom, and from four and a half to five inches at the top; the height varies from twelve to sixteen inches. It is not advisable to melt more than fifty pounds in one crucible at a time; the usual charge is but thirty or forty pounds.

FLUX.

The flux used to cover the melted steel, and protect it against the air and flame of the furnace, is glass-powder. It is not indifferent what kind of glass this powder is made of; glass which contains much iron, lead, arsenic, manganese, or, in fact, any metallic oxides, will not answer for the purpose, and should be carefully avoided. So also of crystal, crown, and coloured glass. What we require is a hard, strong, soda glass, such as is generally used for good window-panes; it is white when in thin sheets, but assumes a light-green appearance as it increases in thickness.

A flux is not absolutely necessary if the pot-covers fit well; indeed, if good glass cannot be had, it is better to use none at all. Any other flux, such as potash, soda, or glass compositions, must be scrupulously avoided; they are all positively injurious to the steel. We have said enough to show the importance of providing good pot-covers.

How long a pot should be exposed to heat, is not very easy to say. If the steel is not very fluid, it may require five or six hours before the operation can be completed; and if so, the steel will not be good. In Sheffield, from three to four and a half hours is considered sufficient. Steel which melts in less than three hours is brittle, and not strong. A perfectly limpid, and not a slimy, pasty state of the liquid steel, is necessary, and should continue at least a quarter or half an hour, under repeated stirring. The mould after casting is covered with fine sand or clay, to protect the hot steel from the air.

TILTING OF STEEL

Is one of the most important operations in the manufacture. Good tilting improves the steel, while imperfect work degrades it. Experience is the only safe guide here. The force-hammers should strike in rapid succession, even if the blow is slight. The degree of heat in the bars varies according to the quality of the steel; cast-steel bears the least, and natural steel the highest heat. Too hot or too cold tilting makes the steel brittle.

CHAPTER VI.

NATURE OF STEEL.

HARDNESS.

When heated to redness and suddenly plunged into cold water, or suddenly cooled in any other way, steel becomes hard — so hard, if of good quality, as to scratch glass. The degree of hardness depends not only on the quality of the steel, but also on the degree of heat to which it has been exposed, the medium in which it is cooled, and the manner in which that cooling is performed.

FINE CAST-STEEL

Is susceptible of a high degree of hardness, almost equal to that of the diamond; but it is then too brittle to be of practical use. Shear-steel is less hard, if hardened in the same manner as cast-steel, and is still more brittle. Spring-steel is not capable of so great a degree of hardness as either of the above varieties, and, if manufactured from hot-blast or impure iron, is very brittle.

GERMAN STEEL

Is frequently found to be very hard and tenacious, equal to good cast-steel; but the quality of German steel is so irregular, that no dependence can be placed upon it. We frequently find very hard and tenacious steel, and very soft and brittle steel, in the same bar of but a few feet long. We often also find fibrous iron and good steel in the same fracture of a bar. The hardest iron or steel known is the white cast-iron or steel-iron of Germany, of which German steel is made. It is, however, so brittle when hardened, that it will not serve for any practical purpose. Some kinds of wrought-iron may also be hardened, but the metal is never sufficiently tenacious to assume a fine edge; for the edges formed of it are so brittle as to break when exposed to slight pressure.

The hardness as well as the nature of steel are greatly affected by exposure to too much or too little heat. A dark cherry-red heat is sufficient to give to the best kinds of cast-steel their greatest degree of hardness. Shear-steel will bear a higher heat than cast-steel, and German steel will bear almost the welding heat of iron — at least a bright white heat — without injury. Every kind of steel has a certain degree of heat by which it assumes the hardest as well as the most tenacious form. If heated beyond that point, the thin steel cracks, and the heavier pieces fly, either in the cooling operation, or after the termination of that process. If cast-steel is heated to whiteness and cooled, it loses its peculiar hardness and tenacity, becomes brittle, and can never be restored to its original quality. German and shear-steel, if the latter is well refined, can bear considerable heat without much deterioration in quality. Blistered steel is more sensitive to heat than any other variety, and for this reason is not suitable for welding to iron, or making miners' tools of, though it is frequently applied to those uses. Blistered steel will not admit of such frequent hardening as other steel. If it has been injured by too frequent heating and hardening, it may be somewhat improved by forging with quickly repeated blows of light hammers, and gentle heating. If open cracks from hardening are in the steel, a slight welding heat is to be given in addition.

The more steel has been forged, and the higher the heat it has been exposed to in manufacturing, the more work and higher heat will it bear in the subsequent operations. It never assumes the high degree of tenacity that marks cast-steel, however, even if it should become as hard as the latter. Cast-steel is the hardest and most reliable steel, if cautiously heated. If steel is heated below its normal heat, and cooled suddenly, it does not assume its natural hardness. German steel, heated to a cherry-red, remains as soft as it was in its tempered state. This degree of heat is variable, as remarked above; but if the hardening heat is not carried to the proper point, the hardness of the steel is always less than its quality would lead us to expect; in most cases, it is as soft as if tempered.

THE REFRIGERATION OF STEEL,

For the purpose of hardening it, is performed in most cases by simply heating it, and plunging it suddenly in cold water. This process is frequently varied by moving the hot steel rapidly in the water, or by violently disturbing the water. The *rationale* of this process is the difference of temperature between the hot steel and the cooling medium, as also the time in which it is performed. If the steel is hotter and the water colder, the steel will assume a higher degree of hardness, or become brittle. By the same degree of heat in the steel, water with ice or snow in it will make the steel harder than water of 70° or 100°, which is generally used in the blacksmith's shop. To increase the hardness of steel, without being obliged to expose it to an injuriously high heat, it may be plunged into mercury, which gives it a high degree of hardness, because it cools more rapidly. After quicksilver, follow a solution of salt, or water slightly acidulated by sulphuric or other acid. Spring or hard water imparts more hardness than river or rain-water. Oil and fat leave the steel softer than rain-water; and cooling in sand, or between cold iron, as in the jaws of a vice, or cooling in air, either in motion or at rest, have all been tried, and impart a greater or less degree of hardness, according to the order of their enumeration. Steel heated to its highest point, and plunged in the coldest medium, becomes what is called glass-hard; that is, it will scratch glass; but it is usually very brittle.

Not only the cooling medium, and the heat of the steel, but the manner in which the refrigeration is performed, have influence upon the hardness and tenacity of the steel. If hot steel is thrown to the bottom of a vessel of cold water, it does not assume a high degree of hardness; but if a rapid motion is given to it, it speedily becomes hard, and the hardness increases with the rapidity of the motion. Large pieces of steel, which have to acquire a high degree of hardness, are refrigerated under a rapid current of water, which falls upon it from a certain height. The best swords at present manufactured are hardened by giving them a rapid motion in the atmosphere. Several kinds of saws, and other articles of steel, are hardened by simply hammering them. Engravers' tools, if made of good steel, assume the finest edge or point by being hammered with quickly repeated strokes of a very small hammer, upon the edge which is to form the cutting point.

TEMPERING.

The fact that each variety of steel requires a different degree of heat for hardening it, and the difficulty of estimating that heat, because there is no way of measuring it, has given rise to the operation of tempering. The steel is therefore heated to the highest degree which it can bear without being permanently injured, and is then cooled so as to impart to it the greatest hardness. It is then ground or polished so as to show a bright surface, and gently reheated until the bright surface shows a certain colour. The colours produced by the increasing heat on the bright surface are, in succession, yellow, brown, purple, light-blue, dark-blue, and black. These shades are used for the following purposes: yellow for lancets, razors, penknives, cold-chisels, and miners' tools; brown for scissors, chisels, axes, carpenters' tools, and pocket-knives; purple for table-knives, saws, swords, gun-locks, drill-bits and bore-bits for iron and metals; and blue for springs, small swords, &c. Articles which are to be softer are made still darker; but when the black shade is reached, the steel is annealed and soft. These colours are the result of oxidation. The increasing thickness of the film of oxide which accumulates on the bright surface of the steel is less and less transparent as the heat increases. The character or composition of the oxide is in all cases the same.

In a blacksmith's shop, the tempering is generally done by heating the object, if a chisel or pickaxe, from the heavy part towards the edge; and when the heat moves towards the edge, and has imparted the desired colour, the instrument is suddenly plunged into cold water, to arrest further tempering. The thick part is thus not only tempered, but annealed, because it is heated beyond tempering. This mode of tempering tools is practical, and based on correct principles; but it requires care on the part of the blacksmith that he does not go beyond the colour which he intends to impart. The degree of hardness is tested by scratching the article with a file; but the test is uncertain, and shows merely if the hardening is too soft, but not if it is too hard.

Sometimes the tempering is performed by covering the steel with a film of oil or fat, and heating the steel until this oil or fat is inflamed. This is a very imperfect method, and cannot be depended upon; it generally makes the steel too soft. Small objects are very well tempered by putting the steel between the jaws of the fire-end of a pair of blacksmith's tongs, which are heated beyond the tempering point. As soon as the steel shows the desired colour, it is dropped in cold water. This is perhaps one of the most successful methods of tempering steel.

A somewhat scientific, but at present not much practised mode of tempering, is to heat the glass-hard steel in a bath of fusible metal, kept at a certain heat, the objects being laid on an iron plate. This way is best adapted to temper knife-blades and saw-blades in masses; but we should hesitate to recommend it for general use.

CHARACTERISTICS OF STEEL.

The signs by which to distinguish good from bad steel are very difficult to describe; however, we shall endeavour to do so. If there is an opportunity of forging some of the steel, it is advisable to do so; for there is no better means of ascertaining its true nature. A bar is gently heated to cherry-red, and drawn out into a gradually tapering square point. The operative who performs this labour, if familiar with working in steel, will judge of the quality from the manner in which it forges. If it is cast-steel, it forges harder than any other; after this follows good German steel, then shear-steel, and at last blistered steel. Hard wrought-iron is the softest. If the trial is performed, and cannot be depended upon for want of experience, the forged point is heated to cherry-red, and cooled in cold water; if possible, ice or snow-water. After this hardening it is tried by a file, and, if it should be found to be soft, it may be concluded that it is either iron or German steel. It is then heated again to a higher degree of heat, and hardened; if it is not hard after this heat, which may be a white heat, it is iron. In either case, the steel is to have a uniform heat; for the thin point will naturally be hotter than the thicker portions. The hardened point is then screwed between the jaws of a vice, and just enough broken off to show the fracture. The power used in breaking forms the rule by which to judge of the tenacity of the steel under trial. The broken point may be tried by crushing it under the face of a hardened hammer, when laid upon a dull but hard file. If the steel is good, it will resist the crushing, and will cut the hammer-face and the file. The degree of resistance of this grain of steel to the crushing power is the best rule by which to judge of it; for many kinds of steel feel hard to the file, and even cut glass, or other hardened steel, and yet show no tenacity. Here we find the true criterion of good cast-steel, and natural or German steel. The latter may be as hard as the first, but is never as tenacious when glass-hard. As tenacity in steel is of greater importance than hardness, it is an object to attend to this trial most carefully. Hard iron will be found to be easily ground to dust in the experiment. Some kinds of steel, particularly those which have been forged a great deal, or which never had much carbon, or in which other matters predominate over carbon, will not bear to be drawn into fine points. It may be quite strong when in large pieces, or even tenacious; but still it will that is not sufficient. Steel which is really good will take a fine point, and be tenacious if not tempered, unless it has been overheated. If the steel will not take a point, it of course will not receive an edge, and is therefore useless for any of the finer articles of manufacture. The white crude steel-iron of the Germans is harder in a body than the hardest cast-steel, or the hardest German steel; but it will not take a strong point, nor receive a fine, smooth edge.

The marks by which to know good steel, by sight, sound, or strength, are fallacious, and cannot be depended upon unless assisted by long experience; and even then the result is always uncertain. The fresh fracture of steel is of a silver-grey colour, inclining in many instances to white, particularly in shear and German steel. Certain kinds of cold-short wrought-iron have a similar appearance and bright fracture; but they are far from being steel.

Hardened, refined, or much-forged steel is always more bright in its fracture than cast, annealed, or tempered steel. The lustre of a fresh fracture in steel, however, is as uncertain as its colour. Phosphorus and silicon have the property of imparting a rich lustre to iron as well as steel, and hence the difficulty of distinguishing steel by this test. Hardened steel has more lustre than that which is tempered, and hammered steel more than that which is annealed. Cast-steel not hardened frequently shows a fracture similar to that of fine-grained cast-iron. Baltimore pig-iron has more the appearance of good cast-steel in its fracture, than many kinds of shear and natural steel.

TEXTURE.

The most characteristic feature of steel is its texture, or grain. The grain of good steel, when hardened or soft, is uniformly round when viewed through the microscope; no flickering of light, as if broken by the planes of small crystals, is visible. The fracture shows a velvety uniformity, of a more or less white colour, and of more or less lustre; but always of great regularity and uniformity; no spots which are more bright or more dull than others.

Good steel does not look like mottled cast-iron, or cold-short bar-iron. The fracture of good steel has the appearance of deadened silver; it is of a uniform colour, grain and lustre, with the entire absence of sparkling particles.

SOUND

Is a characteristic of steel. A well-forged and polished rod of sound steel, when suspended by one end and struck by any hard substance, emits a sonorous, silvery tone. Iron does not possess this sound; fibrous iron gives out a dull, unpleasant sound; cold-short iron is more sonorous, but still there is no comparison between it and the silvery tone of a well-forged bar of steel. Hardened steel is less distinct in this quality; and tempered steel emits but a dull, shingling sound, like a broken bell, or cracked porcelain. German steel, as brought into market, is also inferior, because all this steel is chilled before being packed; it is, however, in all instances, inferior in sound to cast-steel.

COHESION

Is one of the most characteristic qualities and the greatest merit of good steel. The absolute cohesion of good steel is twice as great as that of the best bar-iron, or 120,000 pounds to the square inch; of good cast-steel, even 150,000 pounds. We refer to annealed and forged or tempered steel. Glass-hardened steel bears less weight than forged steel; but the hardened and tempered steel bears still more. Steel which, when glass-hardened, bears but 100,000 pounds, will, if tempered, bear 130 or 150,000. Good cast-steel is here again preferable to any other. What has been said of the absolute cohesion of steel may also be said of its relative cohesion; it is far superior in this respect to either wrought or cast-iron.

ELASTICITY.

The most remarkable quality of steel is its elasticity; it is in this respect superior to any other material, India rubber not excepted. A good spring, made of good steel, will last for centuries, in constant use, without losing its flexibility. A good Damascus blade will bear any amount of bending, without deviating the smallest fraction from its original form, when the bending force is relaxed. Good cast-steel, well worked, will do the same; but its curvature is more limited, and it is more brittle, than Damascus steel. A clock or watch-spring, being always on the extreme of flexure, will last for years, or even centuries, without being deteriorated to an appreciable extent.

SPECIFIC GRAVITY.

The specific gravity of steel is between 7.5 and 7.9, according to quality and treatment. Hardened is not so heavy as tempered steel; well-forged steel is the heaviest. Very much in this respect depends upon the quality of the steel. The best qualities are most subject to these expansions and contractions by hardening.

The mode of working steel, also, has an influence upon this fluctuation. If steel is made too hot, or the difference between the heat of the steel and the medium of refrigeration is too great, for a certain kind of steel, it will expand a great deal in hardening; but, if hardened by the proper heat, its expansion will be quite small.

FUSIBILITY OF STEEL.

The heat by which steel fuses is very variable; but all kinds of steel melt at a practicable heat. The finest cast-steel melts at a lower heat than any other steel, and the German spring-steel requires the highest heat — too high a heat for the best crucibles. We may assume that cast-steel melts at 2700°, blistered and shear-steel rather higher, and natural steel at 3500°.

THE WELDING PROPERTIES

Of steel are in many respects very decided, but vary in the degree of heat. The heat which is required to weld German steel, to itself or to iron, is sufficient to convert cast-steel into cast-iron. The welding of two pieces of cast-steel is a matter of some difficulty; but it may be welded to iron, by the help of a little borax, which is sprinkled on the joining surfaces to remove scales of oxide. Spring or shear-steel, and natural steel, may be welded to themselves, or one to the other, or to iron, just as we choose. The heat applied in these cases is to be given with caution, to avoid the burning of the carbon; for that would injure the quality of the steel. Sand or dry clay should be sprinkled over the hot steel, to protect it against the direct attacks of the blast. When iron and steel are to be welded together, the iron is always nearest the intense heat or blast; the steel is held in the more subdued fire. If steel is heated too often or too intensely, it is transformed into iron, and frequently bad iron. Forging delays, but cannot prevent this result.

MAGNETISM

Is more tenaciously retained by steel than by iron. The latter absorbs it most quickly, but does not retain it well; the former absorbs it slowly, but retains it for years. The finest steel is more qualified to retain magnetism than any other; and steel of a dark-blue colour is superior to glass-hardened or hammered steel. The most uniform steel in hardness, texture, tenacity, and fineness of grain, is the best for magnetic instruments; and cast-steel is of course to be preferred to any other.

APPENDIX.

In our last chapter we have enumerated the various qualities of steel, and their characteristics, in a concise form, to bring the subject properly before our readers. We shall now proceed to take a philosophical view of the matter.

Steel is certainly iron; but it has less impurities or foreign admixtures than cast-iron, with more carbon and less of other impurities than most kinds of wrought-iron. We cannot say that steel is simply a carburet of iron; that is not true; for it contains, besides iron and carbon, many other ingredients. Steel, as it improves in quality, gradually increases the number of its component parts. These, at first sight apparent impurities, belong to its nature, and constitute, in proper connection with iron, the character of the steel. The best and finest steel, such as first-rate cast-steel, contains the largest quantity of alloyed admixtures; these make the steel fusible, but at the same time impair its capacity to resist the action of heat without melting. Such steel cannot be welded to itself, or but with difficulty, and falls to pieces like cast-iron when struck by a hammer in a temperature at or beyond cherry-red. Blistered, shear, spring, and file-steel, and similar kinds, contain fewer impurities than cast-steel. But these descriptions of steel melt with great difficulty in a crucible, and are never so tenacious, fine-grained, and durable as cast-steel. German, Damascus, and similar qualities of steel contain a still smaller amount of foreign matter; they have body, and resist fire as well as wrought-iron; but they have not the fineness of cast-steel. They are not, therefore, so capable of receiving a fine edge; nor are they so tenacious as cast-steel.

If steel is, according to this, an impure iron, and a very impure iron, too, we are not to conclude that any impure iron will make steel, or that impure iron ought to make *good* steel. It is neither the amount nor the quality of foreign matter combined with iron which converts it into steel; "it is the *form* in which foreign matter is combined with iron, which constitutes steel." Every atom of the constitutional elements of steel is to be combined with its fellow atom, so as to form a well organized atom of steel—not to form an atom of iron, then an atom of iron and carbon, and then a third atom of iron, carbon and silicon, or other matter; and these incongruous atoms grouped together in an irregular form. An atom of iron, which is alone, and is not combined with its ratio of other matter, is soft—is of another nature than its neighbour atom, which is combined with such elements as impart hardness to the combination. All the alloys are more hard than the elements of which they are composed; and so it is with the alloys of iron. Pure iron is very refractory; this causes the difficulty of fusing it as perfectly as other alloys, and it is therefore less uniform. Hence steel of impure iron is apt to be brittle or tender, and will not take a fine edge. Iron, such as cast-iron—and, in fact, any other alloy—if it contains too much of alloyed matter, is brittle. If it contains too much carbon, as in crude steel, it is very brittle. If silicon, phosphorus, and other matter predominate, we always see brittle iron. Where the elements of composition are well balanced, we generally find the iron tough, soft, and of good quality. Scotch pig-iron is one of the most impure kinds of iron manufactured in the world; still, it has qualities which make it superior to any other iron as a foundry metal. Iron smelted of some kinds of bog-ore, and by charcoal, frequently contains but one or two per cent. of phosphorus and carbon, and still is so brittle as to be useless for any purpose save shot. If to such brittle iron we add sulphur, copper, calcium, or similar matter, it improves in strength and utility. These are the reasons why a composition of various kinds of ore, melted together, make a stronger iron than a majority of the ores, melted singly, would indicate. The same reasons explain why the quality and strength of wrought-iron is greater when compounded, in refining it, of various kinds of pig-iron. The composition is in all instances stronger than the average sum of strength of each kind of iron refined by itself.

Steel is iron alloyed with other matter; and nothing can impart a more correct idea of the nature of steel, than the nature of alloys generally. These always fuse at less than the mean temperature of the fusing heat of the metals separately. Thus, pure iron is infusible; but an alloy of ninety parts of iron and ten of gold is almost as fusible as gold itself. Pure iron, we repeat, is infusible, and carbon is infusible; but when alloyed, they melt readily at a practicable heat. Silicon is infusible; but when combined with pure iron and carbon, the mass melts very readily. Five parts of lead, three of tin, and eight of bismuth, melted together, dissolve in boiling water; while the mean degree of the melting heat of the component parts is 514°, or nearly a cherry-red heat. Almost all the alloys are malleable when cold, but brittle when hot; there are but few exceptions to this rule. This quality of the alloys is very distinct in bronze, but still more in cast-iron. There are some kinds of anthracite pig-iron which are very tenacious when cold, but which, in a cherry-red heat, cannot bear their own weight. There is a charcoal cast-iron used in Pittsburgh, of which turnings ten feet long may be cut, but which, at a cherry-red heat, drops to pieces by its own weight. If such iron is freed of the greater part of its alloyed matter, or if it is converted into wrought-iron, it is as tenacious when almost at the welding heat, as when cold.

Many alloys consist of definite equivalents of the single or component parts; and it may be assumed that a definite relation between metals exists in all instances, the same as the law of equivalents throughout chemistry and nature. It appears that peculiar properties belong to the rational compounds, which are not so definitely expressed in the accidental composition.

The law of combination of different metals is exemplified and has been observed in a number of cases.

Brass composed of definite equivalents, atom of copper to atom of zinc, when alloyed, is a far superior metal to that kind of brass which is not compounded according to this law. There are at present but very few instances of definite compounds investigated; but it is in all cases strongly indicated that a rational compound is natural in all instances.

THE HARDNESS

Of alloys is generally greater than that of their component parts. A slight admixture of soft tin, say ten per cent., renders copper very hard and tenacious. If the amount is more than one atom of tin to one atom of copper, the alloy of these two of the most malleable metals is so brittle as to have hardly any cohesion. One atom of tin to one of copper is the metal of which Lord Rosse's specula are made; it is as hard as steel, and has so much cohesion as to bear working, turning, and polishing. Sixty parts of iron and forty of chromium form a composition as hard as diamond, though the metals separately are not hard.

A high degree of hardness may be imparted to iron and steel by the admixture of one-fourth of one per cent. of silver. Copper may be hardened externally by the fumes of zinc and of tin. Carbon and phosphorus have the same hardening effect upon soft iron.

THE TENACITY, MALLEABILITY AND DUCTILITY

Of the single metals is generally impaired in their alloys; the same is the case with iron and its alloys. More information on this subject may be derived from the "Encyclopædia of Chemistry," by James C. Booth; articles, "Alloy" and "Affinity."

An opinion expressed by eminent metallurgists on the nature of steel, namely, the hypothesis that the carbon in tempered steel is a mechanical admixture, while in crude white iron or hardened steel it is a chemical combination, is a doctrine to which we cannot agree at the present time. It has been proved that silicon is a necessary part in the constitution of steel. It has also been found that iron, in forming steel, which contains silicon, sulphur, phosphorus, arsenic, and similar matter, does not need or absorb as much carbon as if the iron is free from such admixtures. Carbon may be replaced in steel by other matter.

It requires more than common sagacity and penetration to perceive the difference between the nature of the alloys of iron in the annealed state, and in their hardened condition. To assume, however, that the iron in the one case is a mechanical, and in the other a chemical combination, caused merely by the manner and time of cooling, is something which we cannot believe in.

The hardening and annealing of steel is a phenomenon of great interest, and rich in information; but it is not a singular phenomenon; it is related to those of the same nature in other metals, though it differs in degree.

We do not commonly say that brass or bronze, when hammered, change from a mechanical mixture to a chemical alloy, or vice versa. The same phenomenon is observed here as in tempering or hardening steel. Bronze or brass becomes hard in hammering, and is softened by annealing, just like steel. More analogous, however, than the above metals to steel, is glass; this, when heated and thrown into cold water, becomes very brittle, but by annealing is made soft and tenacious. We do not think of ascribing this difference in the nature of glass, when cooled slowly or suddenly, to the alteration of its constituent parts to such an extent as to convert it from a mechanical mixture into a chemical compound. One of the essential conditions of transforming a mechanical mixture into a chemical combination is, that the atoms are liberated—that the mass is perfectly fluid, so that an interchange of atoms may be possible. In all cases, at least one of the constituent parts is to be fluid, or in a gaseous form, or a change from a mechanical to a chemical constitution is of course impossible. Now, if we admit that carbon in a gaseous form may combine with iron chemically, if both in combination are suddenly cooled, we cannot admit that the same happens in glass; for in glass there is no element which can possibly be in an elastic fluid, or in a limpid state. Furthermore, silex, silver, manganese, and other matter, show a similar relation to carbon as iron; and we do not think that anybody would assume two states of combination between iron and silicon, and between iron and silver; the alloy may be soft or hard. It requires also a strong imagination to believe that in hammering annealed steel, a change from a mechanical to a chemical formation is effected, and still steel is hardened quite as well by hammering as by refrigeration. There is no heat to make carbon volatile.

Speculations like the foregoing may seem, at first sight, but a waste of time, and of no practical use; such, however, is not the case. The theory or science of any art is always, at first, based on hypothesis; of the truth of which we can know nothing until it is demonstrated by experience. The nature of steel in its hardened and tempered state has not been, and cannot be, based upon positive facts; we have to reason by analogy. The science of making steel, as well as the investigation of its nature, is therefore based, and will be always based, upon hypothesis. The nearer that hypothesis is to the true state of facts, the more perfect will be the science, and the greater will be the advantages derived from the science in the art of manufacturing steel. Thus far, science has been of very little assistance to this important branch of industry; the whole is based upon practice. Why is this so? There is scarcely any art at the present time which is not indebted to the researches and investigations of our scientific men. We believe that the whole science of steel-making is based upon a false foundation—upon an incorrect hypothesis.

In this country, steel-making is in its infancy; it has in no way advanced so fast as the manufacture of iron. We have no ore which is almost native steel, like the Germans; nor can we expend as much labour in making iron as is done in Sweden. Our social relations do not admit of it, and nature has not favoured us with similar conditions. Still, we have an abundance of good iron-ore, and a supply of fuel unparalleled in the known world. We have hands who are willing to work, and heads which are able to plan: why can we not make steel? We make at present nearly eight thousand tons per annum; but that is little in comparison with what is consumed, or would be consumed, if it could be furnished at reasonable prices. All the steel we now make is used for springs, coarse saw-blades, and files.

The manufacture of steel is necessarily involved in great mystery. All practical manufacturers are agreed that good iron is all that is required to make good steel. The art is simple and infallible, if the proper ore or iron is at hand. The ore from which the Germans make their steel is the crystalline carbonate, or sparry ore, which they possess in great purity. The making of steel from such ore is very simple, more so than the making of iron from the same ore. But we cannot make steel in the German fashion, as we have no such ore, nor any suitable for the purpose. There is sparry ore in Vermont, North Carolina, Missouri, and perhaps in other States; but it is not adapted to the manufacture of good steel. Even if we had ore like the German, we should find that their process is not suited to our country.

The wrought-iron made from the German steel-ore is very fibrous, tenacious, and of great cohesion. The Swedish iron of which English steel is made, is tender, very soft, and has no strength; it is almost cold-short. There is therefore a great difference in the constitution. In the first case, German iron is the result of decomposed steel; the crude steel, or a part of it, in the operation of refining, has been converted into iron. In the latter case, this soft, tender Swedish iron is converted into steel; and the softer the iron has been, the harder and more tenacious is the steel, provided the same labour is devoted to it. It is a fact that coke-iron will not make good steel, if treated in the best manner. Hot-blast destroys the quality of iron for steel, or, if not entirely, greatly injures it, even in the best kinds of charcoal-iron. Spring-steel may indeed be made of hot-blast and impure charcoal-iron; but it will not have much strength, nor will it receive a fine edge. Experience has shown that hot-blast iron, of the same ore and from the same furnace, is much inferior to cold-blast; so much, that nobody would think of using it for the purpose of making steel-iron. In Germany, every attempt to use hot-blast iron in the manufacture of steel has been attended with ill-success.

With these facts before us, we think it not difficult to form a reasonable hypothesis on the nature of steel; and this hypothesis will furnish a basis upon which the art of making steel may be established more successfully than by the old theory.

Pure iron is very soft, malleable, infusible, and cannot be welded. The admixture of any other matter makes it stronger, harder, and fusible; and a limited admixture imparts to it the quality of welding. Iron follows the same law as any other metal, and is subject to similar alterations of its nature by foreign admixtures. There is no essential difference between iron, and other metals and their combinations, as a class; but there is a difference in the phenomena in degree. This is a general law of chemistry, and no peculiarity of the metals. All alloys of metals, as we have said, are harder than the mean hardness of their elements; and the same is the case with iron. We may say that carbon, or phosphorus, is not a metal. This does not alter the case, however; for phosphorus and carbon impart to iron the same quality as silver, arsenic, chromium, or copper; all these make iron hard, and so does silicon. The only difference is in degree. One-fourth of one per cent. of phosphorus or silicon makes iron more brittle than five per cent. of carbon, or ten per cent. of copper. All alloys of iron, without exception, are brittle, when combined with it in its pure state, even if they make steel tenacious, as do platinum and its kindred metals. Silicon and phosphorus impart to iron the highest degree of brittleness, and also of hardness; silicon appearing to assume the first rank. Hardness and tenacity are always combined where a perfect and intimate chemical combination has been formed; this is a law throughout art and nature. Imperfect relations, or impure crystals, are never tenacious, never hard; where uncombined particles occur between the legitimate atoms of matter, every quality resulting from a perfect chemical compound is impaired. A mechanical admixture of water in any crystal impairs its lustre, its hardness, and its cohesion.

Silicon and phosphorus appear to be related to iron, as zinc is to copper. The strongest heat cannot disengage all the zinc in combination with copper; the latter will always retain sixteen per cent. of the former. By chemical means, however, we may separate them perfectly. The same is the case with iron and silicon, iron and phosphorus, sulphur, and almost any other matter in combination with iron. Heat alone never can remove sulphur or phosphorus entirely from iron; for, before all the sulphur, which is known to be very volatile, is expelled, the iron crystallizes for want of sulphur, and a portion of the latter is enclosed in the small atomic crystals, and cannot be removed until the crystal is re-opened. The same phenomenon happens with any salt dissolved in water, or in its mother-ley. Silicon is not volatile, and for that reason less inclined to leave iron than any other matter; it may easily be seen why it is so difficult to separate silicon from iron. And as silicon makes iron very hard and very brittle, it is so much the more necessary to remove it, at least as much as possible, before we can expect to have iron fit for making steel. We must be careful not to confound silicon and silex; for iron may contain twenty per cent. of silex, and be perfectly malleable, soft, and strong; still, it would not make steel.

Throughout nature a law prevails that all matter of one kind is combined in certain definite proportions with other matter of a different kind, to form a third matter of still another kind. If two or more kinds of matter are not combined in exactly given proportions, the new matter formed from the combination is imperfect. Such imperfect matter does not show that beauty, that finish in all its parts, which it would possess if the elementary or combining atoms were in exact relation to their affinities. Such an imperfect creation is impure, is abnormal. If such a law pervades all nature, as it certainly does in every instance, why should iron and its relative matter make an exception? We cannot think of any exception to the rule; indeed, it is impossible that there should be any.

In the case before us, it is difficult to produce a legitimate combination of iron with other matter. We shall endeavour to show the cause of this difficulty, and the necessity of removing it.

Silicon is the most tenacious adherent of iron — its best friend; but its influence is so great in making the iron hard and obstinate, that the greater part of it must be removed if we want the iron for steel; indeed, we may say *all* which it is practicable to remove. The finest steel shows but one-eighth of one per cent. of silicon, and often less than that. Carbon, sulphur and phosphorus form volatile compounds with the oxygen of the atmosphere; these compounds do not re-combine with iron, and are very easily expelled. Silex, the oxidized silicon, is not volatile; nor is silicon itself; both remain, therefore, with the iron, in either one or the other form. All other matter increases the fusibility of iron; and so does silicon; but almost all other matter, with the exception of a few metals, such as copper or silver, may be driven off by heat, or oxidized and evaporated. Silicon remains last of all; and its admixture will have the effect of keeping the atoms of iron separate, or keeping the metal in a fluid state, until the silicon is oxidized and removed. The great cohesive power of the iron particles will congeal the fluid iron compound before all the silicon or silex can be removed. It may therefore be asserted that no iron, no matter how it is manufactured, is entirely free from silicon or silex; because most of the iron-ore contains silex, the walls of the furnaces contain silex, all fuel contains it, and fluxes and slag are not free from it. Silicon makes iron hard—silex does not; iron may be strong and tenacious, and contain much silex; but it would not answer for the better qualities of steel. Silex can be in wrought and cast-iron, but not in steel, and much less in hardened steel; for it will inevitably be converted into silicon by the carbon of the steel. We must not conclude, therefore, that soft, fine, strong bar-iron is any more fit for conversion into steel than even cold-short, worthless iron. The qualification of iron for steel cannot be correctly judged of from its appearance; it can only be ascertained by actual trial, and careful chemical analysis.

Experience shows that the best steel contains the largest number of components, the greatest variety of matter. Silicon, sulphur, phosphorus and arsenic are as necessary elements in the constitution of steel as is carbon. Good steel may be made by simply adding carbon to wrought-iron; but then the quality of the steel will depend upon the chemical composition of the iron used. We lay it down as a principle, that the combination of iron with other matter to form steel is to be a true compound of multiples; and we assert further that the best steel is the result of such a combination, and the greatest number of the compound elements. The latter part of the above declaration has been proved by experience; the first part is a true deduction from the works of the Creator. There is no finished form in the whole range of the creation but is the result of multiples of equal space, filled with matter of various kinds.

In converting iron into steel, we have to combine it with such quantities of other matter as to form of one or more atoms of iron, one atom of steel. Steel is a new metal; it is neither iron, glass, carbon, nor anything but steel; it is distinct from iron and all its composing elements. Just as salt is distinct from muriatic acid, and distinct from soda, so steel is distinct from iron, or carbon, or sulphur, or silicon, or any other element. If ninety-nine parts of pure iron and one part of carbon form steel—we make use here of the true parts, instead of the equivalents, to be more explicit to those who are not versed in chemistry—ninety-eight parts of iron and two parts of carbon make better steel than the first; and ninety-seven parts of iron and three of carbon make cast-iron; we are compelled to keep within the limits of two per cent. of carbon, if we want to form steel. If 98 parts of iron, 1 of carbon, and 1 of silicon, form brittle, hard cast-iron; 98 parts iron, 1½ carbon, and ½ silicon, form steel; but 98 parts iron, 1⅞ carbon, and ⅛ silicon, form better steel. We have to keep within the limit of ½ and ⅛ silicon, if we want steel at all. If 98 parts iron, 1 carbon, ⅛ silicon and ⅞ sulphur, make rather brittle steel; 98 parts iron, 1½ carbon, ⅛ silicon and ⅜ sulphur, make a better article—it would be unwise to put more sulphur in. The same rule which guides our labours in these instances, is to be applied in all cases. Every addition of a new element requires an alteration in the quantity of the other components.

The various elements do not combine in equal weights with iron, nor in equal weights among themselves, to form the most perfect compound. We have no experience to guide us in determining the relative quantities of the various elements in steel; but science induces the conclusion that the elements in steel must be combined in the simple or compound ratios of their atomic weights. Good steel must necessarily consist of one or more atoms of iron, one or more atoms of carbon, silicon, phosphorus, and the other elements. The atomic weight of iron is 339.2, of carbon 76.4, of arsenic 470, of azote 88.5, of copper 395.6, manganese 345.0, phosphorus 196.1, silicon 277.4, and sulphur 201.1. All these elements, and still more, have been found in steel. They cannot combine in single atoms; that is impossible; there must be a starting point somewhere. If we commence with silicon, and argue that 1 atom of it combined with 25 atoms of carbon, the ratio of ¼ to 1¾ parts, then it will require 322 atoms of iron to make 98 parts of iron. If such are the combining numbers of these elements to form good steel, it is evident that, if there are more than 322 atoms of iron in the composition, the product will be a mixture of hard steel and soft iron, which of course will not make a reliable edge. If there are more than 25 atoms of carbon, or 1 and a fraction of silicon, the same thing will happen; for neither of them has any combination in steel. If there is more than 1 atom of silicon in 322 atoms of iron which is to be converted into blistered steel, we can well manage to put 25 atoms or 1¾ per cent. of carbon into it. But if 25 atoms of carbon and 1 atom of silex form the best ratio of alloy with iron to make steel, it is evident that, if there are 2 atoms of silicon to 25 of carbon, the compound is not good. If, in this instance, we alloy so much carbon with the iron as to produce 25 atoms of carbon to 1 of silicon, the iron will be converted into good cast-iron. Here we are impelled to the conclusion that similar conditions prevail between all the elements of steel.

We have it in our power to put as much other matter into iron as we please, if the iron is pure; but it is not in our power to combine it with a limited quantity of silicon; neither is it possible to remove all the silex from the iron, in the practical operations attending its manufacture. As the amount of silicon is to be very limited in steel, and as it cannot be removed from bar-iron or steel, it follows that its removal is to be accomplished before the iron is put into shape for conversion.

From the foregoing investigations, we are led to conclude that steel is a definite compound of iron and other matter, and that silex is the chief obstacle to the formation of such a compound. All our energies are therefore to be directed against silicon, or silex; because, if there is too much in the iron, it will degrade the steel. There never can be too little silex in iron to make good steel of it.

How far practice confirms this theory, we will endeavour to show. The East Indians, in making their iron for wootz, pound the ore very fine, and free it by washing, as far as possible, from all impurities. They then melt it in a small furnace, in a very short time, without lime or other fluxes, and obtain but one-fifth of the iron which the ore contains. The remaining four-fifths are converted into slag, which absorbs as much silex as its constitution will admit of; though that cannot be much, as the ore is pure, and the cinder has therefore to absorb its silex from the charcoal and the in-wall of the furnace. We see here how much care is taken to remove the silex at first, and the immense loss of iron that results from its removal.

In making natural steel in Germany, the same principles are carried out, though not to so great an extent. The steel-ore of that country is naturally pure; but it is still cautiously selected with respect to the making of steel. The blast-furnaces where these ores are smelted are well supplied with charcoal, and in most cases work without flux. Limestone, as a flux, is avoided as much as possible. Most of the ores contain a large amount of manganese, which fluxes the silex, and is in all cases the most efficient flux. It is a generally diffused error that manganese is essentially necessary to manufacture good steel; there is no magnesium found in any steel; it serves in every instance to absorb the silex.

The crude iron of the Germans, which is highly purified, and contains hardly anything but iron, carbon and silicon, loses in the first operation in the forge, where it is converted into crude steel, twenty-five per cent., and in each subsequent refining heat from six to eight per cent.; so that, on an average, not more than fifty per cent. of partly iron and partly steel are obtained. Probably not more than twenty-five per cent. of good steel could be obtained from the crude iron.

The process by which Swedish bar-iron is made, is that which is in general use in this country, and has already been described. The difference in quality is chiefly caused by crude iron and labour. Common Swedish bar is not particularly good; we have, if not superior, at least equal qualities of charcoal-iron, even for steel-works. The Swedish and Russian iron of which common shear-steel is made, is, however, more uniform and pure than ours—the consequence of more labour and material spent in making it. The best Swedish iron, that of which the finest English steel is made, is not refined in what is called the German forge, but by a different process. The forge-fire is not lined with iron, or only on two sides; very little iron is melted in at one heat; no slag, scales or ore are used for boiling; and the whole process goes on with great slowness and regularity. Much coal is used, much iron wasted, and a great deal of labour spent in the operation. The iron is very superior, however, and is made nowhere but in the uplands of Sweden, near the ore-mines of Danemora.

The burning of steel, or the converting process, is as well conducted in this country as in any other; and there is also no difficulty in melting blistered steel, as well as tilting shear-steel. All we want is pure iron, and then there is no doubt that we shall be able to compete with the world in making steel.

It is out of the question to imitate Sweden, Russia, Germany, or any other country, in making iron or steel. We should cultivate our own means, without reference to their method, and succeed in our own way. We need not copy the processes of other nations, no matter how highly cultivated those processes may be. Ours are peculiar conditions, and in no way resemble those of any other people.

The only practicable way of making steel in this country is, first to make blistered, and then cast-steel, as is now done. But we want a better article than is made at the present time, and for this purpose we want better iron. There ought to be no difficulty on this score; for we have extremely cheap ore, and, in spending two tons of ore where now but one is used for the same amount of iron, and even more than that, there ought to be no difficulty in obtaining any quality of iron we desire. The magnetic ores at Lake Champlain are not surpassed in purity by any ore in the world; indeed, they are almost pure iron; but they are at present of little value. There is no reason why, from this ore, we cannot make iron equal to the best Swedish, and we could certainly make it more cheaply than we can import the common Swedish bar. Why do not the immense ore-beds in Essex county, New York, make good steel-iron? It certainly is not the fault of the ore; for that is of a very superior quality; nor can it arise from any scarcity of timber — that also is found in the greatest abundance. New Jersey possesses large deposites of material, and has every facility for making good steel-iron; yet her great advantages are not improved.

That Missouri and Wisconsin are not already in the market with the best iron in the United States, may be excused on the ground of the infancy of the iron business in those States. There is no doubt that they could relieve us from the contribution we at present pay to Europe for good iron; and we look forward with confidence to the period when our wants shall be supplied from those States.

Pennsylvania is the only State where steel is made to any extent; and seven-eighths of the whole amount manufactured in the United States is made by her. This is a little remarkable, as Pennsylvania is not favoured by nature for this quality. That State is hardly to be excelled in good merchant bar and foundry metal; but her hydrates, pipe-ores, and argillaceous iron-stones, are not at all qualified for making steel, or at least not good steel. The evil of our not being supplied with the best kind of steel-rods, is chiefly owing to the desire of reducing expenses in manufacturing. The finest iron-ores are wasted to make blooms worth thirty-five dollars per ton; while the judicious expenditure of but a few dollars more would convert the same ore into an iron equal to the common Swedish or Russian bar.

We are forced to the conclusion, from all we have observed, that the making of good iron is not generally understood, and that its importance is vastly under-rated. We consequently suffer under a heavy tax to Europe for steel which we might readily make ourselves, and which we shall have some hope of making, as soon as our manufacturers relinquish the vain attempt to make cast-steel of puddled iron, and natural steel of anthracite or hot-blast iron.

THE END.