THE
MANAGEMENT OF STEEL

GEORGE EDE

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BY

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PREFACE

TO THE FOURTH EDITION.

It has long been acknowledged that a small practical work upon the forging, annealing, hardening, and tempering of steel, and the case-hardening of iron, &c., was wanting amongst us; and it was with the object of assisting to supply this want, that I contributed my mite in publishing and giving my experience in the small work on the Management of Steel. How far my efforts have succeeded in supplying this want, I am not about to say; but the flattering reception and high praise it has received in passing through its several editions, have induced me to issue a much larger work in a revised form. I gave it the title of "The Management of Steel" when I published the first edition, simply because I could think of no other better; and I continue the name, because I am still unable to think of one more suitable. In this present attempt, my aim has been to write a work which would be found as useful to the novice or amateur mechanic as to the practical man; and I have endeavoured to word the subject in such a homely style, that persons totally unacquainted with the processes on which it treats will be able to judge for themselves as to the reasonableness of my remarks. It treats upon the manufacture of iron and steel, the choosing of steel for tools, forging iron and steel, annealing cast iron and steel, hardening and tempering of cast iron and steel, expansion and contraction of steel, shrinking of iron and steel, and the case-hardening of wrought iron, also the toughening of mild cast steel for guns, shot, railway bars, &c.

It will, I believe, be found in the future an inestimable treasure to those young mechanics who may possess it; for, in my opinion, if young apprentices were taught to make themselves better acquainted with the materials they work upon, likewise the materials from which their tools are made, and the management of that material, the advancement of the sciences would be greatly hastened, as this knowledge would increase the powers of the head to contrive, and the powers of the hands to execute. The inventions which become publicly known are few in comparison with those which spring up in the minds of ingenious mechanics and perish with the hour that gave them birth, through the want of a better knowledge of the properties of materials.

Although this work is not calculated to supply all this knowledge, still my aim has been to be of use and to contribute towards it. I cannot expect that it will entirely satisfy the wishes of all my readers; but I have dwelt at greater length on those subjects which I have considered from my own experience to be the most important, and I sincerely hope that its contents may prove of some benefit to those who may favour me by an impartial perusal.

GEORGE EDE.

PREFACE

TO THE SIXTH EDITION.

As there is a growing demand for 'The Management of Steel,' and the Fifth Edition being exhausted, the Author feels great pleasure in issuing this, the Sixth Edition. The present issue is simply reprinted from stereotyped plates. No changes have been made in the book for various reasons, among others, (1) because since the publication of the last edition no improved methods calculated to supersede those already given in the book for the proper and successful dealing with highly carbonised steels, subsequent to their manufacture, have been discovered by, or come within the knowledge of the Author; (2) because in reference to the subject of the treatment, management, and employment of the milder or less carbonised kinds of steel, such as are used for guns, &c., the Author has only just recently given minute, novel, theoretical, and practical information in a new and separate work entitled 'Guns and Gun Material,' which he cannot doubt will be acceptable to those interested in its subjects; and (3) because it is difficult, at present, to see in what additional way the book could be made more definitely and widely useful.

The present is an age in which every branch of technical knowledge is being prosecuted with ever-increasing earnestness. Every advance, no matter how small, is not only a national benefit, but also, in the end, a gain to the world. The Author is thankful that in his own department he has, from time to time, been enabled to render direct, special, and material service to the Government of his own country; and also indirectly by means of what he has written to benefit the cause of industrial science and art generally. He would, therefore, humbly urge all who may have an interest in this line of work to seek not only to attain to what is already known, but also to aim at contributing something additional, be it large or small, to the general manufacturing and labouring prosperity of our time.

It may here be mentioned that the right to translate this book into French and German has already been sold. This fact would seem to be a proof of the importance with which the subject of which it treats is being regarded abroad, and, consequently, of the necessity of our own manufacturers and workmen at home striving to maintain the highest possible proficiency in this branch of technical knowledge.

In conclusion, the Author would anew cordially thank those numerous journals and friends that have been pleased to express themselves in such impartial and favourable terms in regard to the value of the book now going forth again in the present edition.

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THE MANAGEMENT OF STEEL.

CHAPTER I.

MANUFACTURE OF IRON.

It was not my original intention to have explained the manufacture of iron, or the converting of iron into steel, or of casting steel into ingots; more especially when so much has been already written upon these subjects by those better qualified than myself; but, in answer to inquiries, and knowing that my little work is not complete without it, especially as it is likely to come into the possession of many whom books of a superior class never reach, on account of the high price at which they are sold, I have resolved in this edition, before explaining the processes of hardening and tempering steel, to introduce a slight sketch of the processes by which the material is prepared.

Iron is a mineral, and in its native state is called iron ore; it is probably the most abundant, useful and valuable of all the metals; in fact, its value is beyond all estimate. In nearly every country on the face of the globe, more or less of it has been discovered, and there is no doubt that it exists in all parts of the world; and, from its extensive and diversified utility it is one of the most useful substances known. It is a metal of great antiquity, and it is quite probable that it has been known and used from the earliest ages. But the circumstances which first led to the discovery of the ores, and the processes for reducing them into the pure metal, I must leave to the antiquarian. It would also be vain or idle of me to attempt to describe the numberless uses to which iron is applied, when they are so well known. Iron is seldom found pure—that is, it is the most difficult metal to obtain in a state fit for use ; but it commonly consists of an oxide of the metal—that is, it is in combination with oxygen. It is generally mixed with substances such as clay, flint and other impurities ; and, when *combined* with these substances in such quantity as to be worth separating, the substance is called iron-stone, or iron ore, and it is from this that the pure metal is extracted. The origin of the ores is beyond our knowledge ; but, as an instance of the great Creator's wisdom in providing for the comforts and welfare of mankind, those ingredients requisite for fusing and converting the ores into the pure metal, such as coal and limestone, are generally found in the same localities as the iron ores ; and in those countries where coal does not exist, wood is found in abundance.

Iron appears to be the only metal whose solutions, or combinations with oxygen, are not of a noxious nature. Mineral waters containing iron strengthen and increase muscular action ; and, in chalybeates, form the best tonics medicine can boast.

Iron is nearly eight times heavier than water ; its specific gravity is about 7·77. Its texture is fibrous ;

it is of a bluish white or peculiar grey colour, and is susceptible of a high polish. It is hard and sonorous; it also strikes fire with flint, and is highly elastic. For instance, if a bar is bent by pressure applied to it, and if this pressure does not exceed a certain quantity, the bar will resume its original form when the pressure is removed. It is also malleable, which is the property of extending or spreading under the hammer without cracking, but less so than gold, silver, or copper. It is also very ductile, a property similar to malleability, whereby it may be drawn out into wire without breaking. Its tenacity is very great, a property which enables it to sustain a very great pressure or force without crushing or breaking. In a cold state it is hard and stubborn, but at a red heat it is soft and pliable; and, at a white or sparkling heat, it may be welded either to itself or to steel. This is one of its greatest advantages. When two pieces of iron are equally heated, nearly to a state of fusion, they appear to be covered with a strong glaze or varnish. When brought together, they may be united by repeated blows of the hammer, or under pressure, and the union will not be visible. Although fire makes it soft and flexible, so that it can be easily bent, cut, punched, hammered, welded, and fashioned to any desired shape, the difficulty of melting malleable iron is very great. It requires the greatest heat of a wind furnace; but the nearer it approaches to fusion, the more malleable and ductile it becomes.

Iron is employed for mechanical purposes in three states; namely, that of cast iron, wrought iron, and steel.

Cast iron is the metal in its first state, rendered fusible by its combination with those two substances which chemists distinguish by the name of carbon and oxygen. Cast iron is that which results from the fusion of the iron ore with charcoal, coal or coke. Cast iron contains more carbon than steel; and, though it is principally in the superabundance of its carbon that it differs from steel, still, this is not the only cause of the difference between the properties of iron in the two states; for cast iron contains other impurities, which lessen the cohesion of its particles—impurities which steel is freed from. From its carbon, however, some correspondence in their characters is found to exist; thus, some kinds of cast iron admit of being made hard or soft, nearly in the same manner as steel; like steel, it assumes different degrees of hardness, according to the rapidity with which the pieces are allowed to cool. To harden cast iron, it requires to be heated to a higher degree of heat than that to which steel is subjected for the same purpose, and then suddenly cooled in cold water, which imparts to it whiteness of colour, and brittleness, and closeness of texture. Cast iron, when once hardened, will not admit, like steel, of that hardness being reduced by various gradations to any specific degree (called tempering); to soften materially, it must be submitted for some time to a whitish heat, and then very gradually cooled. Cast iron may be termed an impure carbonized iron.

Wrought iron is the cast, or pig, iron, freed from carbon and oxygen, and may be termed a nearly pure decarbonized iron, and, which has previously been remarked, is hardly fusible.

Steel is a combination of iron and carbon, in which the proportion of carbon is very small, varying from one to two per cent., and occupies an intermediate position between cast and wrought iron. Steel is less fusible than cast iron, but much more so than wrought iron.

We will now, for a short time, leave the subject of the properties of the iron in these three states, and commence with the manufacture of iron. By so doing, I presume, the whole subject will be the better understood.

From excavations called mines, by drainage, the employment of suitable machinery, and the industry of the miner, the ore is extracted in a very rough state from the bowels of the earth. It is this circumstance which ranks it among minerals. The first process, after the ore has been taken from the vein, is to calcine or burn the stones (a process called roasting), in order to expel the water, sulphur, arsenic, and other impurities with which the ores are combined, before being cast into the smelting-furnace. The roasting is effected by kindling large fires in the open air, and spreading upon the fires layers of ironstone mixed with cinders, coke-dust, and small coal, or other combustibles, such as wood and charcoal. Sometimes the roasting is performed in a kiln. The fuel and ironstone are put in at the top, and the roasted metal is taken out at the bottom. The loss of weight by the process of roasting is considerable, and in proportion to the quality or purity of the ore; the more impure, the greater the loss of weight. The process of roasting in the open air was at one time almost universally adopted; but some years ago, a Scotch gentleman, Mr. Neilson, introduced the hot blast for smelting the ore—that is, drying and heating the air before it is forced into the furnace. This invention has proved very valuable and economical. Since its introduction, the ore and fuel are frequently used in the raw state, and the process of roasting in the open air has been abandoned by many ironmasters.

The next process is smelting; the object of which is to produce the metal in a purer state, and to form of all the other substances (as far as it is practicable) oxides and slags. In the great iron-works, the ore, broken into small pieces and mixed with a portion of broken limestone, is thrown into the blast or smelting-furnace with coke, coal, or charcoal, in due proportion. The fire is raised to an intense heat by the combustion of the fuel and by the forcing in of a current or blast of air, either in a cold or heated state. It may be well to state here, that earths when alone are scarcely alterable by the most intense heat. Lime, however, although very infusible alone, as a flux promotes the fusion of the other earths which the ores of iron contain. If slags and metal are rendered perfectly fluid they will separate, in consequence of their want of affinity and their difference in specific gravity. Now, pure lime is very seldom, if ever, found native, but always in combination with acids, particularly carbonic acid: and in the intense heat of the smelting furnace the limestone parts with its carbonic acid, and, combining with the earthy matters of the ironstone, forms with them a liquid slag. The metal, as it melts, is deoxidized, and, being the heaviest, sinks by its own gravity, through the fuel, to the bottom of the furnace; more ore and fuel are supplied from the top, and the operation goes on until there is sufficient metal melted to constitute what is termed a charge, which rises almost to the aperture of the blast. The furnace is then tapped at the tap-hole, and the metal run off into moulds; these lumps are called pigs of crude or cast iron, and, for purposes where hardness without flexibility is wanted, the iron in this state is extensively used. Of course it will be necessary to re-melt it to cast it into the required form. The iron in this state varies greatly in quality, as may easily be supposed, from the difference of its chemical composition, some kinds being much purer than others. The quality of pig iron varies according to the purpose for which it is intended: it does not entirely depend upon the quality of the ore, but partly upon the purity of the fuel and the treatment it undergoes. The quality of the iron will vary with the quantity of carbon it contains; and those who are acquainted with and accustomed to the smelting operations, can generally form an opinion as to the state and quality of the metal as it flows from the furnace, and also from its appearance when broken.

The pig iron is assorted and classed by the iron-master as Nos. 1, 2, and 3, and differing in the amount of carbon combined. No. 1 is most highly carbonized, No. 2 less, and No. 3 contains the least. No. 1 runs so fluid as to be the most suitable for ornamental work; it runs fine enough to fill the sharp angles and figures of the mould into which it is poured. Cast-iron cutlery is manufactured from No. 1, and the carbon subsequently extracted from the articles. This is done by heating them for a considerable time in a furnace, and surrounding them on all sides with some substance containing oxygen, such as the pure oxide of iron, or any earthy infusible powders free of sulphur. The articles obtain, by this process of annealing and purifying, a considerable degree of malleability, and it is not impossible to render them capable of being welded. For large works or castings, which require great strength, the iron which contains a smaller proportion of carbon is preferable; and that which has the least carbon, and is freest from other impurities, is probably the most suitable for the manufacture of wrought iron. It may be observed, that the whiter the metal the harder it is also.

Cast-metal articles are made from the iron just treated of. The pig iron is melted at the foundries, and runs in a state of fusion into moulds, either direct from the furnace by channels cut in the sand, or into ladles to be conveyed to the moulds, which are made of either iron, sand, or loam, according to the required shape and size. The moulds (excepting those made of iron), are generally formed by means of a wood or iron pattern, which, sunk in the sand and then withdrawn, leaves a cavity of the desired form, into which the fluid metal is run. If the metal is large in quantity, it is agitated by the workman with an iron rod in order to consolidate the mass, and to get rid of any air or gas which may be confined in the metal; after which it is allowed slowly to cool and crystallize. When cold the castings are taken out. It is a curious fact that if the rod used for agitating the metal be a slender one, it is quickly converted into steel, though of very indifferent quality, which is a satisfactory proof that cast iron contains carbon, the steel-making principle.

Having stated that wrought iron is nearly pure decarbonized iron, it remains to be shown in what way the decarbonization is effected. The first operation for producing this change is called refining. The pig iron is re-melted in a furnace, called a refining furnace, and kept in a state of fusion for some time, exposed to an intense heat, and a blast of air forced over its surface in order to remove some of the impurities of the metal; it is then run out of the furnace into a large flat mould, and acquires the name of plate metal.

The succeeding process is called puddling; the object in this process is to free the metal of its carbon and oxygen. The operation is performed in a reverberatory or puddling furnace, where the cast metal is again re-heated, and converted into wrought iron by keeping it in a state of fusion for a considerable time, and repeatedly stirring it in the furnace, by means of tools, through a small hole in the furnace provided for that purpose; the whole of the metal is thus exposed to the action of the oxygen passing over it from the fire, at the same time adding matters capable of yielding oxygen. When the whole mass has received an equally high temperature, the oxygen and carbon which it contains unite and fly off in the state of carbonic acid gas, and as this takes place the iron becomes more infusible; it gets thick or stiff in the furnace, and grows increasingly so until it loses nearly all fluidity, and the workmen know by this appearance that it is time to submit it to the action of the hammer, or the pressure of a machine called a squeezer. The workman then divides, by means of his tools, the contents of the furnace into several parts, and forms them into separate balls. The balls being removed from the furnace, they are each subjected to a number of blows from a heavy steam hammer (called shingling), or to an intense pressure by a machine called a squeezer, by which the parts which still partake of the nature of crude or cast iron so much as to retain the fluid state are forced out, and the balls brought to an oblong shape, which is a shape more convenient for going through the rollers. The balls, after having undergone the first process of shingling by the hammer, or the squeezer, or any of the other machines invented for the purpose, are then called blooms. The bloom is then raised to the welding temperature in a re-heating furnace, and again submitted to the action of the hammer, or it is at once passed through large rollers having on their surfaces a series of grooves varying in size, and when passed through these grooves in succession, the bloom is reduced and elongated to a flat bar, to the required width and thickness. The bars, after they have passed through these rollers, are cut into convenient lengths by the shears; they are then piled or faggoted together into convenient heaps. Several of these piles or heaps, each of which is composed of five or six bars, are placed at once in the furnace, and, when heated to the welding temperature, they are taken out separately, and are again passed through the rollers to reduce it to the form of a bar; the grooves in these rollers differing according to the shape the bars are required, so that either round, square, flat, or various other shapes may be produced at the pleasure of the maker. Sometimes, in order to produce a superior kind of iron, the cutting and welding and rolling is again repeated. When charcoal is used as fuel in place of coal, or coke, for the manufacture of iron, a superior kind of iron is obtained; but, owing to the expense of charcoal, it is obvious that the iron thus made is more expensive. The bars having received their various shapes from the rollers, are then straightened and sheared to the required sizes, weighed and ready for sale. By these processes the metal is thus converted from a fusible, hard and brittle substance, into a tough and elastic bar; in fact, it has been rendered malleable, ductile, more closely compacted, of a fibrous texture which is hardly fusible, and for purposes where lightness, strength, and durability is wanted, it is more extensively employed than cast iron. In this state it is known in commerce by the name of bar, or wrought iron; and it may now be considered a nearly pure decarbonized iron, and is ready for the smith, and the converter, to be made up or fashioned into the thousand varieties of articles from a needle to Sir William Armstrong's six-hundred pounder.

The loss of weight sustained by iron in the process of refining, puddling, hammering, and rolling, is considerable, generally amounting to one-fourth, and sometimes to one-half. Forged or wrought iron, like cast iron, varies greatly in quality, according to purity and treatment in its manufacture. Thus, some kinds are only tough and malleable at certain temperatures, whilst other kinds are tough and malleable at all temperatures; or, in other words, both when the iron is hot and when it is cold. There are four kinds of iron which require most to be treated of, the other kinds having qualities occupying intermediate positions between these varieties. Iron which is tough and malleable at all temperatures is the best and most useful, as it may be bent in any direction without breaking, both when it is hot and when it is cold. It may be known generally by the equable surface of the forged bar, which is free from cross fissures, or cracks in the edges, and by a clear white, small grain, or rather fibrous texture. The best and toughest iron is that which has the best welding properties, and which bears the highest heat without injury, and which has most fibrous texture, and is of a clear greyish colour. This fibrous appearance is given by the resistance which its particles make to separation. The next best iron, which is also tough and malleable in all temperatures, and which bears a moderately high degree of heat without injury, and which has also good welding properties, has a texture consisting of clear whitish small grains intermixed with fibres. Another kind is tough when it is heated, but brittle when cold, so brittle that it will sometimes break with a single blow of the hammer, or by a sudden jerk, which makes it unfit for axletrees, and other kinds of work where life and property are dependent upon it; but for some kinds of work that are to be exposed to the weather it is very useful, as it will resist the action of the atmosphere better than the other kinds of forged iron, or, in other words, it is less liable to rust; it may generally be distinguished by a texture consisting of large shining plates without any fibres. This kind of iron is generally called cold short iron. A fourth kind of iron (called hot short, or red short,) is extremely brittle when hot, and malleable when cold. This kind of iron at a red heat will hardly bear to be turned over the beak iron of the anvil into the shape of a ring, or collar, without breaking, neither will a small rod at the same heat stand to have a hole pierced through it without splitting, and it is never used for superior kinds of work, for a defective forging is sure to be the result if it is used; but owing to its being much cheaper than the superior kinds, and being very tough and ductile in its cold state, for many purposes it is a very useful iron. On the surface and edges of the bars of this kind of iron, cracks or fissures may be seen; and its internal appearance is earthy, dull, and dark. The cause of the brittleness in these two last kinds of iron is supposed by some to be the presence of sulphur and phosphorus in the iron. The young inquiring mind may be, perhaps, inclined to inquire how does sulphur and phosphorus get in the iron? The answer is, these impurities are frequently combined more or less with the iron ores, and in the roasting process they may not have been properly got rid of; or the iron may have absorbed these impurities from the fuel in the smelting furnace, and the subsequent processes of manufacture may not have properly purified the iron; but it is quite probable that there are other accidental causes which have the effect of rendering the iron brittle. There is no great difficulty in proving sulphur to be injurious to iron; for, if a roll of sulphur (commonly called brimstone) be held in one hand, and a piece of white hot iron be pressed against it with the other hand, the two bodies combine and drop down together in a fluid state, and form a brittle compound, which is neither ductile nor malleable. It is an indisputable fact, and well known to any practical man working at the welding of iron, that sulphur is injurious to the iron; for, if sulphur be present in the fire, the iron will not weld.

CHAPTER II.

MANUFACTURE OF STEEL.

STEEL is a compound of iron and carbon, sometimes formed from wrought iron by heating the wrought iron in contact with carbon, and sometimes formed from cast iron by depriving the cast iron of all impurities except a small portion of carbon. The proportions of iron and carbon vary in the different qualities of steel; but in that used ordinarily the carbon rarely exceeds two per cent.; for some purposes it is as low as one per cent. Good ordinary tool steel contains about one and a half per cent. of carbon. Different kinds of iron produce steel of different characters, and different qualities of steel are used for different purposes.

In this country the most common mode of manufacturing steel is by a process called cementation. Mr. Bessemer has, of late years, however, introduced an entirely new system of manufacturing steel. By his process steel can be manufactured of any degree of hardness direct from the cast iron, without the intermediate operation of rendering it malleable, or, in other words, without the intermediate operation of puddling, &c. The principle of the process consists in directing a blast of cold air upon molten cast iron, the cold air ignites the carbon contained in the cast iron, and causes an intense combustion, and the carbon is consumed; and by this means the cast iron is decarbonized to the state of good tool steel, or to mild welding steel, or to the state of malleable iron, according to the length of time the combustion is continued. As carbon has a strong affinity for oxygen, and cast iron containing more carbon than steel, and steel being a compound of iron and carbon, it will be seen readily that if all the impurities of the cast iron can be got rid of, and the process of combustion can be stopped when the metal is decarbonized to about one or one and a half per cent., good steel must be the product. Mr. Bessemer can manufacture steel, of any degree of hardness, by continuing the process of combustion until the whole of the carbon is consumed, and then adding the required quantity of carbon to form steel by a subsequent operation.

Mild cast steel, or welding cast steel, as it contains a smaller proportion of carbon than ordinary cast steel, is being more and more used, and is gradually superseding the use of cast and wrought iron; and there is good reason to believe that steel of excellent quality, for numerous purposes, will, at no distant period, be manufactured cheaper than wrought iron is now produced by the operation of puddling.

The furnace in which iron is cemented and converted into steel, called a converting furnace, has the form of a large oven, constructed so as to form in the interior of the oven two large and long cases, commonly called troughs or pots, and built of good fire-stone or fire-brick. Into each of these pots layers of the purest malleable iron bars, and layers of powdered charcoal are packed horizontally one upon the other to a proper height and quantity according to the size of the pots, leaving room every way in the pots for the expansion of the metal when it becomes heated. The bars are cut to certain lengths, ten, twelve, or more feet, according to the lengths of the pots. A hole is left in the end of one of the pots, and three or four bars are placed in such a manner that they can be drawn out at any period of the process and examined. After the packing of the pots is completed the tops are covered with a bed of sand or clay. This is to confine the carbon and exclude the atmospheric air. All the open spaces of the furnace are then closed, the fire is kindled, and the flame passes between, under, and around these pots on every side, and the whole is raised to a considerable intensity of heat. This heat is kept up for eight or ten days, according to the degree of hardness required. On the fifth or sixth day a test bar is drawn out of the converting pot for the purpose of judging whether the iron is at its proper heat, and to test the progress of the carbonization. At this period of the process the film of iron is generally distinguished in the centre of the bar, and the fire is generally kept up for a day or two longer in order that the iron may absorb more carbon. If, again, upon the trial of a bar, the cementation has extended to the centre, or, in other words, if the bars of iron have absorbed the carbonaceous principle to their innermost centre, the whole substance is converted into steel, and the work is complete. The fire is withdrawn or extinguished by closing the vents, and the mass is left to cool for several days. The furnace may contain, according to its size, from ten to thirty tons of iron at each charge, and the whole process occupies fourteen or fifteen days.

By this process, carbon, probably in the state of vapour, penetrates and combines with the iron, which is thus converted into steel. The properties of steel being influenced by the properties of the iron from which it is manufactured, those only who possess a knowledge of the properties of the iron used are enabled to prepare steel fitted for any required purpose.

The properties of iron are remarkably changed by cementation, and it acquires a small addition to its weight, in proportion to the carbon it has absorbed from the charcoal. It is much more brittle and fusible than before, and loses much of its ductility and malleability, but gains in hardness, and elasticity, and sonorousness. The texture, which was originally fibrous, has by the process become granular ; and its surface acquires a blistered character, and presents, when broken, a fracture much like inferior iron.

The continuance of the process of cementation introduces more and more carbon ; and, if the cementation be continued too long, or, if the heat be too intense, the steel becomes porous, more brittle and more fusible, in which state it is more difficult to weld ; but, if it has not been over-cemented, it retains the property of welding, and may be welded either to itself or to iron. But the most important alteration in its properties is, that it can be hardened by heating it to a bright red heat, and suddenly quenching it in cold water, which is a property it did not possess when in the state of pure malleable iron; and it is to its carbon that it owes this most valuable property. By the application of heat, hardened steel may be softened down again to any requisite degree. The process of reducing the hardness of steel is called tempering.

It may be well to state, that some kinds of malleable iron may also be hardened in a small degree by heating to a red heat and suddenly quenching in cold water; but the effect is confined to the surface, except, as it very often happens, that the iron contains veins of steel. Pure malleable iron, however, does not possess hardening properties; it should be equally soft, whether suddenly or slowly cooled. Although pure malleable iron does not possess hardening properties, still, it is rendered more rigid by being suddenly cooled. This effect is owing to the compression of the particles into a denser state; and, for some purposes where stiffness combined with a certain amount of flexibility is required, small lumps of pure malleable iron are the better for being immersed in water.

The contractile forces of large lumps of malleable iron when plunged into water will induce strains, which have a tendency to rend open the interior of the mass. The water acting suddenly upon the surface causes the compression to be too sudden, consequently it would be disadvantageous to immerse a large mass of pure malleable iron in cold water. When a lump of pure malleable iron is required more rigid than when in its natural state, and less rigid than when immersed in cold water, it may be heated to a bright red heat and cooled in oil. The oil acting less suddenly than water upon the iron, it is obvious that an internal fracture is less likely to occur.

Iron prepared by the process previously mentioned is called blistered steel, from the blisters which appear on its surface, the blisters being caused by the long continuance of heat, and probably the expansion of air within these blisters. When the bars of blistered steel are heated and drawn out into smaller bars by means of the hammer, it acquires the name of tilted steel. Spring steel is the blister steel, simply heated and rolled, but frequently the iron is specially cemented for spring steel; by the compression and elongation of its particles under the hammer, or between the rollers, the material is improved increasingly in a remarkable degree.

Shear steel is produced by cutting the bars of blistered steel into convenient lengths, and piling and welding them together, by means of a steam-hammer. Striking in rapid succession upon the steel, it closes the seams and removes the blisters. By this rapid hammering the steel is kept in better temper, and fewer heats are required for the same work. The bars, after being welded and drawn out, are again cut to convenient lengths, piled and welded, and again drawn out into bars. It is then called double shear steel; hence, the name, single or double shear steel, according to the extent of the process of conversion. The bars are then ready for forging or rolling, according to the purposes for which it is designed. Shear steel breaks with a finer fracture, is tougher, and capable of receiving a finer and firmer edge and a higher polish than blistered or spring steel; and, when well prepared, it is not much inferior to cast steel. Shear steel is very extensively used for those kinds of tools and pieces of work composed of steel and iron.

Steel of cementation, however carefully made, is never quite equable in its texture, but the texture of steel is rendered more uniform by fusion; when it has undergone this operation it is cast steel. The best cast steel is produced by the invention of Mr. Benjamin Huntsman, of Sheffield, long since deceased. It is about a hundred years since it was first invented, but the process still remains in principle unaltered. Cast steel is made from fragments of the blister steel of the steel works. The process adopted is that of taking the blister steel, converted to a certain degree of hardness, and breaking it into pieces of convenient length, and weighing about a pound each; small crucibles, made of the most refractory fire-clay, which are capable of holding about thirty pounds or more in weight, are then charged with these fragments, and placed in furnaces similar to those used in brass foundries. The furnaces are furnished with covers and chimney to increase the draught of air, and the crucibles are furnished with lids of clay to exclude the atmospheric air. The furnaces containing the crucibles are filled with coke; and, for the perfect fusion of the steel, the most intense heat is kept up for two or three hours. When the steel is thoroughly melted, the melter, with a long pair of tongs, draws out of the fire the crucibles, and pours the contents in its then liquid state into ingot moulds of the shape and size required.

Although steel may be cast into ingots, it is too imperfectly fluid to be cast into very small articles. The crucibles, directly they are emptied, if they are sound, are returned into the furnace and again charged. The ingots of steel, once crude iron, but now changed by chemical action into cast steel, are taken to the forge or rolling-mill, and afterwards prepared for the market by hammering or rolling into bars or plates, as may be required, in the same manner as other steel, but with less heat and with more precaution; for the finest cast steel melts at a lower heat than any other steel, and is, therefore, more readily degraded in the fire, and is dispersed under the hammer or between the rollers, if heated to a white heat. Cast steel is the most uniform in quality, the hardest and the most reliable steel for cutting tools, especially for those made entirely of steel; and it is used for all the finest cutlery. Cast steel is dearer than the other kinds of steel, owing principally to the large quantity of fuel employed for its fusion. Its uniformity of texture enables it to take a fine firm edge, and receive the exquisite polish of which no other steel is in so high a degree susceptible; and its unrivalled superiority is acknowledged in all parts of the globe.

CHAPTER III.

CHOOSING OF STEEL.

It would be far easier for me to choose good from bad tool steel than to describe how to choose it. However, it may be well to state that, in choosing steel for cutting tools, where tenacity as well as hardness is required, some technical knowledge is requisite; although the differences of steel consist in its composition, it is not always necessary to subject it to chemical analysis in order to know its nature or character. The hardness and tenacity of steel, and the other properties of forging and welding, are very useful in distinguishing its qualities; but it is also necessary to ascertain these properties with precision. Marks or signs, by which to know by sight, by sound, or by strength good tool steel, are doubtless fallacious. Sight may afford sometimes an idea of the quality of steel, but it cannot be depended upon; even with great experience the result is always uncertain. The usual method of choosing steel for tools, which require a fine firm edge, is to break a bar, and to observe its fracture and select that which has a moderately fine grain; but this method is not always certain, as a variation in the fracture will be caused by the hardness or softness of the steel, or, in other words, by the difference of its temper, and the greater or less heat at which it has been hammercd or rolled, and some steel breaks of a very close grain, though of very indifferent quality. Several methods may be practised to ascertain the goodness of the steel, but if there is an opportunity of forging some of the steel it is advisable to do so; for, in my opinion, there is no better means of ascertaining its true character. In the first place it will be requisite to ascertain the highest degree of heat the steel will bear without injury, and then to keep always a little below this heat. Steel will not bear the same degree of heat, without injury, as iron; and steel which will not bear a high heat in forging will not bear a high heat in hardening. Blistered steel will resist a far higher degree of heat than highly carbonized cast steel, and good shear steel will endure a white flame heat without much injury; also a welding heat, if subsequently hammered. Although iron will bear a higher degree of heat than steel, yet steel will bear a far greater amount of hardship under the hammer than iron—that is, if the steel is cautiously heated. Good cast steel, which is suitable for the best kinds of cutting tools which have to endure a great amount of hard work, will not bear a white heat without falling to pieces; it will hardly sustain a bright red heat without crumbling under the hammer, but at a middling or cherry-red heat it will bear drawing under the hammer to a point as fine as a needle. Inferior steel, whether at a high or low heat, will not take such a fine point without splitting; and steel which will not take a fine point will not receive a fine firm edge, however skilfully the hardening and tempering may be performed.

There are some kinds of steel which are very tenacious, and which will take a moderately fine sound point, but, found deficient in their hardening properties, must be rejected for the best kinds of tools. Drawing a piece of steel to a point for testing it is a simple process; but, simple as it is, without some degree of attention it may produce false results and mislead the unwary. For instance, suppose we were to take a piece of steel cut from a bar, and commence to draw the extreme end of it to a point, if the extreme end of this piece of steel should happen to be even in a small degree concave, previous to hammering it, we cannot succeed in getting a fine sound point, although the steel should be the best Sheffield can furnish; for, in hammering it, the surface steel will overrun the centre, and cause the extreme end to be concave in a greater degree, and so long as this concavity exists in the end the steel cannot take a fine sound point. To avoid this, previous to commencing to draw the steel to a point, the extreme end of the piece of steel under trial may be either ground or filed to a rounded point similar to a centre punch but not quite so sharp; and, if the steel is tenacious, we will then succeed in drawing it to a fine sound point. Another method is to take a piece of steel just as it is cut or broken from a bar, without filing or grinding the end; heat one end of it to a cherry-red heat, and place it upon the projecting arm of the anvil, called the beak iron; the extreme end of the steel must be allowed to project over the beak iron so as not to make use of it, and then draw the steel to a gradually tapered square point; the small piece which was allowed to project over the beak iron must now be taken off by filing the steel through at the smallest part, after which it must be reheated and drawn to a finer point—that is, of course, if the steel will take a finer point without splitting. A welding heat will of course be required to test the welding properties of steel, but a welding heat should not be used when drawing the steel to a point to test its tenacity under the hammer. The extreme end of a bar of steel, in the state it leaves the tilt or the rollers, should not be taken for testing the quality of the steel; it should be rejected on account that it is looser and more porous than the other parts of the bar. For the sake of having a clearer idea of our subject, let us suppose the piece of steel to have received a fine sound point, and to be possessed of tenacity; the next operation will be to test its hardening properties, and to ascertain the degree of its tenacity. Tenacity is an opposite quality to brittleness; therefore, if the hardness is not accompanied with a certain degree of tenacity, the steel will be of very little service for the best kinds of cutting tools or for surgical instruments; therefore it becomes an object of importance to attend to this trial most carefully. The fine point of this piece of steel under trial may now be cut off, and the steel drawn out again under a low heat to a gradually tapered square point, but not so fine as before; it must then be plunged suddenly at this heat into pure cold water; the hardened point may then be tried with a smooth file, but I may state that this mode of trial with a file is defective, as files differ in hardness and only serve to tell in an imperfect manner the hardness of the steel; but if the point be broken off just enough to show the fracture, and it will easily scratch glass, it is a positive proof that the steel is hard and possessed of good hardening properties. The power used in breaking affords some knowledge of the tenacity of the steel. The broken point may be tried, and the degree of the tenacity of the steel ascertained, by placing it upon a piece of hard cast iron and crushing it under the face of a small hardened hammer; if the steel is good it will resist the crushing, and will cut the hammer's face, and bury itself in the cast iron. Inferior steel, having little or no tenacity, by this test will be ground to powder or crushed flat, nearly as easily as a piece of hard iron, and will not enter the cast iron. The degree of resistance of this grain of steel to the crushing power is a good rule by which to judge of it, for many kinds of steel feel hard to the file and yet show no tenacity. If the steel under trial will take a fine sound point, and after plunging it when red hot into pure cold water require a moderate force to break it, prove hard and will easily scratch glass and resist the crushing power, whatever its fracture may be it is good. The excellence of steel will always be in proportion to the degree of its tenacity in its hard state.

Another mode of trial, more simple and more economical, and less delicate than the former, and on the results of which full reliance may be placed, is carefully to forge a flat and a·diamond-pointed chipping chisel, which must be carefully hardened and afterwards tempered to a violet colour, after which to be ground upon the grinding stone, and then tested upon a piece of hard cast iron. If the chisels resist the blows of the hammer without breaking, and keep a sharp firm edge, full reliance may be placed on the quality of the steel; for in my opinion there is nothing which will indicate the quality of the steel better than a diamond-pointed chisel tested upon a piece of hard cast iron; for it supplies us precisely with the information we are seeking, namely, whether hardness and tenacity are combined in the steel. If the chisels prove good there is no waste of steel, for the result of the test is two good and useful tools. If the steel does not prove satisfactory the chisels need not be wasted, for they may be easily altered into either round, square, or flat punches for piercing hot iron; for the steel would be very bad indeed if it would not do for this purpose—so bad, that it could be readily detected by the eye in the first instance when the bar was broken. In general, in its soft state, a curved line fracture and uniform grey texture denotes good steel; and the appearance of threads, cracks, or sparkling particles is a proof of the contrary.

Good tool steel in its hard state on fracture presents a dull silvery appearance, is more close in its texture than annealed steel, and is of a uniformly white colour with the entire absence of sparkling particles. If aquafortis be applied to the surface of steel previously brightened, it immediately produces a black spot; but if applied to iron the metal remains clean, so that it will be quite easy to select such pieces of iron or steel which possess the greatest degree of uniformity, as the smallest vein, either of iron or steel, upon the surface, will be distinguished by its peculiar sign.

CHAPTER IV.

FORGING AND WELDING IRON AND STEEL.

The forge, furnished with furnaces, steam-hammers, cranes, anvils, swageblocks, and various other kinds of tools, is the workshop in which iron and steel are welded and fashioned with the hammer. Welding is that operation by which pieces of iron or steel, or steel and iron, are equally heated nearly to a state of fusion and appear to be covered with a strong glaze or varnish, are brought together and united by repeated blows of the hammer or under pressure, and the union not to be perceived.

The heat the iron receives in forging is judged by the eye, and is not commonly distinguished into more than these five degrees, namely, the dark-red heat, the blood or low cherry-red heat, the bright cherry-red heat, the white flame heat, and the sparkling or welding heat.

The dark-red heat is not visible in daylight, but shines in the dark with a brown colour, and is used only when stiffness and elasticity are required.

The blood or low cherry-red heat is used to give a fine polish or skin to the iron.

The bright cherry-red heat gives the thin scale or oxide on the iron a black appearance; and forgings of any description ought to be smoothed and finished at this heat.

The white flame heat is that which gives the scales and the iron the same colour, and is used for forging, or changing the form, of iron when welding is not required.

The sparkling or welding heat is that which gives the iron the appearance of being covered with a glaze or varnish, and is used for uniting two or more pieces of iron together, or a multiplicity of pieces into a solid mass.

The heat required for welding iron varies in some degree with the purity of the iron. Pure fibrous iron will bear almost any degree of heat without much injury, if not too long exposed to the heat; while impure iron bears but a moderate degree of heat without being melted or burnt.

Although iron requires to be heated nearly to a state of fusion before it can be welded (at least when heat alone is applied), still care must be taken to prevent the iron from running, or it will make it so brittle as to prevent its forging, and sometimes so hard as to resist the cutting tool, or the file. This accident will sometimes occur with the most skilful workman; and, when it does occur, the whole of the iron which is injured by the extreme heat should be cut off and rejected. If it cannot conveniently be cut off, the whole of the forging ought to be rejected, more especially if life or property is depending upon it.

The ordinary fuel used for the forging of iron in this country is coal; and, from its abundance and cheapness, it is more frequently used in forging steel than either coke or charcoal. Charcoal, on account of its purity compared with other kinds of fuel, is undoubtedly the best fuel that can be used for the heating of steel; but, owing to the scarcity of wood in this country, which makes it so expensive, it is seldom used. Coke, cinders and turf are the next best kinds of fuel for heating steel. Dry coal dust is injurious to steel.

The heaviest works or forgings are generally heated in air furnaces; and the heavy iron forgings are usually made up of scrap iron. The scrap iron is cut up into small pieces by the shears; it is then piled or faggoted into convenient-sized masses of one or two hundredweight, and placed in the furnace. The fire is urged, and the mass is raised to the welding heat; it is then withdrawn, and placed under the hammer, and united into a bloom or slab.

Blooms and slabs are sometimes made of the shavings that are cut from the iron at the turning or boring lathes. From one to two hundredweight of the shavings are thrown into the furnace, and spread evenly over the bottom; the fire is urged, and the workman observes through a small hole in the furnace-door provided for the purpose, and for the introduction of his tools, the progress of the heat. As soon as the iron arrives at the welding temperature, the workman collects it, and makes it up by means of his tools (a rod of iron with an eye at one end, and a hook at the other), and while it is yet in the furnace, into a spherical form; he then rolls it about in the furnace, so as to insure an equable temperature to the mass, after which the furnace-door is lifted, and the ball removed from the furnace by means of a hand truck; the workman then grips it with a pair of tongs, and shingles it under a heavy hammer into a square or oblong bloom; after which the bloom is reheated to the welding temperature, and subjected to a second hammering, in order to get rid of all the dirt, or scoria, which may have got closed up with the iron. In order to make it more compact, and more thoroughly to condense the particles, it is then hammered into the form of a flat slab. Several of these slabs heated and welded together, form the masses of which large forgings are generally built up.

When a mass is too large to be handled conveniently by the forgeman with the tongs, a large iron rod is welded to it, to serve as a porter or guide rod, and the welding of the rod to the mass is performed in a variety of ways. The end of the rod is sometimes inserted into the mass within the furnace; and, when the whole is at the welding temperature, the other end of the rod is struck with the sledge-hammer, which welds it sufficiently to lift the mass from the furnace to the hammer. Sometimes the end of the rod is heated in a separate part of the furnace, and made to arrive at the welding temperature at the same time as the mass; and, when the mass is withdrawn from the furnace, the rod is withdrawn also, and generally welded on by the first blow of the hammer. Sometimes a part of the porter bar is made to form the core of the forgings, and the slabs or masses of iron which form the forgings are welded and built upon the bar. When a mass of iron or forging is too large to be handled by the forgeman with the porter or guide-rod, it is supported by a crane, which serves to swing it from the fire to the hammer; likewise it serves for the different changes of elevation which the work at times requires; it serves also for moving the work to and fro upon the anvil. A cross lever is temporarily fixed to the porter, the use of which is to enable the workmen to turn the work over so as to expose all the parts to the action of the hammer, when it is manipulated with the greatest ease; and the mere sight of the welding and manipulation of large masses of iron, when conducted by a skilful workman, is always interesting, even when of every-day occurrence.

The mingling of the fibres in the scrap iron is generally considered highly favourable to the strength of the forging, which probably it is when the scrap iron is of good quality; but scrap iron of an inferior quality, or a mixture of all qualities (however skilfully the operation of forging and welding may be performed), can never produce a forging so good as new bar iron of good quality, cut up into lengths, piled and welded.

The mingling of the good iron with the bad iron probably does have the effect of improving the bad iron; but the bad iron cannot have the effect of improving the good iron. But it may be said that the hammering has the effect of improving the bad iron, and without a doubt it does do so to a certain degree; and, if hammering improves bad iron, it must certainly improve good iron to a certain degree also, thus showing that new bar iron of good quality must certainly produce a better forging than scrap iron of bad quality, or scrap iron of all qualities; for the forging must certainly be more uniform in metal, and more uniform in temper, consequently it must be more uniform in elasticity and tenacity. The quality of iron is much improved by violent compression such as by forging and rolling. It gives much greater strength to the iron, by its being elongated and solidified, especially when it is not long exposed to violent heat; but when it is long exposed to violent heat, its particles undergo an injurious change of position, and the heat at length destroys its metallic properties; but, though iron is rendered malleable by hammering, still this operation may be continued so long as to deprive it of its malleability, also its fibrous character; and the more readily with the absence of a sufficient degree of heat.

When a large solid forging is required perfectly sound throughout the mass, and which is made up either with scrap or new bar iron, there is no better method than to forge it square; that is, with four flat sides. This plan is seldom adopted with a forging which is required round, on account of a greater amount of time being required to turn it in the turning lathe. Though this method is seldom adopted, it does not make it any the less effective in producing the soundest forging; as it must be evident to those who have ever thought at all upon the subject, that large forgings, which are hammered or forged round upon flat surfaces, or between the half circle swage tools, or even between the V swage tools, can never be so dense and solid as forgings which are forged square (with four flat sides.) A forging forged with six sides will always be denser and more solid than a forging which is forged round between flat surfaces; but it will be less dense, and less solid, than a forging forged with four flat sides, for these reasons, that the larger the squares, the more iron there is under compression at the same time, consequently the denser and more solid the forging becomes. Forgings made in dies are prevented from becoming hollow in the centre; but, with very large forgings, this method is quite impracticable.

When a forging is being made round between flat surfaces, there is such a small quantity of the whole mass under compression at one time, that every blow of the hammer tends to make the forging hollow or porous in the centre by forcing out the sides of the forging at every successive blow; the greater the force of the blows, the greater the effect in causing the forging to become hollow (commonly called spongy) at the centre; the less the force of the blows, the greater the effect in causing the forging to become hollow at the part between the surface and the centre, as every blow of the hammer has the effect of drawing and enlarging the outer case of the metal more than the inner part; consequently it must have a tendency to separate the outer part from the inner part.

It is more than probable that a very strong cylindrical iron forging (suitable for a gun, or for one of the parts of a built-up gun) may be made by taking six V shape rolled slabs, then to place them round a suitable core of iron, then to heat the whole to the proper welding temperature, and then hammering upon the six sides, and welding the whole into a solid mass. The mass may subsequently be rounded between V swage blocks; this will form a good foundation upon which to build a greater amount of iron.

It is quite probable (when rolling these slabs) that a projection could be left in one, two, or more places, upon one side of them, and in their opposite sides a kind of groove or cutting to correspond (as near as it would be practicable to make them) with these projections, so that with a little rough fitting these slabs could be dovetailed together, and made to hold themselves together whilst being heated in the furnace. Plain slabs could be held together by shrinking two or more rings upon them, or they could be held together by dovetailing short pieces of bar iron into them. After the slabs are welded into a solid mass and rounded between the swage blocks, a series of thick rings (made of rolled bar iron) must then be placed and welded upon the mass. These rings must not be welded up previous to welding them upon the mass, neither must they be formed by coiling a long bar upon the mass; the two ends of each ring will require to be scarfed in order that they may slightly over-lap each other when placed upon the mass, and not to form what is called a butt joint. The rings being ready, the forged mass must now be heated to a white flame heat, it must then be drawn out of the furnace, and the thick scale or oxide scraped off; after which, several of these thick iron rings (or as many as may be convenient) must be placed side by side upon it; the rings should be placed in such positions that their scarfed joints may not run in a straight line with each other; they may then be closed upon the forged mass between V swage blocks. The whole must now be placed in a suitable furnace, and uniformly heated to the welding temperature; after which, it must be brought to the hammer, and the whole welded between large V swage blocks: several more of the rings must then be placed upon the mass, and side by side with the first rings, and then heated and welded in a similar manner as the others, and so on until the desired length is obtained. If it is found more convenient to place and weld the whole of the rings at once upon the mass, it is advisable to do so; for the fewer the heats the better the forging.

By the above method, very few heats will be required; and we will have the fibre of iron running in the direction of the length of the forging, as well as in the direction of the circumference. The direction of the fibre is the strongest way of iron; and, let whatever method be adopted, we can only get the strength of the iron. To have the fibre of the iron running in the direction of the length of a rifled gun is probably of the greatest importance.

Steel, like iron, is improved by hammering and rolling; consequently, when a large cast steel block is required of great tenacity for a particular purpose, the metal is not run into a mould of the shape and size of the required finished dimensions, but it is cast into a short thick ingot and then hammered and drawn to the required finished dimensions, or it is rolled to the required finished dimensions between the rollers. Although the steel is improved by being elongated and solidified, still it is questionable whether this is the best way of producing the soundest steel block suitable for a large gun. If every particle of the metal could be made to become cool at the same moment, there would then be no question about this being the best method; but it must be borne in mind that a large mass of fluid steel cools very unequally: it cools in layers, and closes up like a series of hoops, and is subject to very great strains. It is obvious, then, that after the block is drawn out to the required finished dimensions, it still consists of the same number of layers; the layers of course are reduced in thickness, which is unfavourable to the strength of the block. These layers frequently have so feeble a cohesion as to allow of their separation by a very light blow.

For the reasons here given, we may conclude that, the thicker and the less in number these layers, the stronger the block must be.

It is quite probable, then, that the soundest forging may be produced by casting the block square at the breech end, and in order to save steel, to cast the other part of the block with six sides; the block may be cast longer and smaller in diameter than the required finished dimensions; then to upset it, so as to make it shorter and larger in diameter than the required finished dimensions; it may then be elongated and solidified by drawing it out again by the hammer to the required finished dimensions. The breech end should be hammered and left square, and the other parts of the block (after hammering upon its six sides), rounded between half circles or V swage tools (the V swage tools most preferred.)

Casting a steel block of the proposed shape, and giving it the proposed subsequent treatment, would cause more waste of steel, and raise the cost of the block; but it is quite probable that the superior soundness of it would more than compensate for the waste of metal, especially when the block is intended for the largest size gun. If it is intended to toughen this block of steel in oil, it may then be asked, perhaps, whether it is necessary to leave the breech end square until after it has passed through the process of toughening, or whether it will be better to turn it round. The answer is, if the block is bored out to form a tube with a solid end, previous to toughening of it, it will then be better to turn it round; but it is more than probable, if the part which is left solid is left square also, that it will favour the contraction in cooling; but it is not absolutely necessary to leave even this part square, but the extreme end may be turned and left concave in a slight degree.

If it was intended to heat and immerse the block in oil previous to boring of it, it would be better to leave it square (in the state it left the forge) until it had passed through the process; but to attempt to toughen it in its solid state would be a step in the wrong direction, as it would be sure to break.

A common smith's forge is the hearth or fire-place upon which ignited fuel is placed, and it very frequently consists of masonry or brick work. It is furnished with a water tank and coal trough, also with a pair of bellows for supplying the air. The bellows are worked by a hand lever; the small end of the pipe of the bellows passes through the back of the forge, where it is fixed in a strong iron plate, called a tue iron or patent back, in order to preserve the bellows from injury and the back of the forge from requiring frequent repair. The best position for the bellows is on a level with the fire place, although they are often placed higher, and the blast of air passes through a bent tube, in order to gain room.

Above the fire-place is a hood, which is sometimes formed of bricks, but it is more generally made of plate iron; this serves to collect the dust and the smoke from the fire, and leads it to the chimney, and thus prevents it from flying about the shop. The more modern forge is made entirely of iron; and the blast of air is supplied by a revolving fan, worked by an engine. The blast is communicated by a main pipe all round the smithy, and every fire has a branch pipe with a valve and handle fitted to it for regulating the blast. The tue iron at the back of this kind of forge is sometimes made hollow, so that a stream of water may circulate through it from a small tank placed behind the forge. The water keeps the tue iron from burning, or getting very hot, consequently it will last much longer than the solid tue iron; but, if the tank is not kept well supplied with water, this kind of tue iron will burn away much sooner than the others. Clean water should always be put into the tank, and the tank should be supplied with a cover to keep out dust and dirt.

A light crane is sometimes erected near the forge for managing the heaviest kinds of work done by hand forging. The forge is also furnished with a poker, shovel, and rake. In the smithy there are anvils, hammers, swage-blocks, flatters, tongs, chisels, gouges, top and bottom fullers, top and bottom swage tools, drifts, mandrils, flat, square, and round punches, and a multiplicity of other tools of various shapes and sizes ; and it is an object of much importance to have the hammers and other tools perfectly well secured to the handles, to prevent serious accidents.

Forges are sometimes constructed so as to be portable, when the bellows are most conveniently placed under the hearth, and worked by a treadle or hand lever. Sometimes the blast is supplied by a small revolving fan, attached to the forge ; the fan is driven by a fly wheel, turned by hand. Portable forges are generally made of iron, and those with the revolving fan are generally erected upon wheels, and are generally used by the amateur mechanic, by boiler makers for heating the rivets, and repairing their tools. Also on ships, and for various jobs on bridges, railways, &c.

For forging iron and steel, for hardening and annealing steel, the fire at the common forge is sometimes made open, and sometimes hollow. The fires are commonly of three kinds. The flat open fire, the stock hollow fire, and the stock open fire ; the size of which must be regulated by the requirements of the work.

The flat open fire, when allowed to burn itself bright or clear, is ready for the insertion of the work. This kind is generally used for forging and welding small kinds of work, such as the welding of small iron rods together, and the forging of small bolts and nuts, rivets, and small tools; in short, it is used for almost all single-handed work, and for some which is called double-handed work (that is, where the smith has an assistant.)

The stock hollow fire for forging iron is made by inserting the tapered end of a bar of round iron into the tue iron, after which a quantity of small wet coal is thrown upon the hearth and beaten hard round the bar with the sledge hammer; more coal is then added, and the hammering again repeated; and so on, till the coal above the bar is several inches in thickness, and about one foot more or less in width and length. After the hammering is completed, it is beaten close together with the slice or shovel to form a kind of embankment. This is called the stock. The bar is then withdrawn, the slice or shovel at the same time being held against the front of the stock to prevent the bar from breaking the front down. A second stock is then made opposite the first, but without the hole through the centre of it, as in the first stock. A fire is then made between the two stocks, and the work laid in the fire; the work is then covered over with some thin pieces of wood and some small pieces of coke, after which small damp coal is thrown on in a layer of several inches thick, and beaten down with the slice to form the roof. A steady blast is kept up all the time, and as the wood burns away the flame peeps through and forms the mouth of the fire: but the work is not moved till all the wood is burnt out, and the coal well caked together into a hard mass. More blast is then driven in, and the roof of the fire reflects an immense heat upon the work below it. After which the work can be moved about in the fire or withdrawn without risk of breaking down the fire. A lump of hard coke is generally placed against the mouth of the fire to confine the heat; and as the fuel in the inside burns away it is replaced by pushing in some small coal, or soft coke. Sometimes a small quantity of hard coke broken into small pieces is pushed in to give body or substance to the fire. This kind of fire is sufficiently powerful for a moderate share of those works which require the use of a light crane and the steam-hammer, and which cannot conveniently be heated in a furnace; it is used for welding shafts together, also for welding collars upon shafts, and various other kinds of work requiring the assistance of one, two, or more men; it is also used for giving a uniform temperature to large lumps of steel, but in heating this material it must be borne in mind that the blast must be sparingly used.

The stock open fire is made the same way as the stock hollow fire, with the exception of the covering in or roof. This is the most convenient fire for heating the steel when forging tools; it is also the most convenient for heating those kinds of tools requiring only to be partially heated and partially hardened, the remainder part requiring to be kept soft, such as cutting tools for the turning-lathe, cold chisels, drills, &c.; but for those kinds of tools which require to be heated all over or throughout their body, such as screw-taps, dies, circular cutters, &c., the hollow fire is the most convenient.

The hollow fire for heating the steel for hardening is built in a similar manner as the hollow fire for heating steel for forging, with the exception that a larger quantity of wood is required for centreing the arch.

In forging at the common forge, the fire of course must be regulated by the size of the work; and, in heating the work, if the flame break out, the coals must be beat together with the slice to prevent the heat from escaping. The fire should be free from sulphur, brass, copper, lead, tin, paint, or any other thing which would keep the iron from welding. To save fuel damp the coal, and throw water on the fire if it extends beyond its proper limits. To ascertain the state of the work it must be drawn partly out of the fire—that is, when the open fire is used—and thrust quickly in again if not hot enough. To make the iron come sooner to a welding heat, stir the fire with the poker and throw out the clinkers, as they will prevent the coals from burning. Care should be taken, either with iron or steel, not to use a higher degree of heat than is absolutely necessary to effect the desired purpose, with steel especially to use as few heats as possible. The too frequent and excessive heating of steel abstracts the carbon, and gradually reduces it to the state of forged iron again. This, perhaps, calls for a little explanation. When steel is at a low heat the carbon has a very slight affinity for oxygen; hence the steel suffers little change—the change which does take place is so slow that it is not perceptible till after many repeated heatings; but when steel is heated to a high degree in the open fire in the presence of oxygen, the surface becomes so oxidated that a scale of considerable thickness peels off, and with this scale part of the carbon is extracted from the surface of the steel, and, if the temperature of the steel is still further increased, its affinity for oxygen is also increased, and when approaching the point of fusion the affinity becomes very strong, and the combustion is, consequently, rapid; and at a melting heat, in the presence of a large quantity of oxygen, the carbon cannot exist in the steel—at least, only for a very short time. If further proof than this be required, the reader has only to consult the process of Mr. Bessemer in manufacturing steel or malleable iron direct from the cast iron. Steel which has been slightly overheated may be restored in a slight degree by giving it a judicious hammering at a lowered heat. This will, however, improve burnt steel but little, though the hammering will make the steel denser; yet no degree of heat or hammering will restore to steel the carbon or the original fineness of texture of which it has been deprived by being overheated.

The heat steel receives in forging must also, like the heat of iron, be judged by the eye; and the temperature suitable differs in some degree with its quality and mode of manufacture: the heat required diminishes with the increase of carbon. Thus steel requires much more precaution as to the degree of heat than iron, and does not bear the same degree of heat as iron without injury; but it will bear a much greater amount of hardship under the hammer than iron if it is cautiously heated.

Steel requires to be heated more slowly than iron, and requires more moving about in the fire in order to equalize the heat and to receive a uniform temperature throughout; it requires also to be drawn from the fire more frequently, as it requires to be well watched to heat it properly.

The tenacity of steel hammered at a low heat is considerably increased; and, in forging cutting tools, the hammering should be applied in the most equal manner throughout, and should be continued until nearly cold. But the effect of the hammering is taken off again, if the steel is heated to a high degree. When forging cold chisels, they ought always to be finished with the flatter; and they will stand better if the last blows are given upon their flat sides.

The elasticity of iron and of steel hammered cold is considerably increased, that is, providing the hammering is not carried to an extreme. Bell springs are sometimes made of sheet steel, and very frequently of hoop iron thus managed: straight edges, and the blades of squares as they are sold at the ironmongers' shops, are sometimes made of tempered steel. But they are more frequently made of sheet steel hammered cold, and they are not unfrequently made of hoop iron thus managed.

To change the form of iron when it is not necessary to weld it, the white-flame heat is used; and, according to the size of the work, it is battered by one, two, or more men with sledge-hammers. The hammers are generally slung entirely round, with both hands, and held nearly at the end of the handle; they are generally directed to fall upon the work at the centre of the anvil, and the work is gradually moved backwards and forwards to expose the required parts to the action of the hammers. Two gangs of men are sometimes required for the larger work done at the common forge; they relieve each other at intervals, as the work is very laborious. When the iron is nearly reduced to the required shape and size, the strength of the blows is reduced, and the hammers are made to fall upon the work as nearly flat as possible, in order to smooth the work; after which, the flatter or the swage tool is held upon the work, and the blows of the hammers are directed upon the head of the tools to finish off the work, the dexterous use of which saves much trouble in the after processes of chipping and filing.

When it is required to thicken any part of a bar of iron without welding, the operation called upsetting must be resorted to. This consists in giving it the white-flame heat at the part to be thickened, and, while one end rests upon the anvil, hammering at the other till the required size is produced. When the bar is large, if it be lifted and jumped upon the anvil, or upon a lump of iron placed upon the floor, its own weight will supply the required force for upsetting it.

When it is required to weld two bars of iron together, the sparkling or welding heat is used. The ends are first upset or made thicker by jumping them endways upon the anvil; each end is then bevelled off to a thin edge (called scarfing); the two ends are then placed in the fire, and raised to a welding heat, or nearly to a state of fusion: care is required that both arrive at the proper heat at the same time. The bars may in part be prevented from wasting by taking care to supply them at the heated part with powdered glass or sand just before they arrive at the welding heat; the sand or other material melts on the surface of the iron, and serves to form a flux or fluid glass which protects the iron from the impurities of the fuel and defends it from the air, at the same time uniting with and removing the oxide which may have been formed on the heated scarfs, the removal of which greatly facilitates the operation of welding.

When the two bars of iron to be united have attained the welding heat, they are taken out of the fire with the utmost dispatch; a good portion of the scale or dirt which would hinder their uniting is got rid of by striking the bars across the anvil: they are then placed in contact at the heated part, and hammered until no visible seam or fissure remains. If they have not been sufficiently united, the heating and hammering ought to be repeated until the work is perfectly sound.

The larger bars, such as heavy shafts for machinery, are generally part welded within the fire; the two ends are prepared so that one fits within the other (called the split joint); a V piece is cut out of the end of one bar with the chisel, and the end of the other bar is cut so as to fit into it; when the ends are properly fitted, they are placed in their proper positions in the fire, and when they arrive at the proper heat, they are welded together by striking the end of one of the bars with the sledge hammers, or by striking with some other contrivance, such as by a mass of iron suspended by a chain from the ceiling, while several men hold against the opposite bar to sustain the blows. This contrivance is far more effective than the blows of the sledge hammer, more especially when a thick lump of iron is placed against the opposite end; the heat is kept up all the time, and the whole is afterwards lifted from the fire, and finished upon the anvil. The amount of labour saved by this kind of joint for large works, in comparison with the scarf joint, is considerable; and it is probably the most effectual way of getting a sound joint.

When a thick lump is required on the end of a bar, it is frequently made by cutting the iron partly through in several places, and doubling it backwards and forwards according to the thickness required; the whole is then welded into a solid mass. Hammers are frequently made from the iron thus managed, as the iron is less liable to split than the plain bar of iron in punching the eye. Sometimes the iron is prepared for making a hammer, by welding a collar (made of a flat bar) round a bar of round iron; at other times a flat bar is heated at the end and rolled up similar to a roll of ribbon, and afterwards welded into a solid lump.

When a very thick lump is required on the centre of a long bar of iron, the method of drawing the two ends down from a large bar would be too expensive; the method of upsetting the bar would be impracticable, consequently a large collar is welded round the middle. But as there is great difficulty in getting a very wide collar soundly welded upon the bar, two collars half the width of the single collar are placed close together and welded upon the bar; the two collars give the bar a better opportunity of attaining the welding heat, and the union is made perfect. Sometimes a large collar is made upon a bar of iron by three or four pieces of a flat bar, heated and welded on separately; and this is probably the most effectual way of getting a very large collar upon the bar. It is obvious that the method of drawing the two ends down from a large bar will produce the soundest work (providing the bar itself be sound); but then, as I have just remarked, with very long bars it would be very expensive. When a very large steel collar is required to be welded on to a bar of iron, it becomes absolutely necessary to weld it on in pieces; because, from the greater fusibility of the steel, it is quite impracticable to weld a very wide steel collar (made in one piece) upon a bar of iron, for the steel will burn before the iron enclosed in it can attain the welding heat.

It is well known to practical men that a collar made from very fusible impure iron can never be effectually welded upon a bar of pure fibrous iron, because an impure iron, from its greater fusibility, will not stand the heat which is suitable to weld pure fibrous iron; consequently, when a piece of a pure fibrous iron is enclosed in a collar made of an impure fusible iron, the impure iron must burn before the pure fibrous iron can attain the heat suitable to weld its own material; besides, a pure fibrous iron requires a flux to be applied to it just before it arrives at the welding heat, while an impure iron forms a flux or slag from its own material; and, as an impure iron burns at a heat which is not sufficient to weld pure fibrous iron, it forms a slag between the two irons and hinders their incorporation. Again, if the two different irons were heated at different temperatures suitable to both, they could not even then be effectually welded together; because the force of the blows requisite to weld pure fibrous iron will disperse fusible impure iron. It is evident, then, that if there is great difficulty in welding a collar made of an impure iron upon a bar of pure fibrous iron, that there will be still greater difficulty in welding a large steel collar (made in a single piece) upon a bar of iron; therefore, when a very large steel collar is required upon a bar of iron, it becomes absolutely necessary to weld it on in separate pieces.

To weld steel to steel, then, or steel to iron, without injuring the steel, is an operation which demands great nicety of management, as there are a variety of degrees of heat to deal with. The welding heat of steel is lower than that of iron, from its greater fusibility; and the more fusible the steel the less easily it welds. Highly carbonized cast steel (tool steel) welds with greater difficulty than mild cast steel, which contains a smaller proportion of carbon; although mild cast steel is superior in its welding properties to highly carbonized cast steel, still it is inferior in its hardening properties. The steel which contains the smallest proportion of carbon, and which has the most fibrous texture—as, for example, the double shear steel, is the most easily welded; for, it having been most wrought by the hammer, or between the rollers, its fibrous character is partly restored.

Cast steel is the most difficult to weld, on account of its having been in a state of fusion, which entirely destroys its fibrous texture.

The material (sand) which is used to serve as a flux to protect and fit good iron for welding does not answer well for steel, because it is too refractory; and some kinds of cast steel burn or melt at a lower heat than sand, consequently the sand would be useless to serve as a flux.

The material used to serve as a flux for welding blister and shear steel is generally powdered borax, though sand is frequently used. But ordinary cast steel, from its greater fusibility, requires a still more fusible flux, and, for this purpose, sal ammoniac is mixed with the borax.

The borax of commerce, as sold by chemists, is composed of a very large proportion of water; consequently it requires to be put into an iron or other suitable vessel and boiled over the fire till all the water is expelled, after which it requires to be ground to powder before it is used. When it is required to mix sal ammoniac with borax, the proportions are about sixteen parts of the borax to one of sal ammoniac.

The material used to serve as a flux for steel must be suitable to protect it, at the same time purify the surface; and should always be applied just before the metal reaches the welding heat, no matter how high or low that heat may be.

When it is required to weld two bars of blister or shear steel together, they are heated at the ends and upset or made thicker and afterwards scarfed the same way as iron bars for welding; the two ends are then heated to a moderate white heat and sprinkled with borax; the temperature is then raised to the proper welding heat suitable to the steel. Care is required that both arrive at the proper heat at the same moment, after which they are taken from the fire to the anvil and hammered till no visible seam remains.

When it is required to weld two large bars of cast steel together, which are not too highly carbonized, they are first heated at the ends and upset, and scarfed the same way as other bars for welding, with the exception that a thin cutter-hole is punched in the scarfed ends of the cast steel bars for riveting them together previous to welding.

Cast steel will not admit of being made so soft in the fire as iron or the other kinds of steel; consequently, when it is first struck with the hammers, the scarfs are more liable to slip off each other; and it is to guard against this inconvenience that the bars are riveted together, and not with the view of gaining strength in the joint, as might be imagined. When the bars are riveted together, the joint is placed in a bright, clean, and close fire, the steel is heated as high as it will bear without much injury, or as hot as can be done with safety; the material to serve as a welding powder or flux (calcined borax and sal ammoniac) is then put on the heated scarfs, after which the steel is carefully turned over in the fire and supplied with more of the powder. It is not necessary to draw the steel out of the fire to put the powder on, as the powder may be spread on the heated scarfs by a slip of sheet iron, the end of which requires to be made like a spoon; but, whilst in the act of spreading the powder upon the steel, the blast must be sparingly used, or it would blow the powder from off the spoon, and it would be wasted in the fire.

The sal ammoniac cleans the dirt from the steel, and the borax causes it to fuse before it attains that heat which will burn the steel; and when at the point of fusion it is lifted from the fire to the anvil and hammered and welded much in the same manner as other kinds of steel or iron. The blows are given gently at first, owing to the weak state the steel is in by the lessening of its cohesion by the heat. But, as the cohesion of the steel increases, the strength of the blows is increased also; if the bars are not sufficiently united the heating and hammering must be repeated until the joint is perfectly sound.

When it is required to weld steel to iron, the steel must be heated in a less degree than the iron, consequently they ought to be heated separately; and, when they arrive at the welding temperature suitable to both, they must be brought to the anvil, the dirt which would hinder their incorporation must be brushed off, they must then be placed in contact with each other at the heated parts and united by hammering. Should there happen to be any defective part in the weld, the heating and hammering must be repeated, taking care in the second heating (as far as is practicable) to keep the iron facing the hottest part of the fire, or the steel is liable to be injured.

When a large quantity of steel is required to be cut down into suitable lengths for screw taps, or similar articles, it is generally the smith who is appointed to cut it to the required lengths; and, whilst in the smithy, perhaps a few words upon the cutting of cold steel with the cold chisel, will not be out of place. I was once working for an employer who had a large order for screw taps, and I was appointed to cut the steel into lengths with the rod cold chisel (a short thick chisel with a hazel stick twisted round it to form the handle); but, previous to commencing to cut the steel, my employer informed me that he did not much approve of cutting the steel down into lengths with the cold chisel, as he had discovered a fracture in a large number of his taps which he had previously hardened, and, as this fracture was at the end of the taps, he was inclined to think that it was caused in the cutting and breaking down of the steel. Being myself rather inquisitive in such matters, I closely examined the taps, and found that the fracture was not caused by the cutting and breaking down of the steel, but by boring the centres too large and too deep. Though the fracture in this instance was not caused at the time of the breaking down of the steel, still, it very frequently happens, that an internal fracture is caused in the steel in cutting and breaking it into lengths, especially when the steel is nicked with a dull or blunt chisel; and the fracture will not at all times be visible until after the steel is hardened; but after it is hardened it can readily be detected. As a remedy to prevent this fracture, I would advise those who cut their steel down into lengths with the cold chisel, always to keep a good sharp edge upon the chisel and nick the steel all round, instead of only upon the two opposite sides as is often done. The steel will then break easier and be less liable to splinter on the outside, and less liable to fracture inside.

When the steel is too large to be conveniently cut and broken cold, it will sometimes be more economical to heat the steel to a red heat before cutting it; sometimes it will be more economical to cut it into lengths in the turning lathe by means of an instrument called a parting tool.

Steel is sometimes heated and sawn into lengths by means of a circular saw driven by machinery, but this is far from being the best method for cutting the best kinds of cast steel.

Most workmen when cutting steel down into lengths with the cold chisel, adopt one or other of the following methods: they first nick the steel with the chisel, and then lay the cut across the square hole of the anvil, in order that the steel may lie hollow, and then strike it with the pane of the sledge-hammer; sometimes the chisel is held in the nick, while the nick lies across the hole of the anvil, and the blows of the hammer directed upon the chisel; the steel is sometimes made to lie hollow by laying it across the anvil, at the same time hold a rod of iron (generally the poker) beneath it near to the nick, and then break it by striking with the sledge-hammer, the blows of the hammer being directed upon the nick; sometimes the steel is broken by first nicking it with the chisel as before, and then striking the bar across the beak iron of the anvil.

It may, perhaps, be thought by some, that there was no necessity for speaking upon these simple methods of cutting and breaking steel into lengths; but I have thought it necessary to notice them, on account of having witnessed very serious accidents happen by adopting these methods, by the steel flying and striking workmen who happened to be working near where steel was being cut and broken. In my opinion any contrivance, or any hint which may have a tendency to prevent accidents, cannot be useless.

When it is necessary to cut a large quantity of steel into lengths with the cold chisel, and where a number of workmen are at work, a piece of temporary boarding ought always to be placed in front of the anvil, at about two or three yards distant from the anvil; the chisel should be sharp, and also properly well secured to the handle, as accidents have happened from the neglect of this. The striker ought not to stand in front of the steel, as it is very dangerous to do so; but he should stand rather on one side, for, if the steel is very hard, it will sometimes unexpectedly break with the first or second cut of the chisel. The steel ought not to be laid across the hole of the anvil to break it, as this is a very dangerous practice (although frequently adopted.) A better plan is, after the steel has been nicked on all sides with the chisel, to place the swage block upon its edge, and then put the steel through one of the holes, the piece of steel to be broken being allowed to project through the hole. It may then be broken off with a very light blow of the hammer, and the piece of steel will drop down close to the swage block. If these methods be strictly adhered to, many a serious accident will be prevented.

CHAPTER V.

ANNEALING OF CAST IRON AND STEEL.

There are many substances which, when rapidly cooled after having been heated, become hard and brittle. Glass, cast iron and steel possess this peculiarity. Although hardness (as will subsequently be shown) is such a useful and important property in steel, still, when steel becomes hard in the process of manufacture, or in the process of forging it into various kinds of articles, the hardness becomes then an inconvenience, at least, when the articles require to be turned, engraved upon, filed, or screwed; and the only remedy for removing this inconvenience is to reheat the steel, and allow it to cool very gradually. This process is called annealing. Glass vessels are generally annealed by permitting them to cool very gradually in longer or shorter time, according to their thickness and bulk, in an oven constructed for the purpose. Steel is annealed in a variety of ways. Some artists anneal steel by heating it to redness in the open or hollow fire, and then burying it in lime; others heat it and bury it in sand; others heat it and bury it in cast iron borings; others heat it and bury it in dry sawdust, and some anneal it by surrounding it on all sides in an iron box, with carbon, and then heat the whole to redness. This latter process is undoubtedly the most effectual method of annealing steel; that is, providing the steel is not heated to excess. When this method of annealing steel is adopted, a layer of wood charcoal, coarsely powdered, is placed at the bottom of an iron box, and then a layer of the steel, upon this another layer of charcoal, and upon that again another layer of steel, and so on until the box is nearly full, finishing with a layer of charcoal. The lid of the box must then be put on, and the box luted with clay or loam, in order to exclude the air. The whole may then be placed in a furnace or hollow fire, and gradually heated to redness. The size and shape of the box, it is obvious, must vary with the shape and quantity of the steel requiring to be operated upon. It must be borne in mind that the same care is required in heating the steel in this process as there is in heating the steel for forging or hardening. Overheating the steel in any one of the processes is hurtful. It is seldom necessary to keep up the heat beyond the time that the contents of the box are uniformly heated, unless the steel should happen to contain particles of hard impure iron, when it would then be necessary to keep up the heat for several hours. When the whole has arrived at the proper temperature the box may then be withdrawn from the fire and buried in some hot or cold ashes to become quite cool, or may be left in the fire, and the fire allowed to cool down. It is quite necessary, however, that the steel should be protected from air until it becomes cool. After becoming cool, and being taken out of the box, it is then in a fit state for the fitting or turning room. The steel will then be very soft and free from those hard bright spots which workmen call pins, and which are impediments to the filing and turning of steel. If the steel and the charcoal have been properly protected from the air, the surface of the steel will be as free from oxidation as it was before it was heated, and the greater portion of the charcoal will remain unconsumed, as it has been preserved from combustion; consequently it has undergone little change, with the exception of being hardened, and its colour changed to a deeper black. It can therefore be put aside to be used again. This mode of annealing prevents the steel from losing any of its quality; but the steel absorbs by the process a small quantity of carbon, which is favourable to the steel in the hardening process, which will be explained in the chapter upon the hardening of steel. It may be well to state that animal charcoal is sometimes used as well as wood charcoal for annealing.

Less than a certain heat will fail to make steel hard, but, on the contrary, will soften it; and sometimes this effect is useful. For instance, suppose a piece of steel (for any special purpose)) is wanted in a hurry, and suppose the steel has become by hammering too hard to be dressed with the file, or cut with the turning tool, and time will not admit of its being softened in a box with charcoal powder, the steel may be heated to a cherry-red heat in an open fire, then be drawn out of the fire, and allowed to cool down till the red heat is not visible by daylight, but can be seen in a dark place beneath or behind the forge, then to be plunged at this heat into cold water, and allowed to remain in the water until it becomes quite cool. When taken out of the water it will be found to be more uniform in temper than when it left the forge; consequently it will work more pleasantly with the file or the turning tool. This is a very expeditious way of annealing steel; but the steel will not be quite so soft as steel which is inclosed in the iron box, and annealed in contact with charcoal powder.

There are many who do not know the value of a good tool because the steel they work upon has not been properly annealed, and before the tool has half done its duty it is either worn out or wants repairing; whereas, if the steel had been properly annealed, the same tool would have lasted very much longer without needing repair. Steel required to be annealed in such large quantities as to make it inconvenient, or the expense of enclosing it in boxes too great, may be heated in a charcoal fire completely enveloped and protected from the air. After the steel has become heated to the proper temperature, the fire and the steel may be covered over with pieces of plate iron. The whole may then be covered over with cinder ashes and the fire allowed to go out of its own accord. It will thus be protected until it is cold. Charcoal, especially when it is used as fuel in the open fire, is consumed with rapidity, and therefore very expensive. The steel may, however, be heated in a cinder fire, which is less expensive in the cost of an equal measure and also in the rate of its consumption. This kind of fuel is not so pure as charcoal, but it is purer than coal, and affords a very moderate heat. When the steel is at the proper heat it must be taken out of the cinder fire and placed in an iron box containing coarsely powdered charcoal; the charcoal must completely envelop the steel, and the box will require to be covered up and luted with clay or loam, in order to exclude the air and preserve the charcoal for future use.

Cast iron may be annealed in a similar manner as steel. Cast iron in the state it leaves the moulds is always surrounded with a crust or coating, something similar to the coating of steel which surrounds case-hardened iron; and this coating is sometimes so extremely hard that the best file or turning tool will make no impression upon it, while the interior of the casting is soft and manageable. This hard crust is generally removed by the workmen either by chipping it with the cold chisel, or by grinding it on a large grinding stone, turned by machinery. But when the shape of the casting is such that this crust cannot conveniently be removed with the chisel or the grinding stone, annealing then is the most economical process, as it makes the whole casting soft and much easier to work, but still does not deprive it of its natural character.

To anneal cast iron the heat requires to be kept up much longer than for steel. Cast iron requires to have solid supports to keep it from bending or breaking by the heat. Cast iron, like steel, when annealed, is more uniform in temper; consequently it is less liable to alter its figure by a subsequent partial exposure to moderate heat, than that which has not been annealed.

The outside of cast iron, even when it is annealed, is always somewhat harder than the internal part, unless such processes be adopted as will abstract the carbon from the exterior part; but these processes, it is obvious, deprive it of its natural character and make it in the condition of malleable iron, but without the fibre which is due to the hammering and rolling. Cast iron cutlery is enclosed in boxes and cemented with some substance containing oxygen, such as poor iron ores free from sulphur, the scales from the smith's anvil, and various other absorbents of carbon. The boxes are luted in a similar manner as the boxes when annealing steel or case-hardening iron; they are afterwards placed in suitable furnaces and the cast articles are kept in a state little short of fusion for two or three days; they are then found to possess a considerable degree of malleability, and can be readily bent and slightly forged. Copper forms an exception to the general rule of annealing; copper is actually made softer and more flexible by plunging it when red hot into cold water, than by any other means. The gradual cooling of copper in a similar manner as steel or cast iron produces a contrary effect. When copper is required very soft and the surface very clean, a small quantity of sulphuric acid (vitriol) may be put into the water, which will have the effect of removing all the black scale from its surface.

CHAPTER VI.

HARDENING AND TEMPERING OF STEEL.

We have now arrived at a very important process, justly termed the crowning process. It is that of hardening the articles; and, if the proper steel has not been chosen for the articles, or if the proper steel has been chosen and has not afterwards been properly treated through all the stages which it has had to pass, or if the hardener be not fully aware of the general principles upon which he must proceed, all past efforts may prove futile. It is not requisite that the hardener should be a chemist; but some slight acquaintance at least with chemistry, or of the action of substances upon each other, will be extremely serviceable to him. To be unqualified in this respect will be labouring in the dark: a successful result may often be obtained; but it will be very imperfectly known how it happened, and it will afford no valuable instruction for the future.

There are too many who entertain an opinion that they have nothing new to learn which is worth notice; they are apt, in effect, to say, that, having served an apprenticeship to their business, they ought to know something, and because they ought to know something, they seem to expect submission to their very errors. To such I speak not; to convince them would be impossible, and therefore the attempt folly. But the prudent artizan, whose first care is generally to provide himself with tools adapted to his labours, I would ask to improve his knowledge of that material, the proper choice and management of which constitutes the first step towards success in mechanical pursuits.

The art of hardening and tempering steel constitutes one of the most delicate, curious, and useful branches connected with mechanical art; it is an art of long standing, and always one of anxiety, but by whom or when it was first adopted I am not prepared to decide. In this place it claims notice on account of its contributing so essentially to the perfection of all the other arts. The great steam-engines, iron bridges, Atlantic cables, and iron ships of the present day, are much indebted to this branch of art; and without it the six hundred-pounder guns, or even the Great Exhibition itself, might never have been seen. A proper inquiry, therefore, into this delicate branch of art must prove very useful to the engineer, as well as to the young beginner, and may not prove uninteresting even to the general reader, especially when processes which do not generally appear, and are not often communicated by workmen, are explained. At first sight the art of hardening and tempering steel appears sufficiently simple, when by heating a piece of steel to redness, and plunging it into cold water, it becomes hard; on a closer inspection, however, the mind will soon discover that many operations and contrivances require to be carried into effect by the hardener in order to become efficient in his art, or to be distin guished for skill and promptitude in execution. A slight knowledge of the processes will also discover that a certain amount of patient perseverance is required—an amount of which few who have been brought up at the desk, or behind the counter, can form the slightest idea. But I have not set out with the object to discourage the young practitioner, but rather to encourage him and smooth for him the path which I have myself found so rough, but which I have always endeavoured to explore without entertaining a sentiment of its hardship; and I would advise all young men who are just starting in the world to go and do likewise.

Before proceeding farther, I would state, that I have not undertaken to explain everything in connection with this subject; but my main object in the present chapter is to explain, in a plain way, the chief causes why steel breaks in hardening; also to notice some of the contrivances which I have found in my own experience to be the least expensive, and most easily reducible to practice; the most suitable to prevent steel from breaking; and, if the information be properly studied, it will enable the mechanic to harden and temper any kind of article with which he may have to do.

Many theories upon the cause of steel becoming hard by the process of heating and suddenly cooling it have been formed; but they are so beset with difficulties and uncertainty, that in my opinion the proper cause has not yet been proved. I have previously shown that steel is a compound of iron and carbon; and, as pure iron does not harden by simple immersion, it must be to its carbon that steel owes this valuable property; and, if I may be allowed to theorize on the reason why steel becomes hard by sudden cooling, I should be inclined to state that it is the crystallization of the carbon, caused by compression and sudden cooling, and, being combined with the iron, becomes a hard and solid substance; but, let this be so or not, there is one thing certain, that a new arrangement of the particles takes place by the process of hardening. But, as I shall have an occasion to speak upon this hereafter (in the chapter upon the expansion and contraction of steel), it will be superfluous to speak upon it in this place, but rather confine myself to the mechanical operations of the subject.

It is of considerable importance that the designer of tools or other articles should have some knowledge of the quality of the material to be used; likewise he should have some knowledge of the action of fire and water upon the material; also he should have some knowledge of the practice of the hardener.

The workmen, through whose hands the articles must pass, either in the fitting or the turning-room, should also have some knowledge of the art of hardening; in fact, it is as requisite that fitters and turners should have some knowledge of the practice of the hardener and the action of fire and water upon the steel, as it is for the pattern-maker to have some knowledge of the practice of the moulder.

The superior character of castings depends in a great measure upon the superior skill which has been displayed upon the patterns; and the success in the hardening of steel, in many instances, depends in a great measure upon the ingenuity displayed in the fitting or the turning-room, and also on the ingenuity displayed in designing the article.

Too little attention is generally paid to the quality of the material when required for very particular tools, or, in other words, for tools that require a great amount of labour and time to make them; and in the fitting or the turning-room, or even in the drawing-office, the expansion and contraction of steel is seldom heeded or even thought of, though it is of the greatest importance.

When it is required to make an expensive article, and where there is great risk of its breaking in the hardening, the first thing to be done is to select the proper steel for the purpose and afterwards to anneal it to the fullest extent; if an equal and judicious hammering be given to the steel by the smith before it is annealed it gives a density to the steel and the article will be more durable; besides, it will lessen the risk of its breaking in the hardening, but the effect of the hammering, as I have before remarked, is taken off again by strong ignition, and the smith's labour is lost, therefore it is evident that there is as much care required in heating the steel when it is required to be annealed as there is in heating it when it is required to be forged or hardened. When the steel is annealed it is then in a fit state for the fitting or the turning-room, there to be fashioned into the required article.

The artist employed upon it ought to bear in mind that steel breaks in hardening from its unequal contraction at different parts; the danger increases with the thickness and bulk, and the more especially when certain parts are unequally thick and thin, consequently before finishing any article for hardening one thing should be attended to, which I will attempt to explain, and, if I succeed in making it understood, the artist will have obtained information as to the plans to be adopted with large articles generally. It is this: examine the article and see which part of it is likely to be the last to become cold when it is immersed in the water, and if it is practicable to reduce the steel in that part without inconveniencing the article it is advisable to do so; the steel will then cool more uniformly and be less liable to fracture. If it were possible to get every particle of the steel cold at the same moment, there would be an end to the danger of steel breaking in hardening; but, as this cannot be done, we must approach it as near as we can.

For the better understanding of the subject, let us suppose that a large circular cutter, such as are used for shaping and trueing of work of various shapes, is required to be made, we will suppose it to be required about seven inches in diameter and two inches in thickness, with numerous cutting edges (termed teeth) round the circumference, and a round hole in the centre through which to pass the spindle. It is obvious that the first thing which will require to be done will be to select the proper steel for the cutter and afterwards to forge it to the required dimensions, after which it will require to be annealed to the fullest extent; but as the choosing, forging, and annealing have already been treated of, it will be superfluous to speak more upon it in this place, consequently, let us suppose the steel in its forged and annealed state to be obtained. The first thing usually done after the steel is obtained is to bore the mandril hole, after which it is turned to the required thickness, and the two sides of the block of steel left flat; the superfluous metal upon the circumference is then turned off, which leaves the block of the required diameter. The teeth are now cut upon the circumference of this block of steel, either by means of a file or by a tool whose edge is of the proper form, and can be used either in a planing or shaping-machine, or even with the lathe. But the most perfect teeth are cut by means of another rotary cutter, whose edge is of the proper form and working in a machine constructed for the purpose. It is usual to bore the mandril hole in large cutters the same size as the mandril hole in the smaller size cutters, so that both large and middle size cutters may fit the same mandril, but this is a step in a wrong direction. The larger the cutter the larger the mandril hole should be—not to say that the mandril itself would not be strong enough; but a large mandril hole in large cutters favours the cutters in hardening by allowing the steel to cool more uniformly; whereas a small mandril hole in a large cutter, having two plain flat sides or surfaces, increases the risk of the cutter breaking in hardening. Though a large mandril hole favours a large cutter in hardening, still it is not absolutely necessary to have a large mandril hole in them, because large cutters having a small mandril hole in them may be hardened without breaking them, by taking care previous to hardening them to reduce the substance of the steel.

The substance of the steel must be reduced in that part of the cutter which is the last to become cool when it is immersed in the water. It is obvious that the part which is the last to become cold will be half way between the mandril hole and the circumference, consequently large cutters will require to be dished out or turned concave on both sides; or if a few smaller holes than the mandril hole be bored round the mandril hole, it will answer the same purpose as turning each side concave. Either of the above plans will greatly reduce the risk of all large cutters breaking in hardening, and it does not materially reduce their strength or stability.

It is obvious that the method of turning the sides of large cutters concave cannot be adopted with cutters which require to have teeth on their sides as well as on their circumference; still holes could be bored through these, and probably it would not in the least prevent the cutter from doing its work; still the cutter would not have a very pleasing appearance, and it would not look very mechanical. Consequently, instead of boring holes in these kinds of large cutters, it will be better to make the mandril hole large in proportion to the cutter.

Perhaps it will be of some use to hint, as it is a very valuable hint if properly taken, that a circular cutter of any required thickness, and seven inches in diameter, and which has a three-inch mandril hole through its centre, is less liable to break in hardening than a circular cutter of the same thickness, six inches in diameter, and which has a two-inch mandril hole through its centre.

There are numbers of articles besides cutters which require to be hardened, where it becomes necessary to bore holes in them, or cut out a kind of panel to make them cool more equally. In some instances boring holes in steel articles requiring to be hardened is injurious or unfavourable to the articles in hardening. For instance, boring holes too near the outside edges of some kinds of articles will sometimes cause the article to crack at the hole.

It may be well to state that drilling a hole or centre too large or too deep into screw taps or rimers, and various other articles which require to be hardened, is a great evil, and should in general be avoided; for, when the centres are too large or too deep, it weakens the ends of the articles, and it not only weakens the ends of the articles, but it frequently causes a fracture in the steel at the bottom of the centre.

In all cases, if the centres are not required in the articles after they are hardened, it is advisable to file them out previous to hardening them, and thus prevent all risk of their getting cracked at that part in hardening.

In making steel tools or steel articles of any description sharp internal angles should in general be avoided, as they are very unfavourable in the hardening process; consequently the key ways in cutters should be half circle. In all kinds of articles sharp internal angles are unfavourable to the strength of the articles so that it becomes necessary to leave all the internal corners a little rounded.

It may be useful, perhaps, to add that cutters which are required for cutting soft substances, such as brass or copper, require to have their teeth very sharp, and to be made very hard. The teeth require also to be cut much coarser than for iron or steel, otherwise they soon become choked with the metal, and become hot, and very soon lose their sharp edges, and will not cut, as the term is, sweet, but would polish and glide over the metal almost without effect, were the cutters not seconded by a great amount of power.

When a steel tool or piece of work similar in shape to a piece of a bar of round steel, say, two, three, four, or more inches in diameter, and three, four, five or more inches in length is required to be hardened, it frequently becomes necessary, previous to hardening such a tool or piece of work, to bore a hole through the centre of it, in the direction of its length, in order that the water may pass through the hole, and cool the steel more equally, and reduce the risk of its breaking. But as the two ends are even then always likely to become cool first, it would not be amiss to widen the hole a little more in the centre than at the ends, and so farther reduce the risk of its breaking in hardening.

It is unnecessary, perhaps, to remark, that the largest size screw taps and hobs are very liable to break in hardening, and, though a hole might be bored through them to prevent their breaking, still this would not give a very pleasing appearance, nor would it look very mechanical. Independent of the appearance of the tap or hob, a hole through large screw taps or hobs would be very apt to cause them to become oval in hardening; and if this did occur it would cause the tap, when in use, to make the hole larger than it was intended to do, and cause the hob when in use to cut very unequally and very slowly, because only two opposite sides of the hob could be made to cut.

It is obvious that a round piece of steel having a plain or smooth surface, and which has a hole bored through it in the direction of its length, would be as likely to become oval in hardening as a piece of steel having a similar hole through it and a screw upon its surface, such as a tap or hob. But then there are means by which a plain surface can be made true again after hardening, such as by lapping or grinding, whereas with taps or hobs these methods cannot be adopted. In all cases it must be borne in mind that, the more uniformly articles are heated, the less liable are they to become crooked or oval in hardening.

For the various reasons above given, another method differing from the boring of holes through large taps or hobs may be adopted, a method which will not at all disfigure the taps or hobs, or cause them to become oval, but which will cause them to harden and cool more uniformly, at the same time prevent them breaking. It is this: to turn the plain part of the tap or hob as small as it will conveniently bear without encroaching upon the required strength of the tap or hob, and to cut the concave grooves (which are in the direction of the length of the best kinds of taps), a little deeper than what they are generally cut.

The method of reducing the steel in that part of large articles which is the last to become cold when they are immersed in the water, cannot with some kinds of articles be adopted; because, were the steel to be reduced in that particular part, it would unfit the articles for the purpose for which they are intended. This would be the case with large circular dies, which frequently require to be turned flat on both sides. It is obvious that the method of boring holes through these kinds of articles, or turning the sides of them concave, cannot be adopted; consequently another method must be resorted to. It is this: to heat an iron ring or collar, and while the die is in a cold state shrink the heated ring tight upon the die; this method will, when the die is heated and immersed in the water, lessen the risk of fracture.

It will be imagined, perhaps, that the object of shrinking a ring upon the die is to compress the die, and by compressing the die it will keep it from breaking; now, if this were the object, it would be a step in the wrong direction. The object of shrinking a ring upon the die is to prevent the water from cooling the outside of the die too suddenly. It must be borne in mind that the more suddenly the heat is extracted from the steel, the more sudden is the contraction of the surface steel; and the more sudden the contraction of the surface steel, the more sudden and greater is the compression of the interior steel; and the more sudden and greater the compression of the interior steel, the greater is the risk of the steel breaking by the outer crust being held for the moment in a greater state of tension (strain). The more the interior steel is compressed the more dense it becomes; consequently, when it becomes cold it occupies less space than what it occupied previous to hardening, and the result is an internal fracture.

It will not be out of place, perhaps, to remark, that if every mechanic were made more acquainted with the chemical properties of the material, and the action of fire and water upon the material, thousands of articles which have been thrown aside might have been prevented from being burnt in forging, and thousands more would have been saved from being cracked in hardening; and the price paid upon the forging, annealing, turning, fitting, and hardening, or making articles from bad material, might have been saved.

Suppose a similar block of steel to the one just treated of be required for a large friction wheel, the method of shrinking a ring upon it previous to hardening of it will not answer, because the ring would prevent the water from effectually hardening the steel in that part which is required the hardest; consequently the same methods will have to be adopted with this kind of article as those which are to be adopted with a large circular cutter, either boring holes through it or turning the sides concave. Suppose an eccentric steel collar is required to be hardened, for example. Let us suppose the hole in the collar where the shaft or mandril passes through to be about two inches in diameter, and the thickness of the metal one inch and a half on one side and about the quarter of an inch on the opposite side, from the irregular form of this article it will easily be seen that there is great risk of its breaking in hardening. The unequal thickness of the steel causes unequal contraction, one side of the collar being so thin it is cool almost instantly. The stout side contracts after the thin side is fixed, the thin side in its then hard state cannot give, consequently it breaks. Before such an article as this is sent to the hardener, a piece of iron should be fitted to the thin side of it so as to make both sides about equal in thickness. The iron must be fitted to the inside, as it is the outside of the collar which is required hard. This piece of iron is to prevent the thin part of the collar from cooling too suddenly, and thus prevents the collar breaking. The piece of iron, of course, must be bound upon the collar with a piece of binding wire, after which it is ready for hardening. I may here remark, that a square lump of steel is less liable to break in hardening than either a cylindrical or a spherical lump, even though there be more bulk in the square lump than what would form either the spherical or the cylindrical lump.

Although this is such an important subject, and much more might be said, still it is not necessary, perhaps, to enlarge more upon it, as the mind will have discovered by this time, the method of proceeding with tools or articles of any description requiring a great amount of labour and time to make them; and where there is great danger of their breaking in hardening. The same, or similar methods will have to be adopted in all cases where large masses of steel require to be hardened, if we wish to obtain satisfactory results.

The information here afforded, coupled with the workman's own experience and ingenuity, will, doubtless, be sufficient to prevent his finding difficulty in forming for himself any particular idea upon the subject he may want; consequently I will now pass on to the process of hardening and tempering.

In the process of hardening steel, water is by no means essential, as the sole object is to extract its heat rapidly; and the more sudden the heat is extracted, the harder the steel will be; consequently, those substances which act most suddenly upon the steel will produce the greatest effect, though they will not always produce the most satisfactory results, for intense cold has a very unfavourable effect upon steel. Good cast-steel receives by sudden cooling a degree of hardness almost equal to that of the diamond, and almost sufficient to cut, or make an impression, upon every other substance; and, when of the best quality, and the hardness not carried to extreme, a certain amount of tenacity is also combined with the hardness.

If steel is heated to a red heat, and allowed to cool gradually, it becomes nearly as soft as pure iron, and may, nearly with the same facility, be worked into any required form. If steel be too hard, it will not be proper for tools, or instruments of any description, which are required to have very keen edges, or very fine points, because it will be so brittle that the edges will soon become notched, or the points break off on the slightest application to the work; if, on the contrary, the steel be too soft, the edges or points will turn or bend; but, if the steel is duly tempered, it will resist breaking on the one hand and bending on the other.

The degree of heat required to harden steel is different in the different kinds. The best kinds require only a low red heat; the lowest heat necessary to effect the desired purpose is the most advantageous, and to impart to it any extra portion of heat must partly destroy its most valuable properties; and for this misfortune there is no remedy, for, if cast steel is overheated, it becomes brittle, and can never be restored to its original quality; therefore, it will be quite incapable of sustaining a cutting edge, but will chip or crumble away when applied to the work.

There are various ways of applying the heat to articles when they require to be hardened. The methods to be adopted will of course depend upon the shape and size of the articles; also, upon the quantity requiring to be operated upon, for in some instances a large quantity can be heated and hardened as expeditiously as a single article. Sometimes it is requisite to heat the articles in the midst of the fuel in a hollow fire; sometimes it is requisite to heat them in an open fire; and sometimes it is requisite to enclose and surround them with carbon in a sheet-iron case, or box, and heat the whole in a hollow fire, or in a suitable furnace; at other times, or in some instances, it is more convenient to heat them in red-hot lead. When a large quantity of some kinds of articles is required to be hardened, the method of heating them in red-hot lead is very convenient and very economical; but to be constantly employed dipping articles in red-hot lead is, I believe, very injurious to health. I have myself been so employed, and have felt its very bad effects; and I have, therefore, avoided using it as a source of heat, except in cases of great necessity.

A more uniform degree of heat can be given to some articles by heating them in red-hot lead, than by any other means, especially some kinds, which are of great length; consequently, they will keep their proper shape better in hardening. A gas flame, or the flame of a candle, is very convenient for heating the points of some small articles; some small articles may be sufficiently heated by placing them between the red-hot jaws of a pair of tongs. Some small articles may be heated by taking a piece of bar iron, and, after heating it to redness, cutting it half way through with the chisel, and then placing the articles in the nick, which will heat them sufficient for hardening. Sometimes it is necessary to insert a piece of iron pipe in the midst of the ignited fuel of the fire, and then to place the articles in the pipe.

When a large number of steel articles are required to be hardened all over, or throughout their body, and which are too small to be heated in the midst of the ignited fuel of a hollow or open fire, and perhaps it is inconvenient to heat them in red-hot lead, or if it be thought hazardous to enclose them entirely in a sheet-iron box, from an apprehension that the heat might increase too much, the following scheme may be adopted. Place as many of the articles at once as may be convenient to manage into a sheet-iron pan, without a lid, and cover them with charcoal dust, place the whole in a furnace or hollow fire, and slowly heat them to redness. They should be occasionally and carefully moved about in the pan by the use of a small wood or iron rod, in order to equalize the heat; the charcoal dust prevents the articles from scaling so readily, and has a tendency to prevent the rod bending them when moving them about in the pan. When the articles arrive at the proper heat they may be immersed in water or oil, or water with a film of oil upon the surface, according to the degree of hardness required in them.

A rod of good steel in its hardest state is broken almost as easily as a rod of glass of the same dimensions, and this brittleness can only be diminished by diminishing its hardness; and in this management consists the art of tempering. The surface of the hardened steel is brightened, and it is exposed to heat. As the heat increases there is a curious and uniform change in the colour of the surface. The colours which appear upon the surface of the steel are supposed to be the result of oxidation. The thickness of the coat or film of oxide, if such it be, determines the colour, and the thickness of the coat depends upon the temperature to which the work is exposed.

It is quite probable that these colours are the result of oxidation; but the present state of my knowledge does not enable me to prove that these colours would not appear if the steel could be heated in a vacuum, a space unoccupied with air, neither does the present state of my knowledge enable me to prove that these colours are not due to the new arrangement of the particles, quite independent of any chemical change;

but, let the cause be what it may, these colours are a very useful index, for by them any degree of hardness retained by the steel may be ascertained. The colours which successively appear on the surface of the steel, slowly heated, are a yellowish white or light straw colour, a dark straw, gold colour, brown, purple, violet, and deep blue. Finally, the steel becomes red hot, and a black oxide is formed. It will be more readily imagined that the various colours are the result of oxidation, when it is seen that the action of the oxygen of the atmosphere upon the steel in a red-hot state converts the surface of the steel into a black oxide; and this black oxide, like the various colours, increases in thickness with increase of temperature, and if it is hammered or scraped off it is again quickly formed.

There are various ways of applying the heat for tempering or reducing the hardness in steel articles. The methods to be adopted will, of course, depend upon the shape and size of the articles; also upon the quantity requiring to be operated upon; for in some instances a large quantity can be tempered as expeditiously as a single article. The heat for tempering should not be too suddenly applied, as a certain amount of time is essential for the particles to rearrange themselves, and the slower the heat is applied the tougher and stronger the steel becomes. When it is required to temper an article or articles to any of the colours previously spoken of, they must be brightened after they are hardened. But before proceeding farther it will perhaps be well to state that previous to brightening the articles the hardener ought always to make himself sure that the articles are quite hard. If the articles are not properly hardened, or, in other words, if the articles are not possessed of a certain degree of hardness, it will be time and labour lost afterwards to temper them ; besides, the articles will be practically useless for the purpose they are intended for until they have been hardened and tempered over again. Therefore, in order to make sure of good work, the hardener should always try the hardness of the steel with a smooth file, a file finely cut. It has already been inquired of me, and may be inquired again, perhaps, why is it necessary for a practical man who is thoroughly acquainted with the quality of the material he is hardening, likewise with the temperature suitable to harden the material, to try the hardness of the steel, when he knows from experience that the steel hardens properly at a certain temperature. The answer to this is, the hardener may be a practical man, and may be thoroughly acquainted with the quality of the material, likewise with the temperature suitable to harden the material ; but if he is not a careful man his knowledge will be of little service, and the necessity for trying the hardness of the steel before it is tempered is soon made evident: besides, if proper attention is not paid to the water it will deceive the hardener. Again, the most careful and experienced hardener is liable to be deceived in the temperature of the steel when hardening in twilight. It has previously been stated, that it is requisite at times to enclose some kinds of articles, when they require to be hardened, in a sheet iron box, and surround them with charcoal. When this method is adopted, the articles will require a much more considerable amount of time to heat them than is readily imagined by those who are not accustomed to this method. Charcoal is a bad conductor of heat, and if the hardener be unacquainted with the conducting quality of the charcoal, he will be apt to draw the box out of the fire and immerse the contents in the water, before the central articles have acquired the proper temperature suitable for hardening them, and those articles which are below a certain heat cannot become hard. Here again is exhibited the necessity of trying whether all the articles are hard before beginning to temper them. In some instances (though the steel be the very best that Sheffield can furnish), one or two badly tempered articles would get the manufacturer of them a bad name, and would in some instances get all the order condemned, even if all the other articles were right. The use of the file for proving whether the articles are hard can be dispensed with when the articles are brightened on an emery wheel, or a small dry grinding-stone running at a quick speed, for the person employed to brighten them will find, if they are properly hardened, plenty of brisk, lively sparks fly from them when they are held upon the emery wheel or the grinding stone. But if they are not hard there will be very little fire in them. Therefore, with a very little attention, those articles which are soft (if any there be) can be detected, and may be put aside and heated again with the next batch.

After the articles are brightened, the hardness can be reduced to any particular standard, by placing them upon a hot bar or plate of iron, or upon the surface of melted lead, or in a bath of a more fusible metal kept at a certain heat, or in hot sand, or burning charcoal, or the articles may be held in the inside of an iron ring heated to redness, or they may be placed in the mouth of a furnace, or in an oven heated to the proper temperature, or they may be placed in or upon a gas stove specially constructed, or they may be heated in any other convenient way.

The above methods of applying the heat for tempering is to suit those kinds of articles which have been wholly quenched. When any of the above methods of applying the heat is adopted, and the articles are exposed to a higher degree of heat than that which is required to reduce them to the exact temper, they must be removed from the heat immediately they attain the desired colour, otherwise the temper will become too far reduced, or in other words the articles will be too soft for the purpose they are intended for. After they are removed from the heat they may be immersed in water or oil, or they may be allowed to cool in the air of their own accord; for it matters not which way they become cold, providing the heat has not been too suddenly applied; for when the articles are removed from the heat they cannot become more heated, consequently, the temper cannot become more reduced. But those kinds of tools which are heated farther than what they are required hard, such as a large portion of the small kinds of turning tools, cold chisels, and the larger kinds of drills and numbers of other kinds of tools, and which are only partially dipped, and which are afterwards tempered by the heat from the back of the tool, must be cooled in the water the moment the cutting part attains the desired colour, otherwise the body of the tool will continue to supply heat, and the cutting part will become too soft.

It is, perhaps, too obvious to require remark, unless it be for the information of those who are unaccustomed to these processes, that if, after tempering an article it proves too hard for the purpose it is intended for, it is not absolutely necessary to reharden it, though in some instances it is more convenient to do so, the temper may be farther reduced by exposing it again to heat; but, if an article is too far reduced in temper, it becomes then absolutely necessary to harden it over again. When a very large number of small articles are required to be tempered, it will be too slow a process to temper them to a certain colour; therefore, a more expeditious method must be adopted. A very convenient way of tempering a large quantity of small articles at once, and of heating them uniformly, no matter how irregular their shape, providing the heat is not too suddenly applied, is to put them into a suitable iron or copper vessel with as much tallow or cold oil as will just cover them, and then to place the whole over a small fire and slowly heat the oil until a sufficient heat is given to the articles for the temper required. It may be well, perhaps, to remind the young mechanic that the temperature of the oil or tallow may be raised to six hundred degrees of heat, or rather more, consequently, any temperature below a red heat may be given to the articles by the heated oil. Certain degrees of temper retained by steel articles when they are heated in oil may be estimated by the following circumstances: when the oil or tallow is first observed to smoke, it indicates the same temper as that called a straw colour. The temperature of the oil, if measured by the thermometer, will be about 450 degrees.

If the heat be continued, the smoke becomes more abundant, and of a darker colour; this indicates a temper equal to a brown. The temperature of the oil at this stage, if measured by the thermometer, will be about 500 degrees. If the oil or tallow be heated so as to yield a black smoke and still more abundant, this will denote a purple temper. The temperature of the oil at this stage, if measured by the thermometer, will be about 530 degrees. The next degree of heat may be known by the oil or tallow taking fire if a piece of lighted paper be presented to it, but yet not so hot as to burn when the lighted paper is withdrawn. This will denote a blue temper. The temperature of the oil at this stage, if measured by the thermometer, will be about 580 degrees. If the articles are lifted out of the vessel at this period, they will be found to possess a considerable amount of elasticity. This temper is not unfit for some kinds of springs, but only when a rather mild kind of steel is employed; the steel in this state may be wrought, that is, it may be turned or filed, though with difficulty.

The next degree of heat may be known by the oil or tallow taking fire and continuing to burn, at the same time rising higher in the vessel. If the articles are lifted out of the vessel at this period, the oil will burn upon them with a white flame. This is the temper which is mostly used for spiral, and some other kinds of springs.

If the whole of the oil or tallow be allowed to burn away before the articles are lifted out of the vessel, it imparts the temper which clock-makers mostly use for their work. This temper is the lowest used, when the steel is required to be at all harder than in its natural state; for a small degree of heat more would just be seen (red) in a dark place.

Any single article, to spare the trouble of heating it in a vessel with oil or tallow, may be smeared with oil or tallow and held over a clear fire, or over a piece of hot iron; or, if the article is small, it may be held in a gas flame, or in the flame of a candle, and its temper, when heated, ascertained in a similar manner. It will not, perhaps, be out of place to state, that I was once asked by a young man the way to harden and temper spiral springs made of steel wire. I informed him that he must first of all harden them either in water or oil, according to the substance of the steel; and, if he had a sufficient quantity to do which would pay for the waste of the oil, it would be a very convenient and expeditious method to tie them all together with a piece of iron wire, and place them in an iron saucepan or any other suitable vessel he might chance to have, with as much oil or tallow as would cover them, and then to place the whole over a small fire, and slowly continue the heat until the oil takes fire, and continues to burn; after which, to lift the springs out of the vessel by means of an iron rod, and then to give them one dip into some cold oil. This was to give the springs a black colour ; they were then to be allowed to cool in the air of their own accord.

When I gave the above information, I did not think for one moment that this young man would attempt to boil the oil over the fire in the dwelling-house; but he informed me that he did so, and the result was that he nearly set the house on fire. I have just mentioned this circumstance merely as a warning to those who are unacquainted with the nature of oil at this high temperature, so that they may not fall into the same error; they must not attempt to boil oil unless they have a place suitable for it, or serious accidents may happen.

Before putting any article in the fire to heat it for hardening, it is necessary to examine its shape in order to know which way it will require to be immersed in the water so as to lessen the risk of its cracking ; every kind of article requires to be dipped a particular way according to its shape. For instance, if the article is unequally thick and thin, or in other words, if there is a stout part and a thin part, the stoutest part should always enter the water foremost. By dipping the article with the stoutest part of it entering the water foremost, it causes the steel to cool more uniformly, and lessens the risk of fracture. If the thinnest part of the article be allowed to enter the water foremost, it increases the risk of fracture, because it will become cool much sooner than the stouter part of the article, consequently the stout part of the article contracts by the loss of heat after the thin part is fixed; the thin part in its then hard and brittle state cannot give, consequently it breaks; or, if it does not break at the time of the hardening of it, it is held in such a state of tension (strain) that it is ready to break when applied to the work.

Though it is requisite when hardening steel articles to let the stoutest part of the articles enter the water foremost, in order to allow the steel to become cool more uniformly, still it is not practicable in all instances to get the stoutest part of the articles into the water foremost, as will subsequently be shown.

When it is not practicable to get the stoutest part of some kinds of articles into the water foremost, some other method which will keep the thin part of the articles from cooling too suddenly, and which will cause the steel to become more uniformly cool, must be resorted to. The various methods to be adopted for lessening the risk of fracture when hardening various kinds of articles, will be explained as we go along.

The water which is to be used for hardening steel tools, or any other kind of articles made of steel, should never be quite cold, but should have, as the term is, the chill taken off; or, to use other words, the water requires to be made a few degrees warmer. The reason for this is, that when water of too cold a temperature is used, it abstracts the heat so suddenly from the surface of the steel, that it causes a too sudden contraction of the surface steel, and the expansion of the interior steel in its still red-hot state is more than the hardened crust can bear, consequently it frequently causes the steel to break.

It is quite probable that the interior steel for the moment becomes both heated and expanded in a higher degree by the sudden compression, for the sudden contraction of the surface steel by the sudden loss of heat must act on the interior steel something similar to a blow from a heavy hammer or the pressure of a squeezer; and if the steel should happen to be a little too hot at the time of dipping it into pure cold water, there is as much danger of its breaking as there is of a glass bottle breaking when boiling water is poured into it; heat and cold act on glass and other brittle substances in a similar manner that they act on steel. When boiling water is poured into a glass bottle, the expansion of the inside glass is so sudden that it is more than the outside can bear, consequently the bottle breaks; if glass is heated to a red heat and plunged into cold water it breaks into a quantity of small pieces from the sudden contraction; if a stone is thrown into the fire it breaks from the sudden expansion of its surface.

The more the water is used for hardening steel the softer it becomes, and has a tendency to act less suddenly upon the steel; consequently the less frequently the water used for the purpose is changed the better it is for hardening of steel—that is, providing the water has not by continual use become greasy. The water is not made better for giving the steel a greater degree of hardness by being long in use, but it is made better for the purpose because it is less likely to crack the steel than fresh water; therefore, as the water wastes, fresh water should be added to it. As it is necessary to clean the tank out occasionally, it would be well before using fresh water to make it quite hot, by putting bars of hot iron into it and allowing it to become nearly cold again before using it, or the chill may be taken off the water and the water made softer by putting some ignited charcoal or wood ashes into it. It is obvious that the colder the water the more effectually it hardens the steel, and the more especially when the steel is immersed suddenly and a rapid movement given to it whilst it is becoming cool; but when fresh cold water is used there is always greater danger of the steel cracking. Brinish liquids, such as aquafortis, urine, or water charged with common salt, &c., produce rather more hardness than plain water; but, for most articles, plain water with the chill off gives sufficient hardness to the steel. Water at about sixty degrees measured by the thermometer is the most suitable temperature to prevent steel cracking in hardening. Water holding soap in solution prevents the steel from hardening. There are certainly some kinds of tools, also some pieces of work used in machinery, which require to have a greater amount of hardness given to them than can be given by plain water; there are some kinds of gauges, burnishers, and certain kinds of dies, which require to be very hard, so that it becomes necessary at times to use a saline liquid; a file requires also to have a nice hard tooth. When steel is required to be made extremely hard it may be quenched in mercury, the chemists' name for quicksilver; but this fluid it is obvious can only be used on a small scale.

All bright articles which are made of steel and which require to be hardened are the better for being heated, previous to immersion, in contact with carbon. By heating steel in contact with carbon, or by supplying a small quantity of carbon to the surface of the steel after it is heated, it favours the steel in hardening; but, though it is better to supply a small quantity of carbon to the surface of the steel, still it is not absolutely necessary to do so, because very satisfactory results are obtained with some kinds of articles by heating them in red-hot lead previous to immersion. When red-hot lead is used as a source of heat, the method of supplying carbon to the surface of the steel cannot conveniently be adopted; neither can the method of supplying carbon to the surface of the steel be conveniently adopted when some other methods of heating steel are adopted, such as heating some small steel articles between the heated jaws of a pair of tongs, or between two heated pieces of bar iron, or in a gas flame, the flame of a candle, &c. To supply carbon to the surface of steel articles, the articles may be enclosed in a sheet iron case or box, and surrounded on all sides with either wood charcoal or animal charcoal; the whole will require to be placed in a furnace or hollow fire and heated to redness. Wood charcoal is too familiar to every one to require remark in this place; but it may be necessary to state that the animal charcoal here spoken of is nothing more than any animal matter—such as horns, hoofs, skins, or leather, &c., just sufficiently burnt to admit of being reduced to powder. If it is found more convenient to heat the articles in the midst of the ignited fuel of a open or hollow fire it is advisable to do so; but when any bright steel article is heated in a open or hollow fire, free of wood or animal charcoal, it ought always to be coated with the prussiate of potash, or some other substance which will, after it has arrived at a red heat, protect it from the direct action of the fire and water, at the same time supplying a small portion of carbon to the surface of the steel. Though bright steel when heated in the midst of the ignited fuel of a hollow or open fire is the better for being coated with the prussiate of potash, still there are instances when it will be advisable not to use it; for instance, if the potash were used in hardening saws which require to be sharpened with the file it would cause greater difficulty to file them, consequently, in such an instance, the potash should not be used. When it is required to coat any steel article with the prussiate of potash, the article will require to be heated to redness before the potash is put on to it, otherwise it is useless to put it on, for the steel requires to be sufficiently hot to fuse the potash when first it is applied for the potash to be of any practical service to it. The potash should always be finely powdered and placed in a small box, the lid of which should be full of small holes, similar to a grater or pepper-box. The reason for this is that it is the most economical way of using it, especially if the article is held over a piece of plate iron whilst the potash is being put on; what portion of the potash falls upon the plate must be returned to the box, and thus prevent it being wasted.

After heating any steel article to redness and sprinkling the potash upon it, it must be returned to the fire for a few minutes, or until it attains the desired heat; the article is then ready to be immersed in the water. Sometimes when the article is very large it is necessary to draw it from the fire a second time and sprinkle it again with the potash, in order to give it a thicker coat before it is immersed in the water.

Steel which is hardened with the skin upon it, will undoubtedly be the better if it be sprinkled with the prussiate of potash; for it has always a tendency to penetrate through the thin oxide, and supply carbon to the surface of the steel, which, perhaps there is no necessity for repeating, is favourable to the steel in hardening.

It may be well to state that the access of air to the potash should always be prevented, when the potash is not in use.

Steel in the state it leaves the forge, with the skin or thin scale upon it, is less liable to break in hardening than steel which is brightened previous to hardening. The skin or thin scale upon the steel prevents the water from acting too suddenly upon the steel; consequently the contraction is slower. Common turning tools will always stand better; that is, they will keep a finer and firmer edge, if they are hardened with the skin upon them, than they will if they were brightened (either by filing or grinding) previous to hardening; in fact, all tools that can be ground and sharpened upon the grinding stone after they are hardened, will be the better for being hardened with the skin upon the steel; and, if properly forged by the tool smith (who is generally acquainted with the proper shape of tools, as well as the mechanic who uses them), the tools will require very little grinding; and, as for water cracks in the steel, there will be none. When turning tools are made of the best cast steel, and hardened previous to the removal of the skin or scale, and which are not intended to have very keen edges, but which are intended to sustain a good hard edge for cutting iron and other metals (cast iron especially), they will not require to be tempered after being made hard, but the heat should be carefully regulated at first, as the most useful hardness is produced by that degree of heat which is just sufficient to effect the purpose; for it is quite reasonable to suppose that the hardness of steel depends upon the crystallization, and the intimate combination of its carbon; therefore, the heat which effects this must be the best.

As there are a number of tools used in the turnery which cannot be ground upon the grinding-stone owing to their peculiar shapes, it becomes necessary then, whilst the steel is in its soft state, to fit these kinds of tools up with the file, or to form them in the lathe, or some other machine; consequently these kinds of tools cannot be hardened with the skin upon them. But, as there is greater liability of brightened steel breaking in hardening than that which is not brightened, and as some kinds of tools cannot be ground after they are hardened, it becomes an object of importance that they should stand well. Therefore, extra precautions must be used when hardening these kinds of tools; for, were their cutting edges to chip through being a little too hard, or rub off through being a little too soft, they will be practically useless for the purpose they are intended for, until they have been softened and fitted up again, and subsequently hardened. In some instances the tools would be wholly useless; this would be the case with screw taps, and some kinds of rimers, broaches, &c., for their original sizes would be lost. It must be obvious, then, that if extra care is required with some kinds of tools, it must be with those kinds which take a great amount of labour and time to make them, also with those kinds which cannot be repaired.

It is well known that, when iron is heated to a high temperature, and forged upon the anvil, a thick unequal scale is formed upon the surface of the iron, by the action of the oxygen of the atmosphere; and if steel is heated to the same degree, and forged upon the anvil, a thick unequal scale is formed upon its surface in a similar manner as it is formed upon the surface of iron. This thick unequal scale would cause the steel to harden unequally, if it were not removed previous to hardening of the steel; but it must be borne in mind, that, when tools are made of the best cast steel, and forged at the proper heat, and the anvil kept clean during the time they are being forged, it will prevent this thick unequal scale being formed; but a very thin, equal skin or scale will be formed. This thin equal scale does not prevent the steel from hardening equally, neither does it prevent the steel becoming sufficiently hard for most purposes; but it will prevent the surface steel becoming cool too suddenly, consequently it must be obvious that it will have a tendency to prevent the steel breaking in hardening.

When steel is required to possess the greatest possible degree of hardness, it is obvious that the scale must be removed previous to hardening of it.

There are many large steel articles broken after hardening them, by taking them out of the water before they are thoroughly cold; and, perhaps, a few words upon this will not be out of place. It is the opinion of many mechanics that the cause of steel breaking after it is lifted out of the water is the action of the air upon the steel, when first the steel comes in contact with the air. It is true that large masses of steel frequently break immediately the steel is lifted out of the water; but I am at a loss to see in the slightest degree what effect the air can have upon the steel in this instance. My opinion is this, and which I have formed from experience, that if the steel does not break during the time it is becoming cool, there is no more danger of its breaking after it is lifted out of the water than what there was of its breaking in the water, that is, providing the steel be allowed to remain in the water until its centre becomes quite cool. During the time the steel is in the water becoming cool, and after a certain amount of heat is abstracted from the outer crust, there is a peculiar motion or vibration of the interior particles in re-arranging themselves according to their form. This peculiar motion weakens the cohesion of the particles. The tension of the steel at this period is in one direction; but let the steel be lifted out of the water before the central steel has become quite cool, and the tension is reversed in an opposite direction. This is caused by the central steel imparting heat to the inner side of the hardened crust; and this sudden change is frequently more than the hardened crust can bear, and causes the steel to break. If the steel does not break, it is held in such an unequal state of tension, from the particles not being allowed sufficient time before they were again disturbed to assume the exact arrangement to which they are naturally disposed, that the tenacity of the steel must more or less be weakened. It is not requisite that the steel should lie in the hardening tank until the steel and the water become quite cool; for in some instances the steel article is required for immediate use. In such instances, any vessel, such as a handbowl or a water-bucket, &c., may be sunk into the tank, and the steel article or articles may, while the vessel is under the surface of the water, be lifted into the vessel; after which the vessel can be lifted out, with as much water in it as will cover the article or articles. The vessel may then be sunk, with the article or articles still in it, into another tank of quite cold water, or the vessel may be placed under a water tap, and cold water run upon the articles; and when they are quite cool they can be lifted out with safety. It will be obvious that the greater the mass of steel the greater the risk of its breaking by being removed from the water before it is thoroughly cold.

There are many articles cracked in hardening by heating them all over, or throughout their body, and then partially dipping them into the water. All kinds of articles which are heated all over are the better for being dipped and hardened all over; and then, if one part of the article is required softer than the other parts, it is best to soften it after. To spare this trouble, at the same time lessen the risk of fracture, it will be well not to heat some kinds of articles in any other part but that which is required hard, and then to entirely quench them. The heat of course must not terminate upon the article in a strict line, but should be gradually tapered off. It is obvious that the heat will not terminate in a strict line when the article is heated in a common smith's fire; but, when red-hot lead is used as a source of heat, the heat upon the article is liable to terminate in a strict line unless a vertical movement be given to the article. If only a certain part of a steel article is required to be hardened, and the article be heated throughout its body, and the water into which the article is to be put be quite cold, and the hardener in dipping it stop at any particular part, at the same time hold it quietly without giving it a movement whilst it is becoming cold, there is always great danger of the article cracking at the very spot which is level with the surface of the water; and sometimes the article will break asunder at that particular spot as evenly as though it had been cut with a saw. The tools required by the millwright, pattern maker, carpenter, joiner, and cabinetmaker, are those kinds of tools which are generally attended with the greatest risk by being heated throughout their body, and only immersed half their depth into the water; especially the small and middle-sized varieties of the best kinds, which are always made wholly of the best cast steel, and which are generally filed or ground bright, and fitted to shape previous to hardening. The tools required by these different artists do not differ so much from each other in construction and name as in size, though the very large tools used by millwrights, carpenters, and others for heavy, coarse work are generally composed of iron and steel welded together, the steel forming but a small portion of the whole mass of metal. With these kinds of large tools there is less risk of fracture in hardening, because it is generally shear steel or a mild kind of cast steel (steel containing a smaller proportion of carbon) which is used for welding to the iron. It is obvious that if the steel be properly welded to the iron, a flaw will be less likely to occur, and a rupture more difficult to start.

From these statements the reader may, perhaps, be inclined to think that I am condemning the method which is so much practised in the art, that of partially dipping the articles and afterwards tempering of them by the heat at the back of the tool or article; but, it is not my object to condemn a method which I know from experience to be in a considerable number of instances very convenient and very economical; but, knowing from experience, that certain kinds of articles are so liable to crack when the method of partially dipping them is adopted, I have made it my object to state the cause of their cracking, and to give such remedies as will, in a great measure, prevent these water cracks. When the method of partially dipping a steel tool or other kind of article is adopted, the article may generally be prevented from cracking, by simply putting the water in motion previous to dipping the article, or by giving the article a quick movement when it is in the water as far as it is required hard; either of these methods will prevent the water from acting so evenly in cooling it in a strict line; either of these methods causes the line between the hard and soft part of the article to occupy more space, and lessens the risk of fracture. Water cracks may also be prevented in that part of any article which is required to be level with the surface of the water, by simply coiling a piece of binding wire round that particular part, and when sufficiently heated, coating it with the prussiate of potash previous to immersion. This method prevents the water from acting so suddenly or evenly upon the steel, at that particular part of the article; consequently it prevents it cracking.

Chipping chisels, drills, and all other kinds of tools which are only partially dipped into the water, should never be held still while they are becoming cold; but they should, after they are dipped to the required depth, have a sudden vertical or other movement given to them. I have no doubt that many have noticed when they have been chipping, that their chisels have sometimes broken off about an inch or rather more from the cutting edge, or at that part of the chisel which was level with the surface of the water when it was hardening. The cause of the chisels breaking in this particular spot, arises in a great number of instances from the chisels having been held quietly in the water when hardening. The water cooling them across in a straight line causes the hardened part to tear from the soft part; and the chisels sometimes break with a very light blow of the hammer, and sometimes with the very first blow. I have, myself, witnessed the ends of drills drop off by simply dabbing their points into the wooden bench; I have also witnessed the ends of drills drop off at the grinding stone when they were being sharpened, after having been repaired; I have also witnessed the ends of drills drop off on the slightest application to the work; and from no other cause but from the drills having been held quietly in the water when hardening. But, as these kinds of articles are generally hardened with the skin on the steel, they are less liable to break than articles which are brightened previous to hardening. I recollect once having a quantity of small flat drifts to harden, which had triangular grooves cut in them, to form sharp cutting edges, something similar to a file, but cut coarser and deeper, and I was requested to leave the top part of them (called the heads) soft. So I put a certain number of them into an iron box and surrounded them on all sides with charcoal dust; after luting the box with clay, I placed it in a hollow fire and slowly heated the whole to redness; after which, I opened the box and let the contents drop from the box into the water tank, with the intention of subsequently softening the heads. After taking them out of the water and examining them, I found a number of them very crooked; this was owing to their being so slight and going from the box so suddenly into the water. As these kinds of tools are required for clearing, trueing, and finishing holes, it is obvious that this defect of being crooked is very detrimental; for these tools cannot produce true work if they are crooked, besides, they are more liable to break when they are struck with the hammer than if they were straight.

As the above method did not afford a very satisfactory result, I adopted another method. I placed a certain number of them in a sheet-iron pan without a lid upon it; I surrounded the drifts with charcoal dust, the same as previously, and heated the whole to redness in a hollow fire; as they became heated I gripped separately the head of each drift with the pliers, and dipped it endways and perpendicularly and slowly into the water. This method had the effect of causing them to keep straight and answering the purpose so far, but it took a longer time to dip them separately; so, thinking to save this extra time, I thought I would only dip them in the water as far as they were required hard, and that would save the time and trouble of softening the parts which were not (according to order) to be made hard, namely, the heads of the drifts. But not caring about going a-head with any large quantity until I made myself sure that all was going on well, after I had dipped about two dozen of them, I thought it necessary to examine them, and I did not find one of them but what was cracked at that part of the drift which was level with the surface of the water when hardening them; so I dipped the remainder of them all over, and separately, and hardened them throughout, and not a crack appeared in one after. After tempering them to the proper temper, I made some lead red hot in an iron ladle and dipped the heads that were to be soft into it, and accomplished my object very nicely.

This tearing of the particles from each other when the hardening terminates in a strict line is not at all times sufficient to cause the steel to break asunder, neither is it at all times sufficient to show signs of fracture; but whether the steel breaks asunder or not, or whether there are signs of fracture or not, this tearing of the particles from each other when the hardening terminates in a strict line, must always with highly carbonized steel more or less take place, when it is known that hardened steel occupies more space than soft steel, and that the density of the steel is different in the two states.

When it is required to harden large circular cutters which have teeth round their circumference, or large cutters having teeth on their sides as well as on their circumference, or, I may state, such cutters as those which have previously been treated of, they may be enclosed in a sheet-iron case or box and surrounded on all sides with either wood charcoal or animal charcoal. The box will require to be luted with clay or loam and the whole placed in a furnace or hollow fire and heated to redness. A certain amount of time is essential to allow the steel to soak, or, in other words, to get heated uniformly throughout. After the cutters are properly heated they must be lifted out of the box separately, not by the tongs or pliers, as they are apt to spoil the sharp cutting edges of the cutter, but by a rod of iron (the poker) put through the spindle hole of the cutter. The hardener must be provided with a proper tool for bearing the cutters while he dips them into the water, as the pliers do not answer well for this purpose. The most suitable tool for dipping the cutters is made by taking three pieces of round iron about one quarter of an inch in diameter and three or four inches in length. Grip the three pieces at the end with the tongs and weld the three opposite ends together, after which the welded end must be scarfed and welded to the end of another piece of iron about one quarter of an inch in diameter and about eighteen inches in length; this forms a stem with three prongs at one end of it. The three prongs must be turned back so as to stand at right angles with the stem; so that when the stem is put through the spindle hole of the cutter and gripped with the hand the cutter will lie upon the three prongs. A kind of ring or loop should be turned at the end of the stem to keep the stem from slipping through the hand by the weight of the cutter, but the loop must be sufficiently small to pass through the spindle hole of the cutter.

It may be inquired, will not a long bolt, with a large flat head, answer the same purpose as a stem with three prongs at the end of it? The answer to this is: it would answer quite well as regards the bearing of the cutter, but the large flat head would prevent the water from passing freely through the spindle hole of the cutter, and would thus prevent the cutter from cooling uniformly. After the cutter is lifted out of the box, this wire stem must be put through the spindle hole of the cutter and gripped with the hand; and while the cutter rests upon the three prongs it must be immersed into the water, and instead of moving the cutter backwards and forwards in the tank, it should be moved up and down so that fresh water is continually passing through the spindle hole during the time the cutter is becoming cool. The deeper the tank the better it is for the purpose. Care must be taken whilst moving the cutter up not to allow it to come above the surface of the water, or it will be liable to crack. Should the tank not be sufficiently deep to allow moving the cutter up and down, the cutter may, after it is beneath the surface of the water, be turned sideways, and whilst one end of the wire stem is gripped with the right hand the opposite end can be gripped with the left hand. The cutter can easily, whilst it is beneath the surface of the water, be shifted towards the middle of the wire stem, which will keep the cutter or the heated water as it passes through the spindle hole of the cutter from burning the hands. It is advisable to keep the cutter moving until it is sufficiently cool to be gripped with the hand. If more than one cutter has been heated, the wire stem must be taken out of the water, as it will be required for dipping the other cutters. There is no necessity for removing the first cutter from the water until all the cutters that have been heated have been immersed; but, if the first cutter has increased the temperature of the water too high, more cold water should be added to it before the second cutter is immersed, and so forth, if necessary, until all that have been heated have been immersed. The cutters, may, after they are hardened, either be allowed to remain in the water until the water is thoroughly cold, or they may be lifted out of the water by the method previously explained. If the cutters are uniformly heated and immersed in the water, in the manner just described, they will keep their proper shape better than by any other means; while they are much less liable to crack, because they cool more uniformly. Any size cutters, dies, bushes, rings or collars, or ring-gauges, may be heated and immersed in the water in the same manner as circular cutters. It will be obvious that gauges or dies which have no holes, or which have only a small hole through them, cannot be dipped with the same kind of tool as circular cutters, consequently the pliers will be quite suitable for gripping these kinds of articles. It is not absolutely necessary that circular cutters, dies, bushes, rings, gauges, &c., should be enclosed in a box to heat them, neither is it absolutely necessary to surround them on all sides with wood or animal charcoal, as it will answer equally as well, and be a far more expeditious method, to carefully and slowly heat them in the midst of the fuel of a hollow fire; but when these kinds of articles are heated for hardening in the midst of the fuel of a hollow fire, they should always be coated with the prussiate of potash. Dies having engraved surfaces are undoubtedly the better for being heated in a box and surrounded with wood or animal charcoal; because it would not answer very well to fill the fine engraving with the prussiate of potash, neither would it answer to heat them in contact with the air. The method of enclosing these kinds of articles in an iron box, and surrounding them on all sides with wood or animal charcoal, answers three good purposes: it causes the heat to be very slowly and equally applied; the surfaces of the dies are rendered rather more steelly by the absorption of carbon, and it prevents the scaling occasioned by the contact of the air. If dies or any other kind of steel articles be previously polished, and well defended from the air, they will be, when hardened, nearly as clean as before. Small cutters, after they are hardened, require to be brightened in one, two, or more places, and tempered to a yellowish white or light straw colour. A very good way of applying the heat for tempering most kinds of circular cutters is, to place the cutter upon a piece of round bar-iron. The most suitable piece of iron for the purpose is made by slightly tapering several inches of a piece of round bar-iron. The size of the iron, previous to drawing the taper upon it, should be a little larger in diameter than the diameter of the spindle hole of the cutter; so that, if it is necessary (whilst tempering the cutter) to draw the cutter upon the stouter part of the iron, so that the iron may fit the hole tightly and supply more heat, it may be done. To temper the cutters by the use of this piece of iron, the tapered end of the iron will require to be heated to redness; it must then be put into the spindle hole of the cutter, the iron and the cutter must be supported with the left hand, whilst a slow rotary motion is given to the cutter, by the use of a small stick of wood, with the right hand. This method will equalize the heat, and cause the temper to be more uniform. As soon as the light straw colour appears upon the brightened parts of the cutter, it must be removed from the heat; after which, it may be immersed either into water or oil, or it may be allowed to become cool in the air, for it matters not (after it is removed from the heat) which way it becomes cool—that is, providing the heat has not been too suddenly applied. Though this is the most suitable method for applying the heat for tempering most kinds of circular cutters, still there are some kinds of circular cutters requiring to be tempered after they are hardened, where it will be found more convenient to temper them upon a piece of flat bar iron, heated to redness. The heat must not, in any instance, be too suddenly applied. It is advisable, in some instances, when tempering some kinds of circular cutters upon a piece of flat bar iron, to place a piece of cold plate iron between the cutters and the red-hot bar, in order that the heat may be more slowly and equally applied. It will be found necessary, when tempering some kinds of circular cutters upon a piece of flat bar iron, to turn them over occasionally during the time they are becoming heated, so as to expose their opposite sides to the heat, and thus impart to the cutter a more uniform temper. The yellowish white or light straw colour gives tenacity to the steel without materially reducing its hardness; it also lessens the risk of small cutters breaking when in use. There is no necessity for tempering or reducing the hardness of the largest size circular cutters; because, owing to the larger body of steel, they are much longer than the smaller size cutters in becoming cool. A larger quantity of steam is also formed at the sides of the large cutters, which prevents the water, for a few moments, from acting upon the steel; consequently, the largest size cutters cannot become so hard and brittle as the smaller size cutters.

The hardness, of course, depends, in some measure, upon the quality of the steel; likewise the temperature of the water and the temperature of the cutters when they are immersed in the water. If the quality of the steel, from which large and small cutters are made, be equal, and if the temperature of the water in which the large and small cutters are immersed be equal also, and if the large and small cutters be equal in temperature when they are immersed, this variation in the hardness of the largest and smallest size circular cutters, for the reasons just given, must certainly take place. It will be obvious, then, that if the smallest size cutters require only to be reduced in temper to a yellowish white or light straw colour, that the largest size cutters will not, after hardening, require to be tempered; but the hardening strain may be made more uniform throughout the body of large cutters by boiling them in water for several hours.

Dies which have engraved surfaces, after they are hardened, require to be tempered; not because the engraved surfaces of the dies are too hard, but because the whole body of the steel requires to be toughened, in order to better fit the dies to withstand the continual hardship to which they are generally exposed when in use. To temper these kinds of articles the engraved surface of the dies will require to be brightened; the dies must then be placed upon a piece of flat bar iron, several inches of which must be heated to redness. If it is required to temper a quantity, several may be placed at once upon the bar. Care must be taken that all the dies may not arrive at the proper temper at the same moment. The dies should not be placed upon the hottest part of the bar at first; but they should, as they become gradually heated, be pushed upon the hotter part of the bar. The dies will require to be moved occasionally during the time they are becoming heated in order to equalize the heat. As soon as a light straw colour appears upon the brightened surface of the dies, they must be removed from the hot iron; and, if the heat has not been too suddenly applied to them, they may be allowed to cool in the air of their own accord. If the heat has been too suddenly applied, and has changed the under side of the die or dies to a deep blue colour, it will then be requisite to cool them either in water or oil, otherwise the bottom side of the die, after it is removed from the hot iron, will continue to supply heat to the engraved surface and reduce the hardness too much; and the die or dies will be practically useless for the purpose they are intended for, until the operations of hardening and tempering of them have been repeated.

Hardening these kinds of articles a second time without hammering them increases the risk of their breaking; and as they cannot be hammered without spoiling the engraving, it must be obvious that very great care is required when hardening and tempering them, and the hardener ought never to place more of the dies upon the hot bar than what he can conveniently manage.

When it is required to harden steel rings or collars which have one thick edge and one thin edge, such as the collars of some turning-lathes, these may be enclosed, several at once, in a sheet-iron case or box, and surrounded on all sides with either wood or animal charcoal. The box will require to be luted with clay or loam, after which the whole may be placed in a furnace or hollow fire and the steel rings or collars heated to the proper temperature suitable for hardening them. To spare the trouble of enclosing these kinds of articles in a box and surrounding them with charcoal, they may be heated in a suitable furnace without being enclosed in a box, or they may be heated in the midst of the fuel of a hollow fire. When these kinds of articles are heated in a furnace or hollow fire in contact with air, and the fire free of wood or animal charcoal, they should always be coated, previous to immersion, with the prussiate of potash, in the manner previously explained. When the rings or collars arrive at the proper temperature suitable for hardening them, they must be drawn from the fire and placed upon the same or a similar kind of wire tool as that which is used for bearing circular cutters, whilst they are becoming cool when they are immersed in the water. The rings or collars may be immersed in the water separately, or two or three may be immersed at once, by taking care to place them upon the wire in such a position that the stoutest edge of each ring or collar may enter the water foremost. Previous to immersing these kinds of articles in the water, and when it is intended to place two or three of them at once upon the wire to be immersed together, it will be necessary to examine the depth of the water in the hardening tank, in order to ascertain whether the depth of the water is sufficient to allow the rings or collars when immersed being moved up and down without risk of bringing a part of the uppermost collar above the surface of the water. If the water is not sufficiently deep to allow these kinds of articles, when two or three are immersed together, being moved sufficiently to remove the heated water from the inside of them, it will be far better to immerse them separately, and thus lessen the risk of their breaking. These kinds of articles require to be very slowly and uniformly heated, and should not be plunged too suddenly into the water. The more uniform the temperature the less liable are they to become oval or out of shape, and the more uniform they become cool the less liable are they to crack; consequently it must readily be seen that these kinds of articles require to be immersed very slowly. It must also readily be seen that it is quite requisite that the thickest edge should enter the water foremost. The degree of heat required to harden these kinds of articles will, of course, depend upon the quality of the steel from which they are made. Sometimes rings and collars are made of the best cast steel; they are made by punching a long hole near to the end of a steel bar; after the hole is punched a round taper mandril is driven into it to widen the hole; it is then cut off the bar near to the hole and worked upon the beak iron of the anvil. When the ring or collar has nearly reached the proper form and size it is finished upon a larger mandril than the first, after which it is annealed and turned in the turning-lathe to the required dimensions. When rings or collars are made of the best cast steel by the method here explained, they will only require to be heated to a low red heat to harden them.

Sometimes rings and collars are made of shear steel. They are made by scarfing the extreme end of a bar of shear steel; the ring or collar is then partly formed by bending the scarfed end of the bar round the beak iron of the anvil; the partly-formed ring is then cut off the bar, and the second end is scarfed; the two ends are then brought together, and united by welding. The shear steel rings are then finished upon a mandril; after which, they are annealed and turned in the lathe to the required dimensions. When rings or collars are made of shear steel by the method here explained, they will require to be heated to a bright cherry-red heat to harden them. Sometimes rings and collars are made of iron, and made to take the place of steel; they are made in a similar manner as the shear steel rings or collars. In order that the iron rings or collars may be made hard, and take the place of steel, they are, after they are finished being turned in the lathe with the exception of polishing, case-hardened.

It is seldom necessary to temper or reduce the hardness of steel bushes, rings or collars; because the generality of these kinds of articles are required for bearings for different parts of machinery, where they have to endure a great amount of friction, consequently they require to be very hard to keep them from wearing. Ring and plug gauges, which are made of steel, require a great amount of hardness given to them to prevent them from wearing; consequently these kinds of articles will not, after hardening, require to be tempered.

Ring and plug gauges are sometimes made of iron, and made to take the place of steel by being case-hardened, previous to lapping or grinding to their proper sizes. The method of case-hardening will be explained in a subsequent chapter.

It has already been shown, that the more uniformly steel articles become cool when hardening, the less liable are they to fracture; and it has been previously recommended that the stoutest part of steel articles should enter the water foremost. It becomes necessary, perhaps, to state here, that this method of immersing steel articles cannot in all instances be adopted; for there are no means by which the stoutest part of some kinds of articles can be made to enter the water foremost. For instance, with such an article as a feather-edge circular cutter it is not practicable to get the stoutest part into the water first; consequently, when this method cannot be adopted, some other which will have a tendency to cause the steel to cool uniformly must be resorted to. It will be obvious that the method of fitting a piece of flat iron to the thinnest part of this kind of article cannot conveniently be adopted. The process of concaving the sides to reduce the substance of the steel in that part of the cutter which is the last to become cool cannot be adopted, because this would unfit a feather-edge cutter for the purpose for which it is intended. It is evident then, that if none of these methods can be adopted with a feather-edge circular cutter that there is great risk of the largest kinds breaking from unequal cooling. When it is required to harden a large feather-edge circular cutter, it must be very slowly and uniformly heated to a cherry-red heat; the most convenient way of heating it is in the midst of the fuel of a hollow fire. As soon as the temperature of the cutter is sufficient to fuse the prussiate of potash, it must be taken out of the fire and coated with the potash, and then be returned to the fire for a few minutes, or until it acquires a cherry-red heat; after which it must be drawn out of the fire, and immersed in the water in a similar manner as other kinds of circular cutters. It will be obvious, from previous remarks, that if the temperature of these kinds of large cutters be properly regulated at first, they will not, after hardening, require to be tempered.

Previous to putting this kind of cutter into the fire, it will be well to cut out two rings from a piece of wire cloth and bind one of them upon each side and at the thin part of the cutter. Several short pieces of binding wire will be required for binding the wire rings upon the cutter. These wire rings will not prevent the thin part of the cutter from hardening, but if they be properly bound upon the cutter they will have a tendency to cause the potash to cling more firmly to it and prevent the water from acting too suddenly upon the thin part of the cutter, thereby causing it to cool more uniformly. It will not be necessary to bestow this trouble upon the smaller size cutters of a similar shape; but, with large expensive cutters, to lessen the risk of fracture is not labour lost.

It occurs to me, also, that the use of the wire rings may be dispensed with by taking a certain portion of the prussiate of potash and mixing with it a certain portion of flour or bean meal, or some similar substance, and, after heating the cutter to redness, and giving it one coat with the pure prussiate of potash, to give the thin part of the cutter a second coat with the mixture. If this mixture adheres to the thin part of the cutter it will prevent the water cooling it too suddenly, and thus prevent the cutter breaking; but I have never given this mixture a trial myself, and cannot speak upon its value with certainty.

When it is required to harden an eccentric ring or collar, it may be heated in the midst of the ignited fuel of a hollow fire. If it is made of the best cast steel it will require to be uniformly heated to a cherry-red heat and coated with the prussiate of potash in a similar manner as other articles, after which it must be immersed endways and perpendicularly in the water and entirely quenched. It will be obvious that there would be no difficulty in getting the stoutest part of such an article into the water foremost, but it will not answer to adopt this method in such a case. If the stoutest part were to enter the water foremost it would certainly cause the collar to cool more uniformly, and probably it would prevent the thinnest side of the collar breaking; but then, by going sideways into the water, it would cause the hole in the collar to become oval and the outside of the collar to lose its proper shape, which would unfit it for the purpose for which it was intended; consequently it is quite requisite that a piece of iron should be fitted to the thin side of the collar (as has previously been remarked), and that the collar should be immersed endways and perpendicularly in the water.

When it is required to harden a large piece of round cast steel in which a hole has been bored through it (such a piece as has previously been spoken of), it may be surrounded with wood or animal charcoal in a sheet-iron box and heated either in a furnace or a hollow fire in a similar manner as other articles, or it may be heated in the midst of the ignited fuel of a hollow fire. If it is heated in the midst of the ignited fuel, it will require to be coated with the prussiate of potash. Whichever method be adopted for heating it, it will require to be heated to a cherry-red heat, after which it must be withdrawn from the fire and placed upon the same kind of tool as that which is used for dipping circular cutters—it must be immersed endways and perpendicularly in the water. During the time it is becoming cool it must be moved up and down in the water in order to allow fresh water to pass through the hole, or, in other words, to remove the heated water out of the hole; or it may, after it is beneath the surface of the water, be turned upon its side and drawn backwards and forwards until it is cool.

It may be inquired, what makes the difference whether the steel be moved about in the water during the time it is becoming cool or whether it be held still, when it is known that heated water always rises to the surface. The answer to this is, that the heated water does not rise to the surface so suddenly as the heat is required to be extracted from the inside of the article; consequently, it is quite requisite that it should be moved about in the water in order that the cooler portions of the water may pass through the hole and cool the article more uniformly.

It has previously been stated that it is injurious to bore holes too near to the outside edges of steel articles; but it is obvious that boring holes near to the edges cannot, with some kinds of articles, be avoided; therefore, if the hardener is required to harden any kind of steel article which has holes in it near to the edges, it is advisable before putting the article in the fire to stop the holes with a piece of loam: this method will prevent the steel breaking at the holes. It may be useful to some who are not much accustomed to harden steel to know that, if a piece of binding-wire be wrapped round any part of a steel article, and a piece of loam wrapped round the wire, it will prevent the steel from hardening in that part when it is immersed in the water; consequently it will prevent the steel breaking at the part where the loam is on. The wire is for no other purpose but to prevent the loam from falling off; the loam requires to be dried upon the article before it is put into the fire, otherwise it will probably crack and let the water get at the steel. But, for the sake of making this subject properly understood, as it may often prove very useful to the hardener, let us suppose that the middle part of a piece of one inch square cast steel is required to be hardened and the two ends required to be kept soft. We will suppose it to be four inches in length and at each end of it a countersunk round hole, for the reception of a bolt three-eighths of an inch in diameter, having a cheese-shaped head three-eighths of an inch in thickness, and three-quarters of an inch in diameter.

It must easily be seen, by the shape of this kind of article, that if a proper method is not adopted there will be some difficulty in hardening it to make it answer the requirement, namely, quite hard in the middle and soft at the ends, and not cracked at the holes. If this kind of article could be made hot in the middle without heating the two ends there would be an end to the difficulty ; but it is obvious that, owing to the shortness of this kind of article, this cannot be done, so that, whatever method be adopted in heating it for hardening, it will require to be heated throughout its body. Fires are sometimes made so that a very short heat may be got upon any part of some kinds of articles ; but this is an article which will require a certain amount of time to soak, consequently the middle part of it cannot be properly heated in a short open fire without the two ends becoming hot: it is evident, then, that the article must be heated throughout its body. There are various methods that could be adopted in hardening this kind of article. First, it may be heated in an iron box in contact with charcoal, or it may be heated in the midst of the ignited fuel of a hollow fire ; when it is sufficiently heated it may be lifted out of the fire with the pliers, one end of it must then be dipped into the water and partially cooled, after which the opposite end must be dipped and partially cooled in a similar manner. This operation is to partly cool the steel to keep it from hardening at the parts which are required soft.

When the temperature of the two ends is reduced beyond that which will harden the steel, the whole of the article must be immersed in the water and entirely quenched. A certain amount of dexterity is required in cooling the ends, otherwise the middle part of the article which is required hard will become too low in temperature to harden properly. By adopting this method, the middle part of the article is hardened and the ends remain soft. Still this method is not perfect; because the article frequently becomes cracked at the holes when cooling the ends.

Another method of hardening this kind of article is to heat it the same as before, and immerse it at once in the water. This, of course, hardens the ends as well as the middle. The ends may subsequently be softened, though very imperfectly, by placing them between pieces of iron heated to whiteness; or the heat may be more suddenly applied by punching a hole (the size and shape of the end of the article) in two separate pieces of stout iron, and, after heating the two pieces of iron to a whitish heat, placing the ends of the article into the holes. This method of hardening this kind of article is not perfect; because the article is liable to become cracked at the holes in hardening, and the hardness is liable to become reduced in the middle of the articles by heating the ends to get them soft.

Another method is to heat the article in a hollow fire and harden it throughout, after which the two ends may be made soft by dipping them, one at a time, in some red-hot lead. This method is not perfect, because the article is liable to become cracked at the holes in hardening, and too much time is required for heating the lead for softening the ends; and, as time is money, this becomes a very expensive way. Though red-hot lead is an excellent thing for heating some kinds of articles, and would answer quite well for softening the ends of this kind of article, still it is quite unnecessary to make use of it in this instance.

The most convenient and satisfactory method of hardening this kind of article, is to wrap a piece of binding wire about the holes, and then to fill the holes with loam, at the same time cover the ends and the wire with the loam; this will form a small ball of loam at each end of the article; the wire is to prevent the loam falling off. After the loam is placed upon the ends it will require to be gradually dried before it is put into the fire; after the loam has become dry the article may be placed in the midst of the heated fuel of a hollow fire; that part of the article which is not covered with the loam will require to be coated with the prussiate of potash, the potash may be put on without drawing the article out of the fire by using a slip of iron, one end of which should be the shape of a spoon; the article will require to be heated throughout to a cherry-red heat, after which it must be drawn out of the fire and immersed in the water and entirely quenched. Those parts of the article which are surrounded with the loam, namely, the holes, will remain soft and will not crack, because the water cannot penetrate through the loam quick enough to harden the steel. I have myself had numbers of articles to harden similar in shape to the one just described, and by adopting the method of stopping up and surrounding the countersunk holes with the loam I never knew one to crack; though I have seen numbers of the same kind of articles cracked at the holes when the loam has not been used. It may be imagined, perhaps, that, if one method were given for hardening this kind of article it would have been sufficient; but I have thought it necessary to mention various methods (at the same time I have stated which is the best method) in order that it may set the young mechanic thinking, and to afford him a better opportunity of judging for himself which is the best method.

It has previously been stated that sharp internal angles are unfavourable to articles which require to be hardened, and it has been hinted that sharp internal angles should be avoided; but, as they are required in some kinds of articles, and as they are often left in articles when they are not required in them, I will state that, when I have an article to harden which has sharp internal angles, I always bind a piece of binding wire in the angles of the articles, and when I have a circular cutter to harden, which has a flat key way in it with sharp angles, I always make a kind of key, by bending a piece of binding wire backwards and forwards and then bind it into the key way of the cutter. This of course does not strengthen the cutter, but it has a tendency to cause the potash to cling more firmly at the key way, and prevents the water acting too suddenly upon the weakest part of the cutter. It may, perhaps, be thought by some that it will be better to fit an iron key into it; if an iron key was fitted tight into it, it would have a tendency at the period when the cutter was shrinking from the hot to the cold state, to split it, as the cutter would have to compress the key, which would hold it for the moment in a greater state of tension (strain) than if the key was not there.

It has previously been stated that it is injurious to make the centres too deep or too large in some kinds of articles, which require to be hardened; consequently, it will be well to remark here, that, if the hardener meet with articles that he considers have too large a centre in them, it will be well to stop up their centres with a piece of loam previous to hardening, and thus prevent them becoming cracked at the centres in hardening.

When it is required to harden a large quantity of small or medium size screw taps at once, they may be enclosed in a sheet-iron case or box, and surrounded on all sides with either wood charcoal or animal charcoal. Preference should be given to the wood charcoal on account of it undergoing no change by being exposed to heat, providing the access of air is prevented; consequently, it can be saved and put aside to be used again. The taps will require, of course, to be packed in alternate layers, commencing with the charcoal on the bottom of the box, to the thickness of about three quarters of an inch, and finishing with a layer about the thickness of the first; the intermediate layers of the charcoal need not be more than one-third the thickness of the first and last layers. Sufficient space must be left every way for the expansion of the steel taps by the heat; otherwise, as they become heated they will bend and damage each other. After the packing is completed and the lid of the box put on, it will require to be luted with clay or loam (in order to exclude the atmospheric air), after which, the box and its contents must be placed in a suitable furnace or hollow fire, and the whole heated to a cherry-red heat. The fire must not be urged, as a certain amount of time is essential to allow the contents of the box to become uniformly heated throughout. When the whole arrives at the proper heat, the box may be drawn to the mouth of the fire, the lid removed, and each tap taken out separately and immersed endways (screw end foremost) and perpendicularly in the water; or the box may be drawn out of the fire, and the whole of the taps immersed at once direct from the box in the water. It is obvious that it is a more expeditious way of hardening to immerse them all at once. But then they are more likely to become crooked than if they were taken out of the box separately, and immersed perpendicularly and slowly into the water. If the hardening tank is made of iron, and the method of immersing the whole of the taps at once is adopted, it will be well to sink a piece of board to the bottom of the tank for the taps to fall upon; the board should be nearly the length and width of the inside of the tank, and may be sunk by placing a piece of iron upon each end of it. If, in addition to this, a piece of iron or a brick be placed at each end, beneath the board, it will have a tendency to cause the board to spring and scatter the taps when they are tipped out of the box, which will cause them to cool more equally. The taps will of course require to be packed in such a position that they will, when the box is held over the hardening tank, fall endways and perpendicularly into the water. When it is required to harden a large quantity of the largest size screw taps they may be enclosed in an iron box, and surrounded with carbon in a similar manner as the smaller sizes. They must not, like the smaller taps, be allowed to fall direct from the box into the water, but must be taken out of the box and immersed separately; but it will be a more expeditious way to heat the largest size taps in the midst of the ignited fuel of a hollow fire, or a suitable furnace. If this method is adopted, the taps will require to be very slowly heated; but several may be heated at once. When they arrive at a cherry-red heat, which is the heat suitable for hardening them, they must be taken out of the fire separately and coated with the prussiate of potash, after which they must be returned to the fire for a few minutes, or until they regain the heat lost while being coated; after which they must be taken out and immersed endways, screw end foremost, and perpendicularly in the water. This method of applying the heat may also be adopted with small quantities of small or middle-size taps. Taps hardened by this method will answer the purpose for which they are intended equally as well as if they were heated in a box surrounded with carbon.

In all cases the taps must be allowed to remain in the water until they become quite cool, after which, when taken out, and previous to using them, they will require to be tempered; but before tempering they must be brightened in one, two, or more places, in order that the colour may be seen, and the proper temper ascertained. It will not be necessary to brighten the square tops or heads, but only the plain round parts of the taps, also one of the concave grooves which are cut along the side of the taps. After the taps are brightened they may be tempered by exposing them again to heat. When a large quantity is required to be tempered, place as many of the taps at once as may be convenient into an oven or gas stove specially constructed; heat the taps until a dark straw-colour appears upon the surface of them. This temper is the best that can be given to screw taps which are required for general purposes, but those required for a special purpose, such as cutting hard cast iron, or some kinds of steel, will then require to be tempered to a yellowish white or light straw colour. As soon as the proper colour appears upon the surface of the taps they must be withdrawn from the heat. If the colour does not further change after the taps are withdrawn from the heat, it is a proof that the heat has not been too suddenly applied; and the taps may then be cooled in oil, or they may be allowed to become cool in the air of their own accord. Should the colour be observed to be changing from a straw colour to a golden colour, the taps must instantly be cooled in water; otherwise they will become too soft for the purpose for which they are intended. Cooling the taps in oil, after they are tempered to the proper colour, has a tendency to prevent them rusting if they are to be laid aside. The greater portion of the oil, of course, will require to be wiped off; but the taps need not be wiped quite dry. Another method by which screw taps may be tempered, is to place a piece of plate iron into and near to the mouth of any common furnace, such as those which are connected with steam boilers, &c. After the plate is placed in the furnace several of the taps may be placed at once upon the plate and heated until the proper colour appears. The taps will require to be moved about upon the plate during the process in order to equalize the heat. As they become heated, and the proper colour appears upon their surfaces, they must be withdrawn from the heat; their places may be filled up with others, and a continuance of the process may be, if necessary, kept up. It is not every person who makes screw taps that has large quantities to temper at one time, so as to require a furnace, or oven, or gas stove. The amateur mechanic seldom has more than two or three sets at most requiring to be tempered at one time. There are others who have only a few to temper occasionally, merely for the use of the shop; consequently, it may be well to explain another convenient method whereby a small quantity of screw taps may be tempered without the use of the furnace, oven, or gas stove. A small quantity of taps, after they are hardened and brightened, may be tempered by gripping the top of the taps, one at a time, with a pair of tongs, and holding them in the inside of an iron ring, heated to redness, until a dark straw-colour appears upon its surface. The heated ring may be placed upon the anvil or other suitable place. The screw end of the tap must be allowed to project out of the ring when first the heat is applied, otherwise the point of the tap, or the leading thread, will change its colour sooner than the middle part of the tap, and the temper will be unequal. As the top or plain part of the tap changes its colour the screw part must be drawn back into the ring. If the jaws of the tongs by which the tap is gripped be previously heated to redness, it will be the better, as the heated tongs will help to supply heat, and temper the taps more uniformly. It will be obvious that if the top or plain parts of small screw taps be tempered to a blue, that they will be less likely to break when in use; consequently, the heated tongs will be very convenient for tempering the plain parts of the taps to a blue at the time that the screw part is being tempered to a straw colour. The hardener ought to be provided with two rings, and three pair of tongs, so that, whilst one heated ring and one pair of heated tongs are being used, the other ring and another pair of tongs may be in the fire becoming heated. The third pair of tongs should not be heated, but they should be ready at hand; so that, if it should happen that the heated tongs supplied the heat too suddenly to either of the taps, the heated tongs could be laid aside for a few minutes, and the tap gripped with the cold pair of tongs. With care, two, and sometimes three of the smallest or the middle size taps may be tempered without reheating the ring. The larger the diameter of the tap, the longer it will be in changing its colour, that is, providing the heat is properly applied. The thickness of the iron from which the ring requires to be made must be in proportion to the thickness of the tap; or, in other words, the larger the diameter of the tap the thicker the ring will require to be, in order that the ring may retain sufficient heat long enough to temper the tap. The diameter of the inside of the ring will require to be about two inches larger than the diameter of the tap. If smaller than this, it will be apt to supply the heat too suddenly to the tap. The length of the ring will require to be about the same length as the tap, except when the ring is required for tempering very long tapered taps, such as those sometimes required to have the screw part as much as five, six, or more inches in length. When the ring is required for tempering these kinds of taps, it will be more convenient to have it somewhat shorter than the tap and move the tap to and fro in the ring.

The hardener will find in practice that if two or three short rings be heated and placed in a line with each other, and made to take the place of a long single ring, it will be more convenient for tempering these kinds of taps.

Screw taps are sometimes required for some purposes as much as eighteen and more inches in length, the screw part occupying but a small portion (about three inches) of the whole length of the taps. When it is required to harden these kinds of taps, they may be placed in the midst of the ignited fuel of a very small hollow fire; or they may be placed in the inside of a piece of iron pipe, the iron pipe being previously placed in the midst of the fuel of an open fire. The screw part of these kinds of taps is the only part which requires to be hardened; consequently, it is the only part necessary to be heated. They must be very slowly and uniformly heated to a cherry-red heat, and immersed endways and perpendicularly in the water and entirely quenched. These kinds of taps will, like the other kinds, require to be brightened and tempered. The plan of applying the heat by the use of an iron ring will be very convenient, but the method of gripping the taps with the heated jaws of a pair of tongs, it will be obvious, cannot conveniently be adopted; consequently, if they be stout taps, a very thick ring heated to whiteness will be required. The whole of the screw part, and about one inch and a half of the plain part of the tap, must be allowed to project out of the heated ring, in order that the heat may be applied to a certain portion of the plain part of the tap first; otherwise the tap cannot be properly tempered. This part of these kinds of taps requires to be in contact with a greater amount of heat than will at first sight be readily imagined, and it is for this reason that I have suggested a very hot ring. If the diameter of the inside of the ring be somewhat smaller for these kinds of taps than for other kinds, it will not be amiss. As soon as this part of the tap (which is in the ring) has changed its colour to any of the intermediate colours between a light straw and a deep blue, the screw part of the tap which is now projecting out of the ring must be drawn back into the ring, and tempered to the same colour as other kinds of taps, namely, a dark straw colour.

When it is required to harden master taps (commonly called by workmen, hobbs), the same methods adopted with other kinds of taps must be applied, with the exception, that these kinds of taps must be left in a slight degree harder than the other kinds. The reason for this is, they are mostly required for cutting steel, such as the threads of screw dies, also for cutting the threads upon those kinds of screw tools called chasers, &c.; consequently the small and middle size master taps will not require to be reduced in temper lower than a yellowish white or light straw colour. It will be obvious from the manner in which master taps are grooved, that there is greater liability of their breaking in hardening, and less liability of their breaking when in use than the other kinds of taps of the same diameter; consequently, when it is required to harden the largest size master taps, the heat should be carefully regulated at first, so that, after they are immersed in water, become cool, and taken out, they will be ready for use, and thus dispense with the subsequent process of tempering. The largest size master taps will be the better (whether heated surrounded with carbon in an iron box, or whether heated in the midst of the fuel of a hollow fire) if they are coated with the prussiate of potash previous to immersion.

When it is required to harden large or small screw dies, in large or small quantities, they may be heated in a similar manner as screw taps, either by enclosing them in an iron box and surrounding them on all sides with carbon, and placing the whole in a furnace, or by placing them in the midst of the ignited fuel of a hollow fire. Whichever method is adopted, they will require to be uniformly heated to a cherry-red heat. They will require to be immersed plain end foremost in the water; or, in other words, the screw part of the dies should be uppermost when the dies enter the water. It will be obvious that, if the dies are immersed separately, there will be no difficulty in making the plain end of them enter the water foremost; but in order to approach this method as near as practicable, the dies should be packed in the box in such a position that they will all have a tendency (when the box is opened and held over the water tank) to fall plain end foremost into the water. When the dies are heated in the midst of the ignited fuel of a hollow fire, they will require to be coated with the prussiate of potash previous to immersion. A very convenient box in which to heat a moderate quantity of small screw dies or small screw taps, may be made by welding a plug into the end of a piece of large wrought iron pipe. A loose plug will be required for the opposite end of the pipe; it must be the same size as the bore of the pipe, and about one inch and a half in length. Part of the plug must be allowed to project out of the pipe for the convenience of gripping it with the tongs, or tapping it with the hammer when required to be taken out; otherwise, it may be difficult to get it out, especially after it has been luted with loam. The plug will require to be temporarily fastened into its place; this may be done by boring a hole through the pipe and the plug, and driving an iron pin through the two. It will be obvious that when a large quantity of screw dies or screw taps are required to be heated in a box, the box should be larger in proportion to the quantity to be operated upon, and the box will require to be made of plate iron.

After screw dies are hardened, they will require to be brightened and tempered. The tempering may be performed by placing the dies, several at once, upon a hot plate of cast metal; or they may be tempered by placing them upon a piece of bar iron, one end of which must be heated to redness. Those kinds of dies which are used in the screwing machine, and all large screw dies of a similar shape, will require to be placed upon the heated iron, screw part uppermost, in order that the heat may not be too suddenly applied to the cutting part of the dies.

As soon as these kinds of dies are observed to be changing their colour, they must be moved to the cooler part of the iron, otherwise the bottom part of the screw part of the dies will be apt to become softer than the top part, and the temper would be unequal. It will sometimes be found necessary, after the dies are removed to the cooler part of the iron, to turn them bottom upwards for a few moments, or to turn them upon their sides, in order to obtain a uniform degree of temper.

Some kinds of screw dies require to be placed upon the hottest part of the iron at first, and as they become heated should be drawn towards the cooler part of the iron. Other kinds of screw dies require to be placed upon the cooler part of the iron at first; and, as they become heated, they require to be drawn towards the hotter part of the iron. This, of course, depends upon the depth of the dies, or the distance between the screw part and the back part of the dies.

The dies must be allowed to remain upon the heated iron until their cutting parts become uniformly changed to a dark straw colour; after which they may be cooled in water or oil, or allowed to cool in the air of their own accord, according to circumstances previously explained. The smaller size screw dies may be uniformly tempered, and the heat very gradually applied, by placing them upon a stout piece of cold plate iron, and then placing the plate and dies upon a thick piece of iron heated to a whitish heat. The dies must be turned over occasionally in order to expose all their sides to the heat. As their surfaces become changed to a dark straw colour, they may be pushed off the plate into a vessel containing water or oil. If the plate has not become too hot, their places may be filled up with others. If the plate has become too hot, it may be taken off the hot iron and placed upon the anvil face; it will then in a few moments be in a fit state for tempering a second quantity. By putting the plate back into its place (upon the hot iron) a third, and sometimes a fourth quantity, may be tempered without re-heating the iron.

When it is required to harden a large quantity of those kinds of screw tools called chasers, they may be placed (several at once, or as many as may be convenient), in the midst of the ignited fuel of an open fire, or they may be placed in the midst of the ignited fuel of a very small hollow fire. The screw end or cutting part of the chasers, requires to be heated to a cherry-red heat. The blast, of course, must be sparingly used. When they arrive at the proper heat, they must be drawn out of the fire; but, should there be some in advance of the others, these must be the first to be drawn out, after which the heated end will require to be coated with the prussiate of potash. They must then be returned to the fire for a few minutes, or until they acquire a cherry-red heat, after which they must be immersed into the water and entirely quenched. In order to keep up a continuance of the process, as they are withdrawn their places in the fire must be filled up with others. After the whole of them have been immersed and become cool, they will require to be brightened and tempered. They may be brightened upon a grinding stone or an emery wheel, or by rubbing the top surface with a piece of grinding stone, or by an emery stick, or a piece of emery cloth. After the chasers are brightened they may be placed, several at once, upon a piece of flat bar iron heated to redness. The screw end of the chasers must be allowed to project some distance (about one inch and a quarter) over the heated iron, otherwise the heat will be too suddenly applied to the cutting parts of the chasers. As soon as a yellowish-white, or light straw colour appears upon the cutting parts of the chasers, they must be removed from the heat and cooled in water or oil, otherwise the back part of the chasers which was in contact with the heated iron will continue to supply heat, and the chasers will become too soft. As the chasers are removed from the hot iron, their places can be filled up with others. By having two pieces of iron, one piece in the fire becoming heated whilst the other piece is being used, a continuance of the process may be kept up. After the chasers are taken out of the water or oil, and the top surface ground upon the grinding stone, they are ready for use. Though this method is a very expeditious one for hardening and tempering a large quantity, still it is not absolutely necessary to adopt it with a small quantity or a single chaser; because they may with care be hardened and tempered equally as well by heating them and partially dipping them into the water and tempering them by the heat at the back part of the chaser, without the use of the hot iron. It will be obvious that, when this method is adopted, a greater portion of the tool will require to be heated, in order that the back part of the chaser may retain sufficient heat to temper the cutting part after it has been immersed into the water.

When this method of partially dipping the chaser is adopted, it will be advisable to put the water in motion previous to dipping the chaser; or, otherwise, when the cutting part of the chaser is beneath the surface of the water, give the chaser a quick movement; this will prevent the water from cooling the steel in a strict line, and guard against water cracks. That part of the chaser which is beneath the surface of the water must be allowed to remain in the water until it becomes quite cool, after which it must be taken out and brightened. In a short time the back part of the chaser will supply sufficient heat to the cutting part, to temper it to the desired colour. As soon as the proper colour appears, the chaser must be entirely quenched; and, when taken out of the water and ground upon the grinding stone, it will be like those which have been wholly quenched and subsequently tempered on the heated iron, ready for use.

When it is required to harden a screw-plate, it may be placed in the midst of the ignited fuel of a very small hollow fire, or among the ignited fuel of an open fire. It will require to be very slowly and uniformly heated to a cherry-red heat; the blast of course must be sparingly used, otherwise it will become crooked. There is no necessity for heating the whole length of the shank or handle; but it is quite necessary to heat a small portion of it, in order to obtain a more uniform heat upon the plate. As soon as the temperature of the plate is sufficient to fuse the prussiate of potash, it must be withdrawn from the fire, and coated with the potash, in a manner similar to other kinds of tools; after which it must be immersed very slowly, endways and perpendicularly, in water. The largest size screw-plates will generally keep truer by being immersed edgeways and horizontally in the water. The screw-plate must be allowed to remain in the water until it becomes quite cool, after which, when taken out, it will require to be brightened and tempered. It may be tempered by holding it over a piece of flat bar iron (heated to redness) until a dark straw colour appears upon its surface; or it may be tempered between two pieces of flat iron heated to redness, and placed a certain distance apart from each other, in order that the heat may not be too suddenly applied; or it may be held in the inside of an iron ring heated to redness; or it may be tempered in a sand-bath, provided the temperature of the sand is just sufficient to change it to the proper colour—if the sand is hotter than this, there is a great risk of the threads becoming too soft; or the heat may be applied by any other convenient method, after which the plate will be ready for use.

Screw-plates and screw-dies are often ruined by being used upon iron and steel rough from the forge, and covered with scales, which, from their hard gritty nature, grind away the threads. In all cases the rough scale should be removed from the iron or steel, either by the turning tool, file, or grinding stone, previous to screwing it with the screw-plate or the dies. It is not an uncommon practice with some workmen, after they have finished forging a piece of iron-work, and whilst the iron is at a red heat, to immerse it in water and partly cool it, with a view of giving the work a cleaner appearance; but this is a very bad custom, especially when the forging requires to be screwed. It very often happens that the iron contains veins of steel, which harden by immersion; and, though the metal may not be so hard as to prevent its being cut with a hard turning tool, still, when it comes to be screwed with the stocks and dies, or with the dies belonging to the screwing-machine, or with the screw-plates (which tools are always less hard than the turning tools), it will spoil the dies or the screw-plates; and because this hard place or places do not happen to be detected when turning the work (on account of using a very hard tool), the steel the dies or screw-plate is made of will be thought bad, or badly tempered. The fact is, the work should always be annealed rather than hardened. In all cases when an impure iron is made use of for forgings, and which will subsequently require to be screwed, either with the screw-dies or the screw-plate, or which may require to be cut with circular cutters or with circular saws, the forgings should always be annealed previous to leaving the smithy. The forgings, of course, will be the better for being annealed, supposing they are to be screwed with the screw tools belonging to the turning-lathe; though it is not of so much importance as when they are to be screwed with the dies, or the screw-plate, or cut with circular cutters, or circular saws, because the screw tools belonging to the turning-lathe can be ground again, provided they chip from being very hard; whereas, the generality of screw dies, screw-plates, and circular cutters, and even circular saws, when very hard, and once spoilt, will not admit of being again sharpened, but will be practically useless, until they have been annealed, and cut up again, and subsequently hardened. Annealing makes the iron more uniform in temper, and will save much subsequent trouble; it will greatly facilitate the work when fitting it up.

When it is required to harden a large quantity of stout circular saws at once (for cutting metals), they may be enclosed in a sheet iron case, or box; they will require to be surrounded on all sides with either wood or animal charcoal. Sufficient space must, of course, be left every way for the expansion of the saws; otherwise they will become buckled in heating. After the saws are enclosed and the box luted with clay or loam, the whole may be placed in a suitable furnace or hollow fire and the saws heated to a cherry-red heat (the fire of course must not be urged.) As soon as the whole arrive at the proper uniform temperature, the box must be drawn towards the mouth of the fire, the lid taken off and the saws taken out separately. They may either be taken out of the box with the pliers or by a small rod of iron, having a small hook turned upon one end of it. The saws will require to be immersed edgeways in a trough containing water, the surface of which must be covered with a film of oil. The oil will float of itself upon the surface of the water and burn upon the saw as it passes through it. The burnt oil forms a coating of coal upon the saw, which protects it from the direct action of the water, and lessens the risk of fracture.

Though saws are the better for being enclosed in a box and surrounded with charcoal when heating them, still, when a single saw is required to be hardened in a hurry, it will be more expeditious to place it upon a piece of cold sheet-iron, and then to heat the iron and the saw in the midst of the ignited fuel of a hollow fire; and when it arrives at the proper temperature, it must be taken off the plate and immersed in the hardening fluid. By placing the saw upon a piece of cold sheet-iron, it causes the heat to be very slowly applied, and it has a tendency to prevent the saw buckling in heating. Oil alone, or oil in which tallow has been dissolved, is sufficient to give the thinnest kinds of saws a sufficient degree of hardness; but those of a medium thickness are the better for being hardened in solid tallow (the saws may be placed separately between two flat lumps of tallow.) Tallow differs from oil in the absorption of heat for its fusion; consequently, a more considerable degree of hardness is given to the steel by the tallow than by the oil; besides, it hardens the steel to a greater depth than oil. Very thin blades of steel may be made sufficiently hard for some purposes by heating the blades to a red heat and then placing them between two heavy surface plates; the surface plates will be better if they be smeared with tallow, previous to putting the blade between them. When the saws are removed from the hardening trough, they are generally brittle and warped; consequently, they will require to be tempered and hammered flat. The tempering may be performed in a variety of ways, depending of course upon the size, shape, and quantity. Circular saws, which are required for sawing hard substances (such as iron or steel), and which have a round spindle hole, about one inch in diameter in them, will require to be tempered to a light straw colour. These may be tempered by first brightening their surfaces, and then placing them upon a piece of hot iron. The piece of iron which will be required for tempering these kinds of saws may be made by the following method. Take a piece of round bar iron, one inch in diameter and eight or nine inches in length; heat one end of it and hammer it so as to make it fit into the small square hole in the anvil; at the opposite end of this piece of iron and at about two inches from the extreme end, weld a moderate sized iron collar; the collar should be made of half round iron, so that it will, after it is welded upon the piece of round bar, form a large lump, the shape of a round ball. The object of this large lump is to retain the heat for a considerable time, so that several of the saws may be tempered before the iron will require to be reheated. If two of these lumps were made, one of them could be in the fire becoming heated, whilst the other lump is being used; so that, if it were necessary, a continuance of the process may be kept up. The object of having this lump the shape of a round ball, is that it may not supply the heat too suddenly to the saw. If this lump was made flat, it would supply the heat too suddenly, unless it was used at a very low temperature; it is evident it would not then temper more than one or two of the saws before it would require to be reheated. The object of having this round lump welded upon a piece of round bar, is for the convenience of keeping the lump in position upon the anvil, and to prevent the operator from always being in a stooping position when tempering the saws. The iron being finished, it is now ready to be heated for tempering the saws. The large lump will require to be heated to a red heat, after which the opposite end of the iron must be placed in the hole in the anvil. The saws may now be placed (one at a time) upon the lump; a slow rotary motion must be given to the saw, by the use of a small stick of wood, in order to equalize the heat. The end of the round bar at the top of the lump will help to supply heat and keep the saw in position whilst it is being turned round upon the lump. As soon as a light straw colour appears upon the saw, it must be taken off the iron and cooled, either in water or oil; or, if the heat has not been too suddenly applied, the saw may be allowed to cool in the air of its own accord. These kinds of small circular saws are generally, after hardening, convex on one side and concave on the other. This imperfection is owing to the outer part of the saw becoming too small to contain the central part. When the practice of securing the saws upon the spindle by circular plates screwed firmly against each side is adopted, a small degree of regular convexity is not very detrimental, because the plates bring the saw straight; but, when they are convex in a greater degree, they will require to be slightly hammered. The outer part of the saw is the part which requires to be hammered, in order to expand the outer part and bring the middle flat.

These kinds of saws may be tempered, and the trouble of brightening their surfaces spared, by smearing them with oil or tallow and holding them one at a time over a slow clear fire until the oil or tallow begins to smoke, after which the saw must be immersed in oil and partly cooled; it must then be held over the fire a second time, until the oil again begins to smoke. If the saw is immersed in the oil and held over the fire a third time, it will ensure a more regular degree of temper. Care must be taken each time the saw is heated not to raise the temperature beyond that which is necessary to cause the oil to smoke; otherwise the saw will become too soft for the purpose it is intended for—namely, cutting hard substances. By this method the saws acquire the same temper as that which they acquire when tempered to a straw colour. A large quantity of these kinds of saws may be tempered more expeditiously by threading them upon a piece of iron wire, and then placing them in a proper vessel with as much oil or tallow as will cover them (the wire is for convenience in lifting the saws out of the vessel, and then to place the whole over a small clear fire, or over a gas flame, until the oil or tallow begins to smoke, after which the saws must be taken out. They may then be cooled in water or oil, or they may be allowed to become cool in the air. This indicates the same temper as that called a straw colour.

Saw-blades which are required for sawing wood require to have the greatest amount of elasticity given to them; consequently, after they are hardened, they will require to be tempered to the same temper as that called spring temper. This may be done by exposing the blade, the surface of which has been brightened, to the regulated heat of a plate of metal till the surface has acquired a blue colour; or it may be heated in a sand-bath heated to the proper temperature. To spare the trouble of brightening them they may, like small circular saws, be smeared with oil or tallow and heated over a clear fire. It is obvious that the softer the steel is intended to be the more grease must be burnt off; consequently those saw-blades which are required for sawing wood, and which require to be sharpened with the file, will require to be heated till thick vapours are emitted and burn off with a blaze; two or three reheatings, and partly cooling them in oil when tempering, will, of course, ensure a more uniform degree of temper. Saw-blades which are required for sawing wood could, like those intended for sawing metals, be heated and tempered in hot oil; but, perhaps, it would not be very economical. The oil, of course, would require to be heated to a very high degree, in order to impart to the saws a spring temper; so that it is questionable whether the time saved by this method would be sufficient to compensate for the waste of oil, which, at this high temperature, is considerable; consequently it becomes those who have such things to temper to adopt those methods which will answer their purpose the best. Saw-blades, unless hardened in a current of air, are generally, after hardening, buckled and twisted in various directions; this is caused by an unequal contraction of the blade, and it would be almost, if not quite, impossible to prevent this unequal contraction, when it may arise from so many causes. The metal itself may be unequal in its texture. It may have been rolled at a temperature which was not uniform throughout the mass, or the blade may have been hammered more in one part than another; this would be sufficient, from its unequal density, to cause unequal contraction; or, if the temperature is not uniform throughout the blade when it is immersed in the hardening fluid, it will cause unequal contraction.

Saw-blades which have become buckled and twisted in hardening will, after they are tempered, require to be hammered flat; this operation requires a considerable amount of care and practice. It is obvious that the blades will require to be hammered at every part except those which are buckled. The hammering draws and expands those parts which are not buckled, and removes the unequal tension which has been caused by the unequal contraction of the blade. The extent to which the blade will require to be hammered, of course, can only be ascertained by experience.

When saw-blades are well hammered, and the unequal tension has been removed, they are then flat and more uniformly elastic; but if the crust of the blade be partially or wholly removed by grinding, or in any other manner the elasticity is proportionately impaired, and to restore the original excellence of this property, the blade will require to be again hammered and afterwards blued. Saws require to be made of the best cast steel, and, like all other kinds of tools, when required for cutting brass, require very sharp cutting edges; they require also to be, in a slight degree, harder for brass and cast iron than for steel or wrought iron, otherwise they soon lose their sharp edges.

When it is required to harden a single saw, such as is used for sawing off the ends of wood screws, or for sawing off the ends of small screw bolts, or for occasionally sawing the grooves in the heads of screws, it may be heated to a cherry-red heat, and then placed flatways and horizontally between two lumps of tallow, or it may be pressed edgeways into a single lump of tallow. When it is intended to harden the saw by this last method, the saw should be slightly hammered at the back previous to heating and hardening it, otherwise the cutting edge will, in hardening, become convex, and the back edge will become concave. If the saw becomes crooked sideways, it may be straightened by slightly hammering it with the pane of a small hammer at the concave side, at the same time pressing with the fingers upon each end of the saw. The saw will be the better for being slightly heated previous to hammering it; it may be heated by placing the back side of it upon a piece of hot iron. If the saw should be found too hard for the purpose it is intended for, the back edge may then be placed upon the hot iron, and the saw tempered to a light straw colour.

When it is required to harden a lathe centre, it may be heated in an open fire; the tapered part only requires to be heated, and this only to a low red heat; the lowest heat that it will harden at is the most advantageous, as the centre is the more likely to keep true, and it will not afterwards require to be tempered. It must be immersed endways and perpendicularly in the water; the back end of the centre must enter the water foremost; it must be allowed to remain in the water until it becomes cool, after which it is ready for use. Lathe centres for large lathes, on account of the heavy weights they sometimes have to carry, ought always to be made of the most tenacious cast steel, which ought only to require a low red heat to harden.

When it is required to harden a large or small quantity of fluted or other kinds of rimers, they may be heated in a similar manner to screw taps, either by enclosing them in an iron box and surrounding them on all sides with carbon and placing the whole in a furnace or hollow fire, or by placing them in the midst of the ignited fuel of a small hollow fire. It will sometimes be more advantageous to heat these kinds of articles in red-hot lead, especially when a large quantity requires to be operated upon, because this is a very expeditious method for heating them, and they generally keep truer in heating by being surrounded on all sides with the uniform temperature of the lead, consequently they will keep truer in hardening. The lead, of course, must be heated to a certain temperature suitable to the steel. If the rimers are made of the best cast steel, the temperature of the lead need not be raised higher than what is necessary to heat the rimers to a cherry-red heat; if the lead is too hot, it will burn the steel, and cause the rimers to be full of very small holes, which of course will unfit them for the purpose for which they are intended. If the lead by chance becomes too hot, it may be cooled down to the proper temperature by dipping a piece of cold iron into it.

When it is intended to heat small rimers in red-hot lead, it will be necessary (previous to putting them into the lead), in order to protect them from the direct action of the heat, and to prevent the lead sticking to them, to brush them over with a little soft soap; the largest and middle size rimers will be the better for being brushed over with black lead, mixed with water, or they may be brushed over with a mixture of lamp-black and linseed oil. If the black lead and water is used, it will be well to dry the rimers previous to putting them into the lead, otherwise the dampness may cause the lead to fly and accidents may happen from it. Whichever method be adopted for applying the heat to rimers, they will require to be heated to a cherry-red heat, after which they must be immersed separately, endways and perpendicularly (except half-round rimers), and slowly in the water. Half-round rimers are very liable to become crooked, or concave on their round side, owing to the round side being the last to become cool; consequently they will require to be immersed in the same steady manner as the other kinds, but not so perpendicularly—they will require to have a more horizontal inclination. They may be immersed perpendicularly, provided they are slowly moved horizontally in the water in the direction of the round side, at the same time that they are being immersed endways. It must be borne in mind that red-hot lead will heat the steel much quicker than the ignited fuel of the fire; consequently, when large fluted rimers are heated in lead, the cutting ribs of the rimers will arrive at the proper temperature much sooner than the central parts of the rimers, or before the innermost centre becomes at all heated; and if the rimers are immersed in the water the moment the cutting ribs become sufficiently heated (and they may be immersed without fear of breaking them), the central parts of the rimers will remain soft; consequently, if large fluted rimers become crooked in hardening, they may be easily straightened. They may be straightened by laying them upon a block of hard wood, or upon a block of lead, and then putting a piece of round iron (the size of the groove) into the groove at the convex side, and then striking the iron with the hammer. If the rimers be tempered previous to striking them with the hammer, they will straighten the easier. When small fluted rimers are heated in red-hot lead, they become heated through almost instantly they are put into the lead, consequently, it must be obvious that if these become crooked in hardening they cannot be straightened in the same manner as the larger sizes; therefore, in order to guard against their becoming crooked, they must be allowed to remain in the heated lead until they become uniformly heated to their innermost centre, and then immerse them endways and perpendicularly and very slowly in the water, and entirely quench them; and if any of them become crooked, it will be well to soften them again, then straighten and reharden them. Care must of course be taken not to raise the temperature of the lead higher than what is necessary to heat the rimers to the proper temperature suitable for hardening them. The method I have myself sometimes adopted when hardening fluted rimers is this. I have heated them separately in red-hot lead, and then immersed them separately, endways and perpendicularly, in the water, having the water of a suitable depth, so that when a rimer was immersed and the extreme end of it made to touch the bottom of the tank and then withdrawn, it would harden the cutting edges of the rimer and leave sufficient heat in the central part, so that the rimer would, if it were crooked, admit of being straightened, either by placing it between the centres of a turning lathe, and striking it upon the convex side with a small wooden mallet, or by placing it upon a block of hard wood, or a block of lead, and striking upon the convex side with the mallet. As this method requires a great amount of experience and dexterity, and as there is great risk of the rimers breaking when they are struck with the mallet, especially if they be allowed to become too cool previous to striking, it will be well, perhaps, for the operator (in order to avoid any considerable obstacle) to adopt the method previously explained, that of immersing them endways, perpendicularly, and slowly in the water, and entirely quenching them.

Rimers after they are hardened will require to be tempered, which may be done by adopting similar methods to those to be adopted for tempering screw taps. Fluted rimers will require to be tempered to a yellowish-white, or light straw colour; six and eight-sided rimers will also require to be tempered to a light straw colour; square, and triangular, and half-round rimers will require to be tempered to a dark straw colour. The reason why square, and triangular, and half-round rimers require to be reduced lower in temper than the other kinds is, that they take hold of the work so deeply that they are very liable to break by the force requisite to turn them round. Six and eight-sided, and square and half-round rimers, which have become slightly crooked in hardening, may be straightened by screwing a chipping hammer (flat face uppermost) between the jaws of a pair of vice; the convex side of the rimer may then be laid upon the hammer face, whilst the concave side is slightly hammered with the sharp pane of a small hammer, at the same time pressing with the fingers upon each end of the rimer. If the rimers (previous to hammering) be slightly heated, they will straighten the easier, and be less liable to break.

Small drills, gouge bits, centre bits, countersinks, gimblets, bradawls, or sprig bits, &c., may be expeditiously hardened by dipping their cutting parts into red-hot lead, and then cooling them in water. When it is intended to dip several of any of these kinds of articles at once into red-hot lead, it will be necessary to have a pair of tongs with long jaws for gripping the articles. One of the jaws of the tongs will require to be made hollow inside, and the other jaw made flat; the hollow jaw is for convenience—for binding a piece of wood into it—so that if the articles should happen to be of an unequal thickness the tongs may grip them all, as the most prominent parts of them will sink into the wood. When the wood becomes too much worn, it may be replaced with another piece. Any quantity of these articles may be heated as expeditiously as a single article, if there be sufficient lead. Gouge bits, gimblets, bradawls, or sprig bits, will require to be tempered after they are hardened. They may be tempered by placing them upon a piece of hot iron and heating them until a blue colour appears upon their surfaces, and then pushing them off the hot iron into a vessel containing cold oil; or, if the heat has not been too suddenly applied, they may be allowed to become cool in the air of their own accord. A large quantity may be tempered at once by placing them in a proper vessel with as much oil or tallow as will cover them, and then placing the whole over a small fire and slowly heat the oil until it will take fire if a light be presented to it, but not so hot as to burn when the light is withdrawn. The articles may then be lifted out of the oil (that is, providing the vessel is furnished with a false bottom), or the whole may be tipped out of the vessel upon a thin sheet of iron which is slightly curved and placed in a slanting position, with a vessel placed at the bottom to catch the oil; the articles may then be allowed to drain and become cool of their own accord, they will then be the same temper as if their surfaces were blued upon hot iron.

Centre bits, and countersinks, for cutting wood, require to be tempered to a purple colour. The heat may be applied to these either by a piece of flat bar iron or by an iron ring heated to redness, or they may be placed in a proper vessel containing oil or tallow, and then placed over a small fire and the whole slowly heated until the oil yields a thick black smoke, but not so hot as to take fire if a light be presented to it. The articles must then be taken out of the oil and allowed to become cool; they will then be the same temper as if their surfaces were changed to a purple colour upon hot iron.

Red-hot lead is an excellent thing in which to heat any long plate of steel that requires hardening only on one edge, for it need not be heated in any other part but that which is required hard, and it will then keep straight in hardening; at least, it will keep very much truer than if it were heated in the midst of the ignited fuel of the fire.

If a long steel plate which requires to be hardened only on one edge, be heated in a furnace or in the midst of the ignited fuel of a hollow or open fire, and then the whole body of it immersed in the water, it will become very much twisted and warped, and will cause a deal of trouble to set it straight again, even though the steel be tempered previous to being hammered, especially to those who are unacquainted with the way of hammering and setting steel plates in a hardened state. If the plate be heated throughout its body, and if only one edge of it (the edge which is required hard), be immersed in the water, or, in other words, if the plate be only partially immersed, the plate will become in a great degree concave on one edge, and convex on the other. The edge of the plate which goes in the water becomes convex, and the edge which does not enter the water becomes concave. This is owing to that part of the plate which is below the surface of the water contracting and becoming shorter by the loss of heat, and compressing the red-hot part of the plate which is above the surface of the water into a denser state; moreover, after that part of the plate which was below the surface of the water has become quite cool, it will be in a slight degree longer than what it was when in its soft state, consequently this has a tendency to push the red-hot part of the plate round and thereby helping to cause the uppermost edge of the plate to become concave.

After the whole body of the plate has become cool, the hardened part, as well as the soft part of the plate, will sometimes be shorter than what it was previous to hardening, even though the hardened part did expand longer in hardening. This is caused by the soft part of the plate contracting by the loss of heat after the hardened part has become cool, and thereby compressing the hardened part into a denser state. If red-hot lead is used as a source of heat, and the edge of the plate only (which is required hard) be put into the lead, it is obvious that the other part of the plate will remain cool; consequently, when the plate is entirely immersed in water, the hot part of the plate will not act with sufficient force to alter the cool part, consequently the cool part of the plate tends to keep the hardened part true. It may be inquired, if the part which goes in the lead expands longer in hardening, and is not able to act with sufficient force to compress the cool part, will not the hardened part become twisted and buckled? The answer to this is: it will not become twisted or buckled by the expansion (though it may become crooked in a slight degree by the unequal hammering, or the unequal density of the steel), because the heated part of the plate has been compressed by the cool part during the time it was expanded by the heat, consequently the expansion will generally be about equal to the compression, and the plate will be about the same dimensions that it was previous to hardening.

Should the hardened part of the plate happen to become in a slight degree longer than what it was previous to hardening, it is a proof that the expansion predominates over the compression; if on the contrary it becomes shorter, it is a proof that the compression predominates over the expansion.

When it is intended to heat articles in red-hot lead, they ought not to be plunged too quickly into the lead: plunging cold steel too suddenly into red-hot lead has a tendency to cause it to become crooked in a similar manner as red-hot steel becomes crooked when it is plunged too suddenly into cold water.

All articles which are heated in red-hot lead should be slightly moved up and down in the lead during the time they are becoming heated, otherwise the heat will be apt to terminate in a strict line, and will probably cause them to crack when they are immersed in the water.

A very good vessel in which to heat the lead when one edge of a long plate is required to be heated, is made by taking a piece of three-inch angle iron, a few inches longer than the plate to be hardened, and slitting and turning, and welding each end of the angle iron so as to form a kind of trough. A long fire will be required for heating the angle iron and the lead; a fire of any length may be made by taking a piece of wrought iron pipe, and boring some holes into it in the direction of its length. The holes will require to be about five-eighths of an inch in diameter, and about three inches apart; one end of the pipe must then be inserted into the aperture of the tuyere. A row of bricks must be placed on each side of the pipe, at a suitable distance from it, so as to leave room for the fuel and the angle iron between the bricks. The pipe will require to be covered over with loam or fire-clay, in order to keep it from burning; previous to covering the pipe over, each hole should be stopped with a piece of wood, so that the loam may not get into the pipe, or stop up the holes in the pipe; after the covering up of the pipe is completed, the pieces of wood may then be pulled out of the holes, and the fire lighted. The fire will burn with more regularity if the first three or four holes (at that end of the pipe which enters the tuyere) be a little larger than the others, as the blast is always strongest at the far end of the pipe. A loose plug will, of course, be required for the far end of the pipe to stop the blast; and, if at any time the pipe becomes stopped by the ashes falling through the holes of the pipe, the loose plug may be taken out, and the ashes blown out of the pipe; the plug may then be put back into its place. If more durable things than the angle iron and pipe be required, a long fire-tile may be chipped out to the proper shape, and made to answer the purpose, and a small special furnace constructed for heating it. A pot for melting a small quantity of lead may be made by welding a plug into one end of a piece of wrought iron pipe; but this is not very durable, as the high temperature of the lead will soon cause it to burn into holes, and allow the lead to run out into the fire.

When a more durable thing than the wrought iron pipe is required, and a larger quantity of lead requires heating, a crucible similar to those used in brass foundries will be suitable. Crucibles containing a large quantity of lead cannot conveniently be heated in a common smith's fire; consequently, a suitable furnace must be constructed for the purpose. When it is necessary to heat the lead in a crucible, it should be made red-hot previous to putting the lead into it; and, in heating the crucible, the same plan must be adopted as that which is generally adopted in brass foundries; namely, putting the crucible in the fire with its mouth downwards), in order that the heat may act upon the inside and the outside of the crucible at the same time, and so cause a more uniform expansion of the crucible, and lessen the risk of its cracking. The crucible need not be reversed until it has become red-hot; then it will be ready to receive the lead. If the crucible be put in the fire bottom downwards, the heat for a time would only act upon the outside, consequently it would cause an unequal expansion, and increase the risk of its cracking.

Another thing to be observed is, that the surface of lead when melted in open vessels becomes quickly covered with a skin, or pellicle. This is occasioned by the action of the oxygen of the atmosphere, the activity of which soon causes the skin to increase in thickness, and wastes the lead so fast that it becomes an object of importance to those who use much lead to check its formation, or convert it when formed into the metallic state again. Charcoal, or fatty substances, assisted by a sufficient heat, convert this dross, or oxide, into metal again; but if a covering of charcoal or cinders be kept on the surface of the melted lead, the oxide will not form. When it is allowed to form, it not only wastes the lead, but is a great obstruction to getting the articles in and out of the lead.

In a former part of this work it has been recommended to allow steel when heating for hardening (in order to assist the process) ample time to soak and become uniformly heated to its innermost centre. In this place (on the subject of heating steel in red-hot lead) it is stated that large fluted rimers may be immersed in the water without fear of breaking them immediately their cutting ribs or edges become uniformly heated to the proper temperature suitable for hardening them, without waiting for the central steel to become heated. As this will probably be noticed by some persons who may not perhaps give it sufficient thought to ascertain the true meaning of it, it will then appear to them that one part of the work is in contradiction to the other part; consequently I have thought it necessary in this place to give an explanation to it so as to prevent the reader misunderstanding it. In the first place, it will be necessary to repeat that red-hot lead will heat steel much quicker than the ignited fuel of the fire; consequently, when such an article as a large fluted rimer is dipped into the red-hot lead, the surface steel will become uniformly heated before the central steel has acquired sufficient heat to cause it to expand (at least, from the short time the rimer is in the lead the central steel can only become expanded in a very small degree); consequently, when the rimer is immersed in the water, the surface steel in cooling has not to compress the central steel, neither has the central steel to contract after the outer crust is fixed; consequently, a large fluted rimer may be immersed into the water (without risk of breaking it) immediately the cutting ribs arrive at the proper temperature suitable for hardening them. If the surface steel of any article, when placed in a hollow or open fire, could be uniformly heated without heating or expanding the central steel, there would be no necessity for allowing the steel to soak or become uniformly heated to its innermost centre; but as the surface steel cannot, in a hollow or open fire, be uniformly heated without causing the central steel to become heated and expanded also, it becomes then quite necessary to heat the central steel to the same temperature as the surface steel, in order that the central steel may admit of being compressed by the surface steel when it is immersed in the water. When the central steel of any article becomes heated and expanded, and not sufficiently softened to admit of being compressed by the surface steel (when becoming cool), it will have a tendency to hold the surface steel in such a state of tension that it will sometimes cause it to crack in several places, and the surface steel will sometimes shell off in flakes; consequently, it must be seen that if the central steel is heated at all, it is requisite to heat it uniformly with the surface steel; it will then lessen the risk of its breaking in hardening. For further information upon this subject, I must refer the reader to the chapter upon the expansion and contraction of steel.

When it is required to harden large or small drifts in large or small quantities, they may be heated in a similar manner as screw taps, either by enclosing them in an iron box and surrounding them on all sides with carbon, and placing the whole in a furnace or hollow fire, or by placing them in the midst of the ignited fuel of a hollow fire. Whichever method be adopted, they will require to be uniformly heated to a cherry-red heat. When they arrive at the proper heat, they will require to be immersed separately, endways, perpendicularly, and slowly in the water and entirely quenched. After the drifts have become quite cool and been taken out of the water, they will require to be brightened and tempered: they may be tempered by adoping similar methods to those which are to be adopted for tempering screw taps. Drifts will require to be tempered to a brown colour.

When it is required to harden a quantity of large common drills, and which have been allowed to become quite cool after having been forged, they may be placed, several at once, or as many as convenient, in the midst of the ignited fuel of a very small hollow fire, or they may be heated in an open fire, taking care to keep their points out of the hottest part of the fire at first, and gradually drawing their points towards the hotter part of the fire as the upper parts become heated. A considerable portion of the drill will require to be heated to a cherry-red heat. The blast, of course, must be sparingly used. When the drills arrive at the proper heat, they must be taken out of the fire separately. Those in advance of the others must be the first to be taken out; a part of the heated portion of the drill must then be immersed in the water. It must not be forgotten that it is requisite to put the water in motion previous to dipping the point of the drill into the water, or otherwise, to give the drill a vertical, or other movement, immediately it arrives to the proper depth in the water. That part of the drill which is below the surface of the water must be allowed to remain in until it becomes quite cool, after which it must be taken out, and the cutting part brightened, which may be done by rubbing the surface with a piece of grindstone, or with an emery stick, or with a piece of emery cloth. The drill may then be laid upon the anvil, or any other suitable place, whilst another is drawn out of the fire and treated in a similar manner. The heated portion of the drills which were not immersed in the water will then continue to supply the heat to temper the cutting parts of the drills. After the second drill has been immersed, it may be placed alongside the first drill, and another drill withdrawn from the fire, and so on, until all that have been heated have been immersed. The hardener must of course (during the time he is drawing the drills out of the fire and dipping them into the water) have his attention upon those he has placed upon the anvil, so that he may see when the cutting parts arrive at the proper temper ; as soon as a uniform dark straw colour appears upon the cutting parts of the drills, they must be instantly cooled in the usual manner, otherwise the upper part of the drills may continue to supply heat, and the cutting parts will become too soft. Should it happen that the heat at the back part of any of the drills is insufficient to temper the cutting part, it will be advisable, in order to complete the tempering, to hold the drill for a few moments in a gas flame, if the gas is lighted ; or it may be placed upon a piece of hot iron, if there is a piece of hot iron ready at hand ; or a few hot ashes may be drawn out of the centre of the fire, and the drill held over them. All drills which are intended to bore holes less than the quarter of an inch (and when a quantity are required to be hardened) must not, like the larger kinds, be heated and partially immersed; but their cutting parts only should be heated to a cherry-red heat, and the drills wholly immersed and entirely quenched. They may subsequently be tempered by first brightening their cutting parts, and then placing them several at once upon a piece of bar iron heated to redness. Their cutting parts must be allowed to project some distance over the heated iron, otherwise the heat will be too suddenly applied. As soon as a dark straw colour appears upon their cutting parts, they must be cooled in the usual manner.

Miniature drills, such as those used by clockmakers and others, cannot conveniently be heated in the midst of the ignited fuel of the fire; though some of them may be heated in charcoal dust, heated to a red heat. These small drills are generally heated in a gas flame, or in the flame of a candle; they are hardened by plunging suddenly their heated points into a lump of tallow or into the grease of the candle. They are tempered, if found too hard, by taking a little of the tallow upon their points, and then placing them in the flame at a short distance above the point, and holding them there until the tallow upon the point begins to smoke; the cutting part of the drill is then of the same temper as if it were brightened and tempered to a straw colour. By any of the methods just explained, the cutting parts of drills are tempered to a straw colour, while the rest is not higher than blue, so that the liability of their breaking when in use is greatly diminished.

It has previously been stated that chipping chisels will be the better if the hammering (when forging them) be continued until the cutting part becomes nearly cool; and, perhaps, it will not be amiss to state here that it is better to harden and temper them after being forged, and while the part above the cutting-edge is in a red-hot state, than to allow them to become quite cool, and then to reheat them for hardening. The reason for this is, greater care is required to heat them properly after they have become quite cool; consequently, there is greater risk of the effect of the hammering being taken off again.

When a large quantity of chipping chisels have been forged, and have been allowed to become quite cool, and which may require to be hardened and tempered, similar methods must then be adopted, as those which are to be adopted for hardening and tempering the largest kinds of common drills, with the exception that the chisels will require to be tempered to a violet colour, that is, if they are required for chipping metals. If the chisels are required for chipping stone, they will require to be tempered to a purple colour. The force required for chipping stone being less than for metals, it is obvious that the chisels are less liable to break; consequently (in order to prevent them wearing away so fast), they may with safety be left in a slight degree harder.

When it is required to harden those kinds of small chipping-chisels which are used for chipping the delicate kinds of work, they must not, like the larger kinds, be heated and partly immersed, but their cutting part only should be heated to a cherry-red heat. They should then be wholly immersed and entirely quenched. They may subsequently be tempered by first brightening their cutting part, and then placing them, several at once, upon a piece of bar iron heated to redness. As soon as their cutting part becomes changed to a violet colour, they must be instantly cooled in the usual manner.

When a common turning-tool is required extraordinarily hard for cutting very hard cast iron, it will be necessary, in the first place, to heat the tool to a red heat, and then give it a judicious hammering until it becomes nearly cool, after which it will be necessary to heat some lead to a bright red heat; a small quantity of charcoal dust must be placed upon the surface of the heated lead to prevent oxidation. During the time the lead is becoming heated, the cutting part of the tool should be heated to a low red heat in an open fire. After the lead has become heated to a bright red heat, and the cutting part of the tool to a low red heat, the tool must then be drawn out of the fire, and while it is at a red heat the scale must be removed with the file; the cutting part of the tool must then, as soon after filing as possible, be put into the heated lead. It must be allowed to remain in the lead until it becomes heated to the same temperature as the lead—a bright red heat; after which it must be taken out of the lead and instantly plunged into a bucket of pure cold water, and a rapid movement given to it, and entirely quenched; after which, when taken out of the water and ground upon the grinding-stone, it is ready for use. By this method the steel acquires a greater degree of hardness than will be readily imagined by those who have never tried it.

When it is required to harden small spiral springs which are made of steel wire, or springs for locks, or any of the other kinds of slight springs, they will require to be uniformly heated to a cherry-red heat, and then immersed in cold oil (not oil which has been long in use and become thick), and entirely quenched. Springs of a medium thickness will be the better for being cooled in water, the water being previously heated to about 60 degrees of heat, and the surface of which should be covered with a film of oil. The thickest kinds of springs will be the better for being cooled in pure water heated to about 70 degrees of heat. Springs require to have the greatest amount of elasticity given to them; consequently, they will, after they are hardened, require to be tempered. They may be tempered separately by smearing them over with oil or tallow and then holding them over a clear fire, or in a hollow fire, or in the inside of a piece of large iron pipe inserted in the midst of the ignited fuel of an open fire, and uniformly heating them until a white flame burns upon them, or, in other words, until the grease burns off with a blaze. If it is a spiral spring (or any other kind of spring which is not thicker at the ends than at the central part) which is being tempered, and which is shorter in its length than the length of the fire, it will be very apt to become heated at the extreme ends first; consequently, as soon as the two ends arrive at the proper temperature (which is known by the grease taking fire) the spring must be immersed in oil: it must not be entirely quenched, but must be taken out of the oil again immediately, and then again exposed to heat. If the oil upon the ends take fire again sooner than the oil upon the middle part of the spring, it must then be immersed again in oil, and then again exposed to heat, and so on until the oil burns uniformly upon all parts; otherwise the spring cannot acquire a uniform temper. After the spring has become uniformly heated to the proper temperature, and the oil burns uniformly upon it, it must then be again immersed in oil, then taken out again immediately and allowed to become cool in the air of its own accord. It will then be fit for use. All kinds of springs, whatever their shape or whatever their size, may be tempered perfectly by this method. It must be borne in mind that there is but one certain temper which gives to steel its greatest amount of elasticity; consequently, the stiffness or pliability of springs must be regulated by the substance and shape of the steel from which they are made. A very convenient way of tempering a large quantity of small springs at once (they must, of course, be previously hardened), and of heating them uniformly, no matter how irregular their shape, provided the heat is not too suddenly applied, is to bind a quantity of them together with a piece of iron binding-wire, and then to put them into a suitable vessel with as much oil or tallow as will cover them. Then place them over a small clear fire, and slowly heat the whole. Just as the oil begins to boil the springs must be lifted out, when a white flame will burn uniformly upon the whole of them; they must then be immersed into cold oil,—they need not be entirely quenched, but they may be taken out of the oil again immediately and allowed to become cool in the air of their own accord, and when cool, they will be like those which have been blazed off separately over the fire, and fit for use. A separate spring may be attached to a separate piece of wire, which may be lifted out of the oil occasionally, to ascertain when the whole is at the proper heat, which is known by the white colour of the flame upon the spring.

Large springs may be tempered by this method, but the time saved with large springs will not be sufficient to compensate for the waste of oil; consequently, it will be more economical to temper the largest springs by blazing over the fire.

It would be well for those who are not accustomed to the operation, before attempting to boil a large quantity of springs, to boil a single one in a small quantity of oil, and so make themselves acquainted with the proper temperature of the oil and the proper temper of the spring.

I will now bring this chapter to a conclusion, not because I have no more to say, but because I do not think it necessary to say more; but I may add, that the hardness of cutting tools and the angles forming their edges, must be varied according to the strength and hardness of the material to be worked. The harder materials require tools with more obtuse angled edges, and no cutting tool will act upon a substance harder than itself.

The number of turns which the mandril of the lathe ought to make in a given time must also be varied according to the strength and hardness of the material to be worked. The velocity of rotation for wood can scarcely be too swift, it must be rather slow for lead, brass, copper, gun-metal, and bell-metal; still slower for ordinary cast iron, forged iron, and steel, and slowest of all for tempered steel, and chilled cast iron; or, in other words, for cast iron which has been cast in iron moulds, or other good conductors of heat.

The reason for these limits is, that a certain amount of time, varying with the material, is requisite for the act of cutting to take place, and that the tools, if much heated, will instantly become soft and cease to cut.

CHAPTER VII.

EXPANSION AND CONTRACTION OF STEEL.

Expansion and contraction belonging to this subject is the enlargement, or increase, or decrease, in the bulk of the steel, as the case may be, in consequence of a change in the particles by the process of hardening. It is pretty generally known to those who are employed at the process of hardening steel, and to those in the habit of fitting up various kinds of work requiring great nicety, that the hardening of steel often increases its dimensions; so that such pieces of work, fitted with nicety in their soft state, will not fit when hardened, and the workman has therefore to resort to the process of grinding or lapping to make the work fit.

The amount of the expansion (or the amount of the contraction of steel) cannot be exactly stated, as it varies according to the size of the steel operated upon, and the depth to which the steel hardens; also in the different kinds according to the amount of carbon combined, and even in the same steel operated upon at different degrees of heat. Steel which is the most liable to injury by excess of heat is the most liable to these expansions; and steel which is less liable to injury by heat is the most liable to contractions. As, for example, the more carbon the steel contains, the greater will be the expansion of the steel; and the nearer the steel approaches to the state of iron, the less will be this increase of bulk.

Although steel expands in hardening, it is not universal for pieces of all sizes to increase in dimensions; for sometimes it is smaller in dimensions after hardening. This, at first sight, appears anomalous; but I will endeavour to give an explanation of it.

Steel, like all other substances composed of particles, varies in its dimensions with a change in temperature. It follows that when the steel is at a red heat, the natural positions of its particles are in a measure displaced, and it is expanded to a greater bulk; and when immersed in water and suddenly cooled, such a change of its particles takes place as to make it hard and brittle. It also contracts to a smaller bulk by the loss of heat; but this cannot so rapidly occur at the central part, because it is protected by the surface steel. Consequently, large pieces of steel do not harden all through; or, in other words, do not harden properly to their centres, but towards the centre the parts are gradually less hard, and will sometimes admit of being readily filed; and as it is only the outer parts of the steel which harden properly, consequently it is only those parts of the steel which harden that increase in bulk. When the steel is immersed in the water, the water begins first of all to act upon the outer crust of the steel, and then cooling it gradually towards the centre. The outer crust being the first to part with its heat, it is of course the first to contract and become smaller. The outer crust in contracting is held in a state of great tension, by having to compress the central steel (the central steel at the time being expanded by the heat). While the surface steel is in this state of tension, and the central steel in this state of compression, the particles of the surface steel (by the strain) are displaced at a greater distance from each other, and the particles of the central steel (by the compression) are compressed into a denser state. The particles of the central steel being compressed into a denser state, it causes the central steel, after it has become quite cool, to occupy less space than what it did previous to hardening. The particles of the surface steel become hard while in this state of tension, consequently the hardened part of the steel becomes fixed, and cannot return to its original bulk: consequently, the hardened part of the steel occupies more space than what it did previous to hardening.

If the displacement of the particles of the outer steel predominates over the compression of the particles of the central steel, the piece of steel under operation will then be larger in dimensions. If the compression of the particles of the central steel predominates over the displacement of the particles of the outer steel, the piece of steel under operation will then be smaller in dimensions. In other words, if the expansion of the outer steel amounts to more than the compression of the central steel, the piece of steel will increase in bulk; if the compression of the central steel amounts to more than the expansion of the outer steel, the piece of steel will then decrease in bulk. The expansion of the steel is greatest when it is heated to a high degree of heat before immersion. This effect is owing to the particles being displaced at a still greater distance from each other, and which may, in some measure, account for the brittleness of steel when overheated. This expansion is, in some measure, reduced in tempering; and this effect is caused by the hardness being reduced and allowing the particles to partly rearrange themselves to their natural positions.

It is believed by some, that the hardness of steel is caused by the compression of the whole of the particles into a denser state; in confirmation of this, they say that steel after hardening always looks closer and finer in the grain. Now, if this were the only cause of steel becoming hard, how does the steel get larger in dimensions? Pieces of steel of all sizes would, according to this, universally become smaller. The compression of the particles of the central steel into a denser state certainly does take place, as I have before remarked; but the particles of the outer parts of the steel are displaced at a greater distance from each other, or the steel could not become larger in dimensions. It is believed by some, that if a piece of steel (in hardening) increases in bulk in one part, that it must decrease in bulk in proportion in another part. Now, if this were the case, how is it that the specific gravity of some pieces of steel is reduced by hardening; and how is it that workmen have often to grind or lap pieces of steel to make them fit the same places which they fitted previous to hardening. It may be said that the steel may be prevented from fitting the place it previously fitted by becoming crooked or oval in hardening; but, if this were the only cause, how could it be made to fit its place again by grinding or lapping? It would be impossible (unless it were softened and upset) to make the lean or concave side of it fit its place again. I may also inquire, what is the cause of steel being whiter in colour after hardening? As I have previously remarked that it is only those parts of the steel which harden properly that increase in bulk, it may perhaps be asked, how is it that a piece of bar steel becomes shorter in hardening? The answer is, that the central steel is compressed by the surface steel endways as well as sideways, by the surface steel contracting shorter by the loss of heat. The central steel contracts after the outer crust is fixed, consequently an internal strain is caused; and, if the steel becomes shorter than what it was previous to hardening, it is because the force of this internal strain shortens the outer steel more than it expands in hardening.

It is quite reasonable to suppose, if the particles of the hardened parts of the steel are removed to a greater distance from each other, that the steel would look considerably more open and coarser in the grain; consequently, it may be inquired, if it is not the compression of the whole of the particles into a denser state, what is the cause of steel looking closer in its texture after hardening? The answer is, if we accept the theory that it is the crystallization of the carbon which causes the hardness in steel, that the carbon expands in the act of crystallization (in a similar manner that water expands by extreme cold in crystallizing into ice) and fills up every pore or crevice, and gives the steel the appearance of being closer and more solid.

Such is a slight sketch of the expansion and contraction of steel; and, although a great deal more might be said, I have not thought it necessary to entangle the reader with a lot of theories, although it may be necessary for his amusement, and for the exercise of sound judgment, to occasionally glance at them in treating fully the purely mechanical operations.

The expansion of steel is prevented in some measure by annealing the steel about three times previous to its being finished, turned, or planed; for instance, after the first skin is cut from the steel it should be annealed again, after which another cut must be taken from it and again annealed, and so the third time. This may appear to some like frittering away time; but in many instances the time will be more than saved in lapping or grinding to their proper sizes after the articles are hardened, especially when it becomes necessary to lap or grind them by hand-labour, for hardened steel works with great difficulty; therefore in some instances it becomes a matter of importance in hardening to keep the article as near as possible to its original size. I have myself had articles to harden which could not be lapped or ground to their finished dimensions in the turning lathe owing to their peculiar shapes, so that the workman has been compelled to adopt the slow process of lapping with a copper file and emery dust, mixed with oil. I have known those articles which were only once annealed, to take several hours to lap them to the finished dimensions after they were hardened; and I have known articles of the same kind, and of precisely the same dimensions (in their soft state), made from the same bar of steel and heated to the same temperature (as near as the eye could judge), and hardened in water of the same temperature, which have been annealed three times, scarcely requiring to be touched with the copper file after they were hardened. As there may be some persons who may perhaps require an article to be after hardening as near its original size as possible, and who may not perhaps be provided with such things as buffs, laps, or stones, I presume therefore that this hint will not be out of place in making those acquainted with it. Another hint deserves a place. I have found that articles made of steel which have been well forged will always keep truer and keep their original sizes better in hardening, and be less liable to break in hardening, than articles which are made of the steel in the state it leaves the manufacturer; for instance, if a very long screw tap, or long rimer, &c., be required for any special purpose, it will be well to take a piece of steel sufficiently large to admit of being forged to the required dimensions. If for a long screw tap or rimer, three quarters of an inch in diameter, seven-eighths round-bar steel swaged down at a cherry-red heat to three-quarters and a sixteenth will suffice (the one-sixteenth is allowed for turning); but if the edges of seven-eighths square steel be hammered down so as to form eight squares and then swaged down to three-quarters and a sixteenth, it will prove even better for the purpose than the seven-eighths round-bar steel, it must be obvious that if similar methods be adopted with larger articles, they will be less liable to break in hardening.

To make mistakes at times is the common experience of all. It may therefore not be out of place to say a few words upon such pieces of iron work as the mechanic may have the misfortune, through some oversight or other, to bore too large, and which would in some instances cause the work to be useless for the purpose for which it was intended were it not possible to contract the hole. The hole could, in some instances, be set in by heating the work at the forge, and then hammering it upon the anvil; but if the shape of the work be such as not to admit of being hammered, or if there be not sufficient metal to allow hammering, or for removing the marks caused by hammering, it will be obvious that this method cannot be adopted. Because this method cannot be adopted, it does not follow that this piece of work should be condemned as useless; for the hole may be contracted by adopting the process of shrinking.

It must not be understood according to the usual term shrinking, that the work should be heated, in order to expand the metal and widen the hole, and then shrunk upon another piece of work whose diameter is larger than the diameter of its own hole: for by this method it must be obvious that the metal cannot return to its original bulk, consequently the hole cannot return to its original diameter. And were it to be heated, and allowed to become cool in the air of its own accord, without being shrunk upon another piece of work, it could even then only return to its original dimensions; on the contrary, the piece of work will require to be uniformly heated to a red heat, and then immersed in cold water and entirely quenched. This method causes a sudden contraction of the metal, consequently the hole becomes smaller. If this does not sufficiently contract the hole, the operation must be repeated. If after the second heating and cooling the contraction be then insufficient, it must be operated upon a third time. If after the third heating and cooling the hole be not then sufficiently contracted, it will be next to useless to repeat the operation, as the particles will have become by this time in their most condensed state; at least, in the most condensed state they are capable of becoming by this operation, and instead of the hole contracting smaller, it will become oval, likewise wider at each end, or, as the term is, bell-mouthed. If it is an iron or steel ring or collar which is being operated upon, it will be found that even in the first heating and cooling it will cause the hole to be, in a slight degree, wider at each end than at the central part. This is owing to the two ends or edges of the ring becoming cool sooner than the central part of the ring; and, while the two ends are becoming cool, they are compressing the central part into a denser state. The central part of the ring contracting after the two ends have become quite cool, causes this unequal contraction. This unequal contraction might in a measure be prevented, if the operator, previous to heating and cooling the ring, take the trouble of shrinking a narrow collar upon the outside, at each end of the ring, and thus cause the ring to cool more uniformly. Should these methods not have the desired effect of sufficiently contracting the hole (either in an iron or steel ring), there is another source open, simply to heat the ring to a bright red heat, and then immerse it endways and perpendicular, and half its depth in the water, leaving the other half to cool in the air above the surface of the water. As that part of the ring which is below the surface of the water becomes cool, it compresses and thickens the other part of the ring, and causes the hole at this compressed end of the ring to be considerably smaller. The ring will require to be reheated, and again immersed in a similar manner, with the exception that the ring must be reversed; that is, the edge which was uppermost in the first instance must now be the lower edge. This method will accomplish what the other methods failed to do. This operation may, if found necessary, be repeated several times; but there is a limit even when this method is adopted, when the particles will assume their most condensed state, and after which it will be useless to repeat the operation, as the ring will (even though it be made of iron) ultimately give way, and the labour will be lost. Ring gauges which have become worn, may generally by these methods be contracted sufficiently to allow for grinding them to their original sizes.

CHAPTER VIII.

CASE-HARDENING OF WROUGHT IRON.

It has previously been shown that wrought iron is nearly pure decarbonized iron, and not possessed of the property of hardening. But I will now endeavour to explain a process by which articles made of wrought iron may be exteriorly converted into steel, and afterwards hardened. The process is called case-hardening, and is an operation much practised, and of considerable use; and in this, as in most of the other arts, differences of opinion exist. Some pretend to great secrets in the practice of this art, using many fanciful ingredients to which they attribute their success; but my object is to explain the most simple and common method adopted, and that which I have found in my own experience to produce the greatest and the most uniform effect. Case-hardening is always a superficial conversion of iron into steel, and only differs from cementation in being carried on for a shorter time; for it is seldom necessary to convert the iron into steel more than the sixteenth of an inch deep, unless it is for certain parts of machinery where great stiffness as well as hardness is required. It is not always merely for economy that iron is case-hardened, but for a multitude of articles for various purposes it is better than steel; for it has the hardness and polish of steel externally, with a core of soft fibrous iron in the centre: for example, if the mandrils of lathes were made of the best cast steel sufficiently hard to wear well in the collars, they would be liable to break by the twistings and sudden checks to which they are at times subjected; but, by uniting a certain quantity of steel with iron, either by welding or by the process of case-hardening, the danger of their breaking is avoided, and probably serious accidents avoided also. The prussiate of potash renders iron nearly as hard as steel, by simply heating the iron to a red heat, and sprinkling the potash finely powdered upon it, and then plunging the iron into pure cold water; but the hardness by this process is entirely confined to the surface, and for those parts of machinery which have to endure a large amount of friction, it is like frittering away time to case-harden them with the prussiate of potash; but for some kinds of articles not exposed to much wear, a sufficient coating of steel may be obtained by this process. A much greater, and the most uniform effect may be produced by a perfectly tight box, and animal carbon alone, such as horns, hoofs, or leather, just sufficiently burnt to admit of being reduced to powder, in order that more of it may be got into the box with the articles; bones reduced to dust will answer the purpose equally as well. The box intended for the purpose of case-hardening should be made of plate iron; the plate iron should not be less than one-eighth part of an inch in thickness; if the box is required to be used frequently, the plate should not be less than three-eighths, or one half inch in thickness, otherwise the box will soon be worn out. The size and shape of the box must, of course, differ according to the size, shape, and quantity of articles requiring to be operated upon. As the iron boxes must vary in their construction, and in order to make this subject as short and plain as possible, let us suppose a square iron box to be already made; the box of course must be furnished with an iron lid (a plain piece of plate iron, the size and shape of the interior of the box), two holes should be pierced in the lid for the convenience of drawing testing pieces out of the box at any period of the process if required. The top of the box may be strengthened and prevented from becoming out of shape so readily by the heat, by taking a piece of iron about three-quarters of an inch square, and bending and welding it into the shape of the interior of the box; and after boring several holes into it, it must then be riveted to the box at about one inch distance from the top; besides strengthening the box, this will answer for the iron lid to rest upon, and thus prevent the lid from pressing upon and bending the articles when they are expanded by the heat. By placing some clay or loam between this iron square and the lid it makes a very secure joint. Two holes should be pierced in the box at opposite sides, just above the lid, for the convenience for fastening the lid in its proper place (with two iron pins), and making the joint the more secure.

For occasional case-hardening upon a small scale, a very good box may be made by welding a plug into the end of a piece of wrought iron pipe, and using a loose plug for the opposite end; the loose plug will, of course, require to be fastened into its place with an iron pin passing through it and the pipe; it will, of course, require to be luted with clay or loam; part of the plug must project out of the pipe for the convenience of pulling it out.

It may happen that the amateur mechanic may have a small article that he wishes to case-harden, and, perhaps, he has no box suitable for the purpose, and, perhaps, he has no convenience for making one. In such an instance a box may be formed of loam; it will require to be gradually dried before it is exposed to a red heat, otherwise it will probably crack.

The articles intended to be case-hardened being previously finished, with the exception of polishing, must be put into the iron box in alternate layers with the animal carbon, commencing on the bottom of the box with the carbon to the thickness of about three-quarters of an inch; upon this a layer of the articles must be placed, then another layer of carbon, about one-third part in thickness of the first will be sufficient; upon this another layer of the articles and carbon, and so on till the box is nearly full, finishing with a layer of carbon about the thickness of the first layer, leaving room every way for the expansion of the articles by the heat, otherwise they will bend each other in the box.

After the packing of the box is completed, the lid must be put on and the box luted with clay or loam, in order to confine the carbon and exclude the atmospheric air. The whole must now be placed in a suitable furnace or hollow fire. The fire must not be urged, as the contents of the box will require to be very gradually and uniformly heated to a red heat; the whole will require to be retained at this heat for a period answerable to the depth of steel required. In half an hour after the contents of the box have arrived at the proper uniform temperature, the depth of steel will scarcely be the thickness of a sixpence; in an hour about double the depth, and so on till the desired depth of steel is acquired.

It may be asked what means there are to tell when the central articles arrive at the proper heat. The answer to this is, a practical man can judge by the heat of the fire and the quantity of articles being operated upon; but I am unwilling to refuse a place for the information of those who are unaccustomed to the operation, therefore I have suggested, in order to prevent the operator from meeting with any considerable obstacle, that two holes be pierced in the lid of the box for the insertion of testing pieces, so that at any period of the process a testing piece may be withdrawn and examined. If, when a testing piece is withdrawn, it be not sufficiently heated, the heating must be continued a little longer; after a reasonable time another piece may be withdrawn. If this second piece is sufficiently hot, it may then be hardened in pure cold water; it can then be broken with the hammer, and the extent of the carbonization ascertained. It must be borne in mind that different kinds of iron absorb carbon unequally; consequently, the testing pieces will require to be made of the same kind of iron as the articles, otherwise they will afford false results. It may be well to state, that the more homogeneous the iron the more equally it absorbs carbon ; consequently, the less likely it will be to alter its figure in hardening than iron which is not homogeneous.

To save breaking or using any of the articles for testing pieces, plain pieces of the same kind of iron as the articles may be used for the testing pieces. The testing pieces will require to be brightened ; they will require to be placed (at the time of the packing of the box) in the central part of the box, and placed in such a manner that they may be easily pulled out of the box through the holes in the lid, either by a piece of iron wire attached to them, or the pieces may be made long enough to project through the holes in the lid, so that they may be gripped with the pliers and withdrawn. The holes in the lid must, of course, be luted with loam or clay, the same as the other parts of the box.

When the articles are sufficiently converted, the box must be drawn from the fire, the lid taken off, and the contents immersed in pure cold water, and when cold and taken out, they are ready for polishing. The articles may (in order to prevent them from rusting) be dried by riddling them in a sieve with some dry sawdust, after which they may be wiped with a greasy cloth.

If the articles be immersed in oil instead of water, they will be much tougher but less hard, though sufficiently hard for some purposes. It is not absolutely necessary to immerse the articles either in water or oil, direct from the box, as it will answer equally well (and sometimes be more convenient) to allow them to remain in the box until they become cool, and then reheat them in an open fire, and immerse them separately. When the case-hardening is required to terminate at any particular part of an article, the part required soft may be bound with thin iron-wire, and then cased with loam. This will prevent the carbon coming in contact with the iron ; consequently it will prevent the carbon penetrating the iron, or, in other words, it will prevent the iron from absorbing carbon at the part where the wire and loam is placed. The loam will require to be gradually dried upon the article, previous to putting it into the box, otherwise it will probably crack.

Another method is to shrink an iron ring or collar very tight upon the part not requiring to be case-hardened ; but this method is not very economical, especially when a large quantity of articles requires to be similarly treated. It will be obvious that to make and fit a separate collar upon each of the articles, when a large quantity is required to be operated upon at once, would occupy a great amount of labour and time, besides a great amount of time will have to be expended in taking the collars off again ; and, as time is money, this would become a very expensive method. To spare the trouble of shrinking a collar upon the article, and to prevent the operator from meeting with any considerable difficulty in getting the collar off again, a collar with a hole somewhat larger in diameter than the article may be used ; the space between the collar and the article must be filled up with loam. There is more economy in this method than in the method of shrinking a collar upon the article, because the collar can be easily taken off and put aside to be used again; whereas, when a collar is shrunk tight upon the article it has generally to be cut asunder before it can be taken off, consequently, the collar is useless for future use. The collar may certainly be got off by expanding it by hammering; but then this will have a tendency to damage the article, that is, if it has been previously finished with the exception of polishing. If the article, after being cemented with the carbon, be immersed in the water previous to taking the collar off, the collar will become hard, because it has absorbed carbon; consequently, it will require to be ground upon the grinding-stone before it can be cut off from the article, either by the chisel, or the file, or the turning tool.

In some instances, when the case-hardening is required to terminate at any particular part, it will be more convenient and more economical to postpone the finishing of the article until after it has been cemented with the carbon.

In order that a few words may be said upon this, we will for example take the mandril of a turning lathe. Let us suppose then that a new case-hardened mandril is required to be made. The iron selected will require to be forged by the smith to the proper dimensions, after which, when cold, it will require to be turned in the turning lathe; those parts of it which will require to be case-hardened must be finished (with the exception of grinding and polishing) to the proper dimensions; those parts of it not requiring to be case-hardened must not be finished, in fact, it is immaterial whether they be turned or not, until after it has been cemented with the carbon. If these parts of the mandril are turned previous to cementing it with carbon, they must not be turned to the finished dimensions; but a greater amount of metal must be left upon these parts than what is required when it is in a finished state.

The mandril being ready for case-hardening, it must now be put into an iron box with as much animal carbon as will completely envelop it. The box, of course, will require to be luted with clay or loam, the whole must now be placed in a suitable furnace or hollow fire and heated in a similar manner as other kinds of articles when requiring to be case-hardened. When the mandril is sufficiently converted, the box must be drawn out of the fire; the mandril must be allowed to remain in the box until it becomes quite cool, after which it is ready for the turning lathe. The case-hardening can now be made to terminate at any particular part of it, by turning the superfluous carbonized metal off, after which it may be reheated in an open fire and hardened in pure cold water. The carbon once added, the hardness and softness may be reversed backwards and forwards much in the same manner as steel.

Iron cemented with animal charcoal, however skiifully the operation is performed, is never as tenacious as iron cemented with wood charcoal; consequently, it is unfit for cutting tools, as it will not take a fine, firm edge, and, were it to pass through the process of forging and melting, it is questionable, even then, whether it is in the nature of the material to produce such an effect. But if case-hardened iron has never been tried for certain kinds of springs, it would be worthy of a trial.

CHAPTER IX.

TOUGHENING OF STEEL IN OIL.

Hardening and tempering of steel in oil is pretty generally known to be no new process, but the toughening of large masses of cast steel in oil is, however, a new process for guns; and in the present system of manufacturing built-up guns, it is more than probable that it becomes necessary to make certain parts of them of steel (toughened in oil). And here I must in justice to that gentleman mention, that Mr. Anderson was the first, so far as I know, who ever attempted to operate upon large masses of cast steel, such as are now operated upon for guns. The successful results in this case, and the toughness acquired in the material by the process, deserve to be noted, as it is not generally known, and the information may occasionally prove useful to the engineer. I may state that the rapid extension of railroads has led to numerous improvements in the material for rails; and, as they require to be of the safest and most durable metal, it is quite probable that rails made from ingots of mild cast steel will in time supersede all other cheaper but less durable materials. It will be readily imagined that, the more homogeneous the metal, the better it will be for the purpose of railway bars. Cast steel, from having been in a state of fusion, is more homogeneous than the usual metal ; and, when it is free from all other substances, except a very small portion of carbon (which is necessary to form mild steel), its qualities then render it eminently well adapted for railway bars; and I am myself inclined to think that, as soon as it can be cheapened (and I have my reasons for believing that it can be cheapened), it will be universally adopted, while wrought and cast iron for the purpose will become things of the past.

Railway bars require to be not only homogeneous in metal but in the temper also ; but it must not be understood, according to the usual term temper among mechanics, that the bars should undergo the regular process of hardening, and then be reduced to a blue, or any other colour ; on the contrary, it is quite reasonable to suppose, from the small amount of carbon which steel suitable for railway bars contains, that the bars can be submitted to no process of preparation so suitable as that of heating them uniformly in a suitable furnace to a bright red heat, and then entirely quenching them in oil, which will leave them in the toughest and most uniform state that mild steel is capable of receiving. I can speak from experience that a bar after undergoing this operation will admit of a very great change of form without diminution of its cohesive power ; and it is quite probable, from the greater hardness of the steel, that the bars will be less liable to waste by the action of the wheels. The bars being uniform in temper throughout, it is obvious, when the upper surface is worn away by the friction of the wheels, that the decay will not be more rapid. The bars being more elastic, they will be less liable to be broken by continual jars and blows, and they will probably be less liable to rust by the action of the atmosphere. It is quite probable, also, that a less weight of metal might be used; but, owing to so many lives and the vast amount of property which depend upon the bars, I am unwilling to recommend a less weight of metal. For many other purposes, however, for which steel is used, I would not hesitate to recommend a less weight of metal when the steel is toughened in oil. I may state that no danger need be apprehended of the steel bars becoming cracked by this process (providing they be uniformly heated throughout.) Any defect, however, whether cracks or flaws, which could not be detected while the bars were in their unequal state of temper, will by this process be made visible. I am inclined to think if the plates belonging to the rollers of rag engines were made of mild cast steel, and toughened in oil, that they would be more suitable than those now in use.

Should there be some who are more attentive to authority than reason, and who inquire by whom a process is used rather than what are its merits, I assure them that the process of toughening large masses of cast steel is daily practised in the Gun Factories' department of Her Majesty's Royal Arsenal, Woolwich. In this department, with a very ingeniously contrived apparatus, the process of toughening large masses of cast steel is performed in the following manner:—A block, or tube, of mild cast-steel (or steel containing a smaller proportion of carbon than ordinary cast steel) is lifted by a powerful crane and placed in a perpendicular position in an upright furnace; an iron coil about six inches in depth and about one inch larger in diameter than the diameter of the block of steel, is placed upon the fire bars, at the bottom of the furnace, for the block of steel to rest upon; beneath this iron coil is placed a piece of plate iron to prevent the cold air as it passes through the bars coming in contact with the extreme end of the block of steel, and in order to obtain an uniform temperature at the extreme end of the block of steel this iron coil is filled with wood ashes. The iron coil becomes filled with the wood ashes while heating the furnace to a red heat with refuse wood previous to putting the steel in the furnace. After the block of steel is placed in the furnace, the bottom end of it is then surrounded with some short blocks of wood; the damper is not lifted until the extreme end has acquired a low red heat, after which the damper is lifted, and the block of steel is then entirely surrounded with longer pieces of refuse wood, thrown in from the top of the furnace. The steel is then slowly heated to a bright red heat by the combustion of the fuel. Wood is used as fuel on account of its purity, in preference to coal or coke; it is not so liable to degrade the steel, but has a tendency to give the steel pliability without diminishing its hardness. Just as the steel arrives at a bright red heat the vent is closed for a few minutes, in order to give the steel ample time to soak and so receive an uniform temperature throughout the body of the steel. For the more uniform the temperature the straighter the block will keep, and the steel will acquire a more uniform temper. I may here state that the heat the exterior steel receives is judged of by the eye, but the knowledge of the heat of the interior steel is only acquired by study, by attention, and practice.

After the steel has acquired the proper uniform temperature throughout, the travelling crane is then brought over the furnace, the cover belonging to the top of the furnace is then removed, after which a pair of large iron tongs attached to the crane fasten themselves at the top end of the steel block or tube. The tongs are so constructed that the heavier the weight the tighter they grip the steel; still it is found necessary to turn a small collar upon the end of the block to prevent the tongs slipping by the weight. After the tongs have fastened themselves upon the block of steel, it is then drawn out of the furnace and sunk into a large iron tank about twenty feet deep, containing several hundred gallons of oil. The heated steel in passing into the oil will sometimes cause the surface oil to take fire, which, after the whole body of the steel is beneath the surface of the oil, is then extinguished by closing the covers at the top of the tank and subsequently covering the covers with a piece of canvas. The tank has a water space which surrounds the oil—the use of the water being to cool the oil. The best way to describe the tank is to state that it is an old steam boiler sunk endways and perpendicular in the ground.

The steel in parting with its heat raises the temperature of the oil, and, consequently, raises the temperature of the water. The water as it becomes heated is drawn off at the top by an escape pipe, and a supply of cold water is continually running in at the bottom. This gentle stream of water running through the tank causes the heat to be gradually taken from the mass, and the whole cools uniformly in about twelve hours, and exceeding toughness is the result of the operation; while it is thus made much higher in tensile strength, offering a much greater resistance to compression. It is also harder and more elastic, and requires a much greater force to break it with the hammer; and it is not worn or indented so readily as when received from the tilt, or annealed. This operation has in many respects the character of annealing, yet it is something more; for it is quite certain that a different change of the particles takes place, as it leaves the steel in an intermediate state between hard and soft; and when mild cast steel is required in this particular state, it can only be accomplished by a slow process of cooling in oil, or some other liquid of the same conducting quality and which requires as high a temperature to convert it into vapour. Steel containing much carbon, oil will harden the surface very much more than its internal parts, so that it will resist the file; but beneath the surface it will be quite soft. In steel containing a less proportion of carbon there appears to be very little difference between its external and its internal parts. In theory there cannot be much difference between the external and the internal parts of steel containing such a small amount of carbon, and not possessed of hardening properties, or only in a slight degree; and in practice, the theory is proved to be correct.

I may here state that the solidity and strength of all substances are supposed to depend upon the strength of the attraction of cohesion between their particles; because the stronger this is, the more it opposes the disunity of the body; consequently, the attraction of cohesion between the particles, after the steel has passed through this process, must be stronger, on account of its offering a greater resistance to separation. It must not be imagined that the oil penetrates into the pores of the steel, and causes it to be more tough; because, if it were possible for the oil to enter the pores, it would then lessen the strength of the attraction of cohesion between the particles, and the tenacity of the steel would be in a measure destroyed. The effect is not in the least owing to the penetrating quality of the oil; but the effect is owing to its imperfectly conducting quality, which causes the steel to part with its heat so slowly, and the elevated temperature it demands to be converted into the vaporous state. A covering of coal is also formed round the steel by the burned oil, which greatly retards the transmission of heat. This slow rate of cooling is necessary to favour a uniform degree of contraction, and give the steel a much longer time for the re-arrangement of its particles, and to make the strain more uniform throughout the body of the steel. Mild cast steel, after it has been toughened in oil, may, with well-tempered tools, be turned, bored, planed, slotted, chipped, or filed with pleasure.

If cylindrical or spherical mild steel shot could be toughened in oil without causing fracture, a more effective shot would be the result; but, owing to the thickness and bulk of shot, it is more than probable that an internal fracture would occur by the contraction in cooling. A cylindrical-shape shot made of mild cast-steel may, however, be toughened in oil without causing fracture, if it be first forged or turned nearly to the required finished dimensions, and then a hole made in the centre in the direction of its length; the hole need not be made completely through, but four inches (more or less) at one end of the shot may be left solid: this will form a kind of tube with one solid end; the solid end will probably be the best for the rear end of the shot. After the hole is made and the shot toughened in oil, and turned to the required finished dimensions, it may be well in order to make it still more effective to plug it up with a plug made of highly carbonized tenacious cast-steel. Previous to putting the plug in its place, it may be heated to a red heat, and quenched in oil; or, it may be quenched in water and used in its then hard state, but it will probably be better to reduce the hardness of it to a brown or blue temper. The shot may be slightly heated in hot oil, or by any other suitable means, in order slightly to expand the hole for shrinking the shot upon the plug; or, the plug may be forced into the hole by hydraulic pressure without heating the shot; or, it may be fastened in by running a small portion of lead round it. It will be well to form a shoulder upon the plug, so that it may take a bearing on some other part of the shot, as well as at the bottom of the hole. The front end of this hard plug may be level with the front end of the shot, but experiments may prove it to be better to allow it to project a short distance beyond the end. This hard core will offer great resistance to compression, and will probably prevent the shot being flattened so readily by the blow; and tempered steel being more elastic than untempered steel, or wrought or cast-iron, it will transmit more faithfully the impulse it receives, and the shot will probably prove a more destructive weapon than a cast steel solid shot in its soft state, for piercing iron or steel-clad ships. Experiments may perhaps prove the shot to be the better by having two or more of these tempered plugs let into it. The toughened shot may perhaps answer well if the hole were filled up by pouring molten cast iron into it, the shot of course to stand in water while the metal is being poured in the hole; the shot will chill the cast iron, and the water will prevent the toughness being taken out of the shot by the heat of the molten metal. It is quite probable also, that a very destructive shot may be made by coiling a rod or bar of iron round one, two, or more pieces of highly carbonized cast or shear bar steel; then to enclose the whole in an iron or steel cylindrical case (the case to have a solid bottom); then to braze the whole into a solid mass, with spelter composed of three parts copper and one of zinc, or with a more fusible kind of spelter if necessary; when cooled down to the proper temperature to quench the mass in oil or pure water, or water with a film of oil upon its surface: it would also be worthy of a trial in its soft state. It may be well perhaps to explain another plan; it is this, to harden one, two, or more pieces of bar steel, then to brighten and immerse them in solder, which melts at a temperature suitable to coat their surfaces with the solder, at the same time rendering the steel more tenacious by reducing the hardness.

After the pieces have been coated with the solder and become cool, then shrink one, two, or more iron or steel rings, in a soft or tempered state, upon them, the surfaces of the rings to be coated with solder in a similar manner as the pieces of bar-steel are coated; then to enclose the whole in an iron or steel cylindrical case, and subsequently solder the whole into a solid mass, with solder of suitable fusibility, to suit the temper of the steel.

It is quite probable that a very destructive shot may be made either by welding a series of rings upon one, two, or more pieces of blister, or shear bar steel, or by coiling a bar of iron round one, two or more pieces of steel, then welding the whole into a solid mass; or, if this order were reversed, iron inside and steel outside, it might probably prove a very destructive shot: but it is obvious that there would be greater difficulty in welding the mass. The steel may, however, in this instance be protected from the direct action of the fire by coiling a thin bar of iron upon it; then to heat and place the whole into a strong die, and weld it into a solid mass, and subsequently turning the outer coil of iron off again.

It may perhaps be asked by those who are not practically acquainted with the hardening and tempering of steel, if it would not be better to make a solid shot entirely of highly carbonized blister, shear, or cast-steel, and subsequently harden and temper it. The answer is, thick lumps of highly carbonized steel, whether hardened in oil or pure water, or water with a film of oil upon its surface, cannot be hardened without becoming fractured either internally or externally. It must be obvious, then, that the shot would be less effective in piercing iron or steel-clad structures than when in a soft state.

Returning to the railway bars, I would state that I am myself inclined to think that railway bars, either of iron or mild steel, may be made more durable, without lessening their safety, by heating them uniformly in a suitable furnace to a bright red heat, and then immersing their tops or heads into some molten highly carbonized cast iron, and, after keeping them in the molten metal for a few minutes, or for a suitable time, which could be ascertained by experiment, to quench them in oil. By this process the metal will probably absorb carbon; consequently it will then acquire a greater degree of hardness, and it is quite probable that their greater durability would more than compensate for the expense of the process.

It would not be impracticable to case-harden the heads of the iron bars by cementing the heads in animal charcoal, and then quenching them in oil; but it is questionable whether their greater durability would compensate for the expense of this process. The bars would be made more durable as regards wear by cooling them in water; but cooling them in water would lessen their safety, unless they were made of a very pure iron.

CONCLUSION.

Before I close these details, I wish to offer a few sentiments to the consideration of the young artist interested in them, whether he is one who is anxious to excel in these particular branches of art, as affording the means of honourable livelihood, or claims merely the appellation of an amateur, who studies mechanical operations from the love of knowledge, the desire of amusement, or the hope of celebrity in making discoveries or improvements. Let him not be discouraged by the failure of first attempts; instead of losing his time in uselessly regretting his disappointment, let him examine into the cause of it, and promptly repeat his experiments with more precaution. It is a mistaken idea that success is absolutely dependent upon length of practice, uncommon are the cases in which it fails to be the early reward of those who persevere; the reward will always be in proportion to the amount of perseverance and ingenuity displayed; there are always difficulties to contend with for the young beginner. But in every branch of art, if one source of experiment fail, there is abundance of other sources still open. Further practical directions might easily be multiplied, but the necessity for much further minuteness of detail upon most of the processes will be removed by a little observation, experience, and perseverance. But those who postpone perseverance, by satisfying themselves with the hope that length of practice will perfect them, will in the end regret their delusion, and may ineffectually try to recover their loss, when habitual languor, and other injurious habits, have rendered the mind averse to observe, and the hand unable to perform.

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