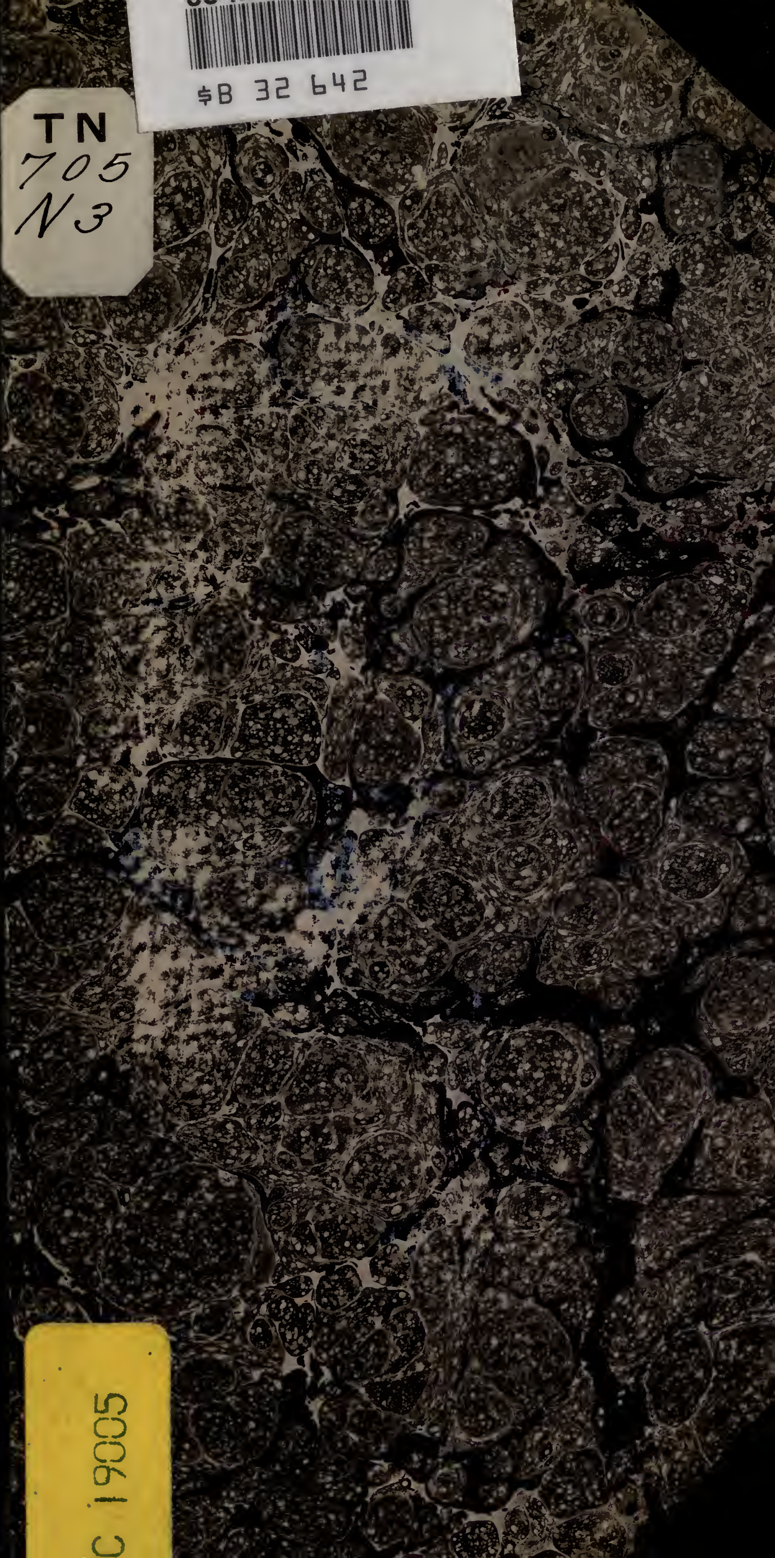


ON THE

MANUFACTURE OF IRON.

[M. Needham]

At a period when the iron trade has arrived at an extent and importance hitherto unknown, some account of the various processes of the manufacture of iron in the district of South Wales may not, perhaps, be uninteresting.

That district, from the establishment of several new works in the course of the last five years, as well as the increase of many of those before existing, has had its relative importance most materially increased, and is at present producing between two and three hundred thousand tons of iron annually. The iron-works of South Wales and Monmouthshire are comprised in a range of country of about 25 miles from one extremity to the other, stretching in the direction of north-west and south-east. The works at Hirwain, in Brecknockshire, and Aberdare, in Glamorganshire, form the extreme points to the westward. Then comes Merthyr Tidvil, with its thickly-peopled neighbourhood and important works, the focus, as it were, of the manufacture; and from Merthyr there is a continued line of furnaces formed by the works at Dowlais, Romney, Tredegar, Sir Howey, Beaufort, Nant y Glo, Blaenafon, the Varteg, Abersychan, and Ponty Pool, which finishes the mineral range in that direction.

It is not proposed to give any account here of the method of working the coal and iron-stone, as that forms a distinct subject of itself. Suffice it to say that, from the nature of the country, the draining of the underground workings by steam-engines, as well as the sinking of shafts or pits, is in a great measure avoided. The minerals are obtained by excavating a tunnel, or driving a heading, as it is technically termed, into the side of a hill. This tunnel is available as a road along which to bring out the coal and iron-stone, and at the same time as a drain for the whole of the work with which it communicates.

The manufacture of iron may be divided into two great heads: first, the production of pig-iron from the ore by smelting; and secondly, the conversion of pig-iron into a malleable state, and the rolling it into bars.

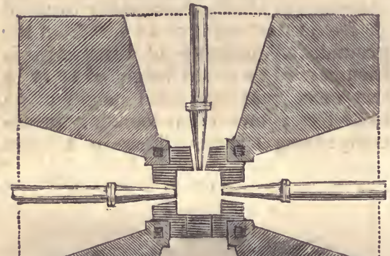
The first process, the production of the pig-iron, is effected by means of blast furnaces. These differ materially in their form and structure. The leading peculiarity of those in Wales is, that they are much larger than those in use elsewhere, and produce, of course, a much greater quantity of iron. The general external form of a Welsh furnace is a square mass of masonry, with a base of from 30 to 50 feet; these dimensions gradually diminishing to about 25 feet at the height of 45 feet from the ground. A cylinder of brickwork is then carried on to the height of 10 or 15 feet more, making a total height of 55 to 60 feet, somewhat resembling the accompanying sketch. There is a large roof extending from one or more sides of the furnace, to shelter the workmen, and keep the cast-house dry, which is not exhibited in this figure, that the

Fig. 1.

shape of the furnace may be more distinctly seen; and there is also a covered communication between the top of the square masonry and the high ground at the back, for the purpose of supplying the materials, which is left out for the same reason. The cylinder at the top, called the tunnel head, is furnished with from one to four doors or openings —generally two—opposite each other, through which are introduced the materials for the supply of the furnace: it is made of fire-bricks, hooped together with iron, and is about eight feet in diameter. The masonry of the whole furnace is also strongly bound together with iron stays. There are arches in the centres of the four sides, forming recesses in the solid masonry. That in front is to enable the workmen to work the furnace and run out the iron; those at the sides are for the more convenient introduction of the blast.

Fig. 2 is a ground-plan of a furnace, in which the square in the centre is the hearth for the reception of the melted iron as it is formed. The recesses are also seen here, and the pipes for the introduction of the blast. The hearth is a cube of about 3 feet each way.

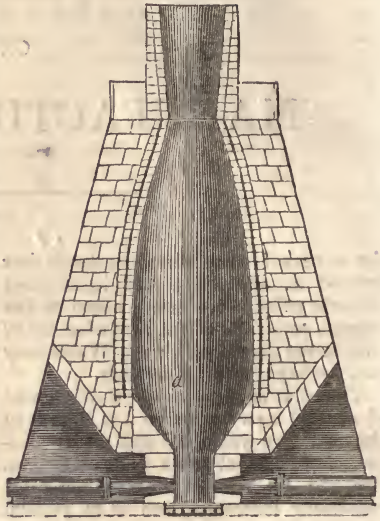
Fig. 2.



The section of a blast furnace is seen in *fig.* 3, in which the broadest part of the interior (*a*) is called the boshes, and is from 14 to 17 feet in diameter. Above the boshes fire-bricks are used as a lining to the masonry, and the diameter is gradually decreased to 7, 8, or 9 feet at the tunnel head.

The hearth and boshes are generally made of large pieces of a coarse grit, or plum-pudding stone, carefully jointed with fire-clay, so as to resist as much as possible the action of the intense heat to which they are to be subjected. Recently, however, some hearths have been constructed of fire-bricks, which is a great saving in expense; and the plan has been found to answer in durability better than was expected.

Fig. 3.



As a proof of the importance that was formerly attached to the quality of the hearth stones, or of the prejudice and want of enterprise of our forefathers, there is a legend that, on the establishment, many years ago, of a work in Monmouthshire, by a Staffordshire person, it was thought necessary to take the stones for the furnace hearths from Staffordshire, and that a stone of some tons weight was actually removed to within a few miles of its destination, when it was discovered that the grit stones to be found in abundance on the spot would answer the purpose as well! Whether this tradition be true or not, it is a fact that a large stone is now to be seen on the London and Milford road, which is pointed out as the identical one alluded to in the above tale.

Much has been said about the best form and dimensions of the hearth—more, probably, than the question deserves, as it is found that, in a very short time, the sides and bottom are so worn away by the constant action of the melted iron, as to become of a sort of rude hemispherical shape.

The inclination of the sides of the interior of the furnace, from the boshes to the hearth, is a matter of more importance. If they are too steep, the materials press with too great a weight upon the melted and melting mass; if, on the contrary, they are not steep enough, the action of the furnace is injured and impeded by the adhesion of the half-melted masses to the sides, sometimes leaving a hollow space underneath, and at others suddenly dropping down in large quantities. These lumps adhering to the sides are called scaffolds, and when a furnace is in this state, it is said to be scaffolding.

There is another and more simple form of constructing furnaces, which has been resorted to in Wales, and which is called a cupola. It is in the form of a large chimney (*fig.* 4), and from the boshes upwards is simply the length of a single brick in thickness. It is held together by an iron hoop at every joint. The bricks are laid in fire-clay instead of mortar, and are from 15 to 17 inches long at the boshes, and gradually diminished upwards to the tunnel head.

Fig. 4.

The lower part of the furnace is of masonry, carefully and very strongly connected with cast iron rings and uprights. The hoops in the upper part are of wrought iron, about 3 inches wide by half an inch thick at the boshes, and proportionably smaller towards the top. This form of furnace is rather cheaper and more simple than the other; but it has been thought that the thinness of the sides occasions a greater escape of heat, and thereby causes a greater consumption of fuel in proportion to the weight of iron produced. If this should be proved to be the case, it is certainly no economy to make use of them, for the saving in the first cost of a furnace is a drop in the ocean, compared with the amount of what may be lost or saved by even a very slight constant difference in its working. This will be seen by and by, when the amounts of the materials consumed will be stated.

One very important particular of a furnace remains to be described. This is the application of the blast. The three recesses, with the blast pipes, are seen in *fig.* 2. The holes through which the blast is admitted to the furnace are called *twyeres* (pronounced tweers). The general practice in Wales is to blow with three twyeres, as seen at *fig.* 2, although very frequently but two are used, and occasionally only one. It is evident that the same quantity of air, or blast, may be introduced into the furnace through one twyere as through three by merely increasing the size of the pipe.

The management of the twyeres requires very considerable practice and skill; and the profitable working of a furnace depends very much upon the way in which this part of the business is conducted.

It has been stated that the twyere is the orifice through which the blast is admitted to the furnace; this orifice, however, does not always assume the same aspect; the constant rushing in of the stream of cold air chills the mass of melting matter to which it is opposed on its entrance to the furnace, and produces a sort of artificial pipe or channel, extending more or less into the interior. It is a rude perforated cone, adhering by its base to the side of the interior of the furnace, and stretching its apex horizontally towards the centre. The different appearances which it exhibits indicate the manner in which the furnace is working, and are the signals to the workman who has the charge of it, (the keeper, as he is called,) to make the necessary changes in the proportions of the materials or the application of the blast. Sometimes the twyeres will become so strong, and project so far, as to meet together in the middle of the furnace. When this is the case, the progress of the blast is, of course, much obstructed. At other times, the twyere will drop off close to the side, which is as prejudicial as the opposite extreme. All these variations are met or prevented by the careful keeper, who will watch every indication of change, and take his measures according to the emergency of the case. Sometimes he will stop one twyere entirely, and provide for the admission of the same blast to the furnace by increasing the size of the remaining blast pipes; at other times he will increase or diminish the total quantity of blast, or he will alter the proportions of the materials at the tunnel head. With all these precautions, he is unable always to keep the furnace in the most advantageous state of working, and, what is more extraordinary, he is unable to account for the changes that frequently occur.

The iron trade can, perhaps, hardly be said to be still in its infancy; but we have certainly much, very much, to learn, before we can boast of anything like a complete knowledge of its different processes. We observe many facts in this, as well as in other branches of the manufactory, of which the most that we can say is, that they are connected with or caused by certain other accompanying facts, though we are ignorant *how* this connexion exists; often, indeed, our knowledge does not extend so far.

We come now to the method of generating the requisite blast, and the mode of equalizing and applying it. It is produced by powerful steam-engines, with one or two exceptions, where a great local facility of water power obviates the necessity of steam. Water, however, can only be used where it can be depended upon in a constant and ample stream even through a dry summer, as it is of the first importance that the blast of a furnace should not be withheld even for a few hours. Instances have been known of the whole contents of a furnace becoming one solid mass from having been cooled by the accidental stoppage of the blast.

The blast-engine is supplied with a large cylinder at the opposite end of the beam to the steam cylinder, and of double its diameter; *i. e.* four times its area. The blowing piston, therefore, will produce a volume of air at each stroke of the engine equal to four times the contents of the steam cylinder, but at a pressure of only one-fourth of that on the steam piston by the joint action of the vacuum and the steam, friction deducted. Thus, suppose that an engine with a steam cylinder 54 inches diameter, and a pressure of 5 pounds per inch of steam, is supplied with a blowing cylinder of 108 inches diameter, it will be capable of keeping up a blast at a pressure of 2½ pounds per square inch; for it is calculated that the pressure in the steam cylinder of such an engine, deducting the friction, is about 10 pounds per square inch. This pressure may be reduced at pleasure, by working the engine more slowly, or with a lower pressure of steam in the boilers.

If the volume of air thus generated were to be passed immediately through small pipes to the twyeres, it would produce an intermitting, irregular blast, almost dying away at the end of every stroke of the engine, and exerting its utmost force between the pauses. This would be very injurious to the furnace, for which great regularity in the blast is a desideratum. To obviate this inconvenience, the air is passed from the engine into a large iron reservoir, called a regulator, from its effect in equalizing the current to the twyeres. The regulator is sometimes in the shape of a sphere, entirely closed up, with the exception of the passages for the ingress and egress of the air, and produces the required effect simply by the elasticity of the large volume of condensed air which it contains: it is then called a dry regulator. Sometimes it is in the shape of a cube or cylinder, open at the bottom, and fixed in a larger vessel or cistern of water. In this case it is called a water regulator, and the column of water at the sides keeps up the requisite pressure within; but there is an inconvenience attending this construction, that is likely gradually to bring it out of use. The introduction of moisture into a furnace with the blast has a bad effect both on the working of the furnace and the quality of the iron produced; and it is found that the condensed air in the water regulator, exposed as it is to a large and constantly agitated surface of water, has the property of taking up a very considerable quantity of moisture in solution. This is particularly the case in summer, as the higher the temperature of the air, the more moisture it is capable of dissolving. This circumstance accounts in part for the fact, that furnaces never work so advantageously in summer as in cool weather; so sensitive are they in this respect, that, after working extremely well for some time with a dry north or east wind, they will frequently change all at once when the wind veers to the west or south, with moisture or rain. It was long thought that the disadvantage experienced in the summer months was to be attributed (by some unknown connexion) simply to the heat of the weather; and it was, therefore, supposed that a cool blast was most favourable to the smelting of iron. So mistaken does this notion now appear, that a patent has been recently obtained for heating the blast artificially before it is passed to the furnace. Care is, of course, taken that it has no opportunity of absorbing moisture with its increase of temperature; otherwise the effect would be injurious, instead of advantageous. The invention has not yet been brought into general use, and therefore no certain decision can be pronounced as to its efficacy: there seems, however, to be a strong probability of its ultimate general adoption and success.

It is ascertained that air cannot support combustion until heated to 1000 degrees of Fahrenheit; and, therefore, until it acquires that temperature from being in contact with the heated medium, it must produce an inverse effect; and the nearer it can be brought to that point before entering the furnace, the better. The natural effect to be anticipated from the change is economy of materials from their more speedy and complete conversion under the action of the hot blast. The degree of heat produced in the blast by the new system is from 300 to 320 degrees of Fahrenheit.

The diameter of the blast pipes at the twyeres is various, according to circumstances. With a strong pressure of blast and three twyeres, a diameter of 3¾ inches may be considered a maximum. The greater the quantity of blast that is introduced, the greater generally will be the quantity of iron produced, though the quality will be deteriorated. Thus, if foundry or melting iron is wanted—that is, the best quality—to be used for melting and running into articles of cast iron, the blast used is not so great as when an inferior quality is made, to be subsequently refined and manufactured into bar iron. In these cases, the quantity of the iron produced is generally increased in proportion as the quality is deteriorated.

But to proceed to the materials used in the production of pig-iron—to the food required to satisfy the voracious appetite of the furnace. The iron stone, or *mine*, as it is technically termed, stands foremost in importance. To this is added a proper supply of coke to keep up the necessary combustion, and a portion of limestone to act as a flux, as will be afterwards explained. The *mine* in South Wales is the argillaceous or clay iron ore, occurring sometimes in strata, sometimes in detached lumps or balls. We cannot here enter into detail with regard to the method of working the minerals, as that would be too great a departure from the immediate subject before us. The mine contains different proportions of iron in different parts of the South Wales district, and also in different strata at the same work. What is generally used may be stated to contain from 18 to 55 per cent. after having remained some time in the air, and before it has been calcined or roasted. From 30 to 35 per cent. may be considered not a bad average of mine throughout a work.

Carbonic acid and clay enter largely into the composition of the ore; and water, sulphur, silex, and perhaps a little arsenic, complete the list of ingredients. It is an important point to get rid of the impurities as completely as possible before the mine is used in the furnace, and for this purpose it is roasted or calcined in kilns, which are kept supplied at the top, as the mine is withdrawn fit for use at the bottom. Care must be taken in this process to give the necessary degree of heat to the kiln, and no more. If there be too much heat, the pieces of mine partially melt and adhere together; if too little, they still contain a portion of water or sulphur, and are obliged to be thrown aside by the *filler*, or workman at the tunnel head, as *raw* or *green* mine. In the operation of roasting there is a loss of weight in the mine of from 20 to 30 per cent.

The coke is also of great importance in the smelting of iron. There is a great difference in the quality of the coal in this district. At one extremity, where the works of the British Company, the Varteg and Blaenafon, are situated, the coal is of a bituminous nature, swelling and caking together in the coking, and binding like the Newcastle coal, but in a less degree, in common fires. At Merthyr Tidvil, on the contrary, it does not possess these qualities. There, it is capable of being coked in a much shorter time, nor does it bind together in the manner just described. In the former case, the ton of coal will produce about 13 cwt. of coke; in the latter, the proportion of coke to coal is greater, though the coke produced will not go so far in the manufacture of iron.

The method of coking in Wales is not

remarkable for that economy to which it may and will probably be brought when coal is of more value than it is at present. The general system is to place the coal in long open heaps, containing 30 or 40 tons, laying the pieces of coal as loose and open as possible, to allow of their swelling, and covering the whole with smaller pieces so as to give the external surface a tolerably level appearance. The heap is then set on fire in different places, and suffered to burn till the whole surface is completely ignited. When this is the case, the coker covers it entirely over with the dust and ashes of former fires, to exclude the air and prevent waste, and it is left to burn out, or rather to cool gradually, till it is in a proper state to be uncovered and carried to the tunnel head of the furnace. The cooling is generally, however, expedited by pouring water upon the cokes before they are uncovered. This is sometimes done to a great extent, and is found to improve the quality of the coke, by making it harder, and expelling more of the sulphur of the coal than would be got rid of without the application of water.

By the system of open fires much of the coal must be reduced to ashes before the air is excluded. This is more particularly the case when the wind is high, as it not unfrequently is in those mountainous and exposed situations. On a stormy night, the unremitting exertions of a double set of cokers are perhaps required on the coke hearth to keep the fires tolerably covered; and in an extensive work, probably sixty or a hundred tons of coal may be wasted in one night in spite of all their labour.

The coke-hearth of an iron work in full operation presents a grand and imposing spectacle in a dark night. The long rows of flame produced by the burning of many hundred tons of coal, extended over a vast space of ground, and flickering in the wind, the black, grotesque figures of the cokers brandishing their long rakes, and partially visible through the thick lurid smoke, with the roaring of the blast and the noise of machinery, seem to realize the descriptions of the infernal regions by Virgil or Dante, rather than anything familiar to our experience in this habitable world.

The bituminous coal of Monmouthshire requires from five to nine days to become thoroughly coked, whilst that about Merthyr takes only about half, or less than half of that time. The coal when coked, has parted with all its moisture, tar, and hydrogen gas, and a great part of its sulphur; and according to its properties, is either of a dull jet black, with the appearance of charcoal, or exhibits a bright metallic or vitreous lustre, with a porous texture. The more carbonaceous matter it contains, the better; and those beds of coal are therefore the most esteemed which present in the fracture the dull, soft appearance of carbonized vegetable matter. Small pieces of coke may be occasionally selected from such a quality that can hardly be discriminated from charcoal, having that fibrous texture and peculiarity of lustre by which it is characterised. Coke, indeed, may be considered only as a substitute for charcoal in the smelting of iron, and was formerly unknown as applicable to this purpose. Charcoal is at present in general use in Russia and Sweden, and indeed is now used at a few works in this country. The iron produced from it is particularly calculated for conversion into steel; but its high price and insufficient quantity would totally preclude its general use, even were it a much greater desideratum than it is. The impurities of the coke of South Wales, or, in other words, the ashes that are left after combustion, are a very important subject for the investigation of the iron-master. They are of many different kinds, some of which are much more prejudicial to the working of the furnace than others; and the strata of coal in which these prevail the most should therefore be avoided altogether, or used with caution, mixed with other qualities of coal. If the coke, after combustion, leaves a red ash or residuum, sulphuret of iron is indicated, the sulphur of which produces a positively bad effect on the quality of the iron smelted in the furnace. If the ashes are white, they probably contain magnesia, silex, or alumine, either singly or combined. The two latter of these earths are only detrimental as so much extraneous matter;—indeed, they may each singly be of service as a flux, according to the nature of the iron-stone with which they come in contact; but magnesia is injurious, as it produces an opposite effect in rendering the flux less fusible by combining with it.

To understand the mode of working the Welsh furnaces, it should be stated, that they are invariably situated on some natural steep declivity, so that, by a little artificial excavation, the ground is made level with the tunnel head at the back of the furnace, and with the bottom of the hearth in front. Thus a perpendicular cliff is formed of about forty feet high immediately in the rear of the furnace, supported, if necessary, by a wall of masonry. The mine kilns are on the upper level, immediately behind the furnace; and thus the calcined mine when drawn from them is at hand ready for the filler at the tunnel head. On the same level, and as near the furnace as possible, is the coke hearth, a large level space, capable of containing some hundreds or thousands of tons, according to the number of furnaces. Again, in front of the furnace, on the lower level, is the cast-house, in which the pigs and castings are run from the furnace; and also a proper space for the convenience of weighing, stocking, or sending them off.

The limestone, the remaining ingredient in the manufacture of iron, is generally procured at some distance, and brought to the tunnel head, where it is broken into small pieces, that it may mix more intimately in the furnace with the mine and coke. It is used as a flux, combining with the clay of the ore, and forming with it a fusible compound, which runs off below in a slag or cinder. Although limestone is the universal flux in South Wales, its use in other districts would not answer this purpose. In South Wales, as has been stated, the iron-stone is argillaceous, but in other places, in the forest of Dean, for instance, in Gloucestershire, it is found in combination with lime or calcareous spar. Now as lime, silex, and alumine are not of themselves readily fusible, they are combined in the blast furnace; and in the selection of the flux, the object of the iron-master is to separate the impurities from the iron in the most complete manner possible. It would obviously be absurd to attempt to use limestone as a flux with the calcareous iron-stone of the forest of Dean, as that would be only adding to what existed in excess before—it would be worse than useless, as it would be filling up the furnace with additional impurities, without facilitating its working. In that district, therefore, clay is the flux and lime the substance which it is to separate from the iron-stone—just the contrary of what takes place in South Wales. If these two kinds of ore (the argillaceous and the calcareous) could be found so near to each other as to be used in the same furnace, no flux would be necessary, as the extraneous matter of each, if used in the proper proportions, would combine together, melt, and detach themselves in the state of cinder without any addition.

In the selection of limestone, all those beds which contain magnesia should be sedulously avoided. The necessity of this will be evident from what has been said above of the injury produced by the magnesia found in coke. The same injury, of course, would arise, in whatever way magnesia is introduced into the furnace. The magnesian limestones of Wales are generally of a coarser texture than those that are aluminous or siliceous, and of a reddish colour; but practice and analysis only will enable the iron-master to determine the quality of stone best calculated for his purpose. The materials are introduced into the furnace at the tunnel head by the filler, whose business it is to see that the coke is brought to him from the coke-hearth properly burned; that the mine is sufficiently calcined and unmixed with clay or rubbish; that the limestone is broken small enough; that the proportion of each material, as directed by the keeper or manager, is maintained; and also to take an account of the number of charges that he puts into the furnace during his '*turn*' of twelve hours. A charge is one barrow of coke, with its proportion of mine and limestone; and the furnace is said to drive fast or slow, according to the number of charges required to keep it full during the twelve hours. The barrow of coke contains about twenty cubic feet, and weighs about six cwt. It is, therefore, the product of about nine cwt. of coal, according to the calculation stated above. The proportion of burnt mine used to the charge varies considerably, according to the working of the furnace, and the quality of the iron wanted to be produced. If foundry iron is wanted, the '*burden*' of mine to the charge must not be so heavy as when forge pigs are to be made. The greater the quantity of mine used to the charge, the warmer, and the more disposed to burn, as it is called, the furnace becomes. If there be an excess of mine, a great additional heat is created, the twyeres will perhaps come short off the sides of the furnace, and all the portions adhering to its interior will melt away.

Even parts of the brick work about the twyeres will be injured by the intenseness of the heat, requiring to be repaired from the outside. Under these circumstances the iron will become thick in the hearth, the quality of it will be very bad, and the quantity small. To remedy all these evils a portion of the burden must be immediately taken off; that is, a less weight of mine must be used to the charge. After a short time, the effect of this change begins to manifest itself. New twyeres begin to form, and to run in towards the centre; the sides of the furnace become cooler, and the quality of the iron improves. Sometimes, when a scaffold has formed on the side, occasioning that irregularity in the working of the furnace which has been before described, it becomes necessary to scour the furnace out, as it is called; that is, to remedy one evil by another—to increase the burden, and produce all this heat and burning, by which the offending mass is melted and got rid of. The burden is then again reduced, and the furnace works regularly as before.

Let us now inquire into the quantities of raw mine (iron stone), coal, and limestone required to make a ton of pig iron. The iron is run from the furnace every twelve hours, and we will assume six tons as the quantity produced in that time, although perhaps five would be nearer the mark as an average. We will assume also, that the furnace is driving 50 charges a turn, with a burden of 6 cwt. of mine; the quantity of burnt mine, therefore, required to make 6 tons of iron will be 50 times 6 cwt., or 15 tons, equal to about 18 tons of raw mine. Thus, according to this calculation, 3 tons of raw mine are used for the production of one of pig iron. The coke for the turn, reckoning 9 cwt. of coal to the barrow (or 6 cwt. of coke), will, in the same way, amount to 50 times 9, or 450 cwt. $= 22\frac{1}{2}$ tons, or 3 tons 15 cwt. to the ton of iron. This is the actual consumption of coal for the supply of the furnace: a further quantity is used at the mine-kilns and engine-fires, which should properly be included in the account, and which will amount to about another ton, making a total of 4 tons 15 cwt. of coal to the ton of iron. These are called the yields of coal and mine, or, more indefinitely, the furnace yields, and are the objects of great attention with the iron master.

The facilities or local advantages of an iron work depend very much upon the capability of the materials to work to a good yield. The importance of this point must be obvious when it is recollected that, by the above calculation, the daily consumption of a single furnace amounts to 57 tons of coal and 36 of mine.

The limestone is a matter of less importance, being generally obtained at a small expense, and used in smaller quantity,—only about a ton being required to the ton of iron.

It has been stated, that the iron is cast, or the furnace tapped, every twelve hours. This operation is managed by the keeper at the bottom. He will occasionally be obliged to cast more frequently, as it is possible, from the hearth being partially choked up, or from the furnace making an unusually large quantity of iron, that it will not hold all that is produced in that time.

The hole through which the iron is let out is, of course, on a level with the bottom of the hearth, and in front of the furnace. It is stopped with a mixture of sand and clay, to prevent the escape of the iron between the times of casting.

There is also an aperture level with the top of the hearth, by which the liquid scoria or cinder is constantly running off, except immediately after casting. The iron, being much heavier than the cinder, sinks to the bottom of the hearth as it is melted; whilst the cinder, forming much more rapidly, soon fills the hearth and escapes, not, however, obstructing the constant passage of the iron, which falls through it to the bottom. The appearance of the cinder is constantly watched by the keeper, as an indication of the working of the furnace, and he can generally tell with tolerable certainty the quality of the iron he is about to cast, by this criterion alone. If it is of a whitish-grey colour, with a fracture somewhat resembling limestone and running freely from the furnace to a considerable distance, he augurs well of the furnace; the materials are then doing their duty, combining properly with each other, and leaving the whole of the iron in the hearth without loss; the furnace is making good iron and to a good yield.

At other times the cinder will assume a glassy appearance, being very tenacious and tough whilst hot, and running down sluggishly. The colour is, perhaps, of a light blue, or dirty yellow, or sea-green. This shows the furnace to be working cold, driving slow, and probably not producing iron to so good a yield as in the former case.

But the most unfavourable aspect observable in the cinder is a jet-black colour, both on the surface and in the fracture; the surface being rough and uneven; and the stream broad, hot, and shallow. These symptoms are always accompanied by an unfavourable yield, as a portion of the iron combines with the clay and limestone in the furnace, and comes away in the state of a black oxide with the cinder, causing its dark colour. Theory would teach us that the most favourable aspect of the cinder would be that of a perfect glass, indicating neither the presence of iron by the black colour, nor the excess of the flux by the stony opaque appearance of the fracture. But in practice, this precise point is found so difficult of attainment, that the appearance of the cinder is always considered the most favourable when it is "*strong of the stone*," as the workmen say.

The keeper has a personal interest in the well working of his furnace, and, if he is a good and steady workman, will watch all these points with constant care. He is paid on the ton of iron produced,—and, indeed, the fillers, cokers, limestone breakers, mine burners, and all others connected with the furnace, are generally paid in the same way; for if any one of these various operations is neglected, the furnace is sure to suffer, and by uniting the men in one common interest, the best security is obtained for the well regulation of the whole. The wages of labour constitute so very great a proportion of the cost of iron, that it is a matter of first-rate importance to economise them as much as possible; and it has been said, with too much truth, that the business of the iron master is a constant struggle with his workmen, the endeavour on his part being to keep down or to reduce their wages; and, on theirs, to get as much for their labour as possible.

This contest, unpleasant as it may be, is to a certain extent unavoidable and natural, and neither masters nor men are to be blamed for making the best bargain for themselves that they can. It may be said, that there is a natural and imperious standard of wages in the state of the trade, beyond the control of the master or the workman; that, when iron is low and the demand dull, it is as impossible for the former to give high wages as it is for him to keep them down in an opposite state of things. This is true; but it is sometimes difficult to convince the workmen of its truth, when the consequence to him will be a diminution of his gains; and, from the same cause, the master will sometimes be unwilling to acknowledge the necessity of an advance of wages so soon as his men desire. His object should be to induce, as much as possible, a mutual confidence between his men and himself; to anticipate their demand for an advance, if he feels that, from the state of the trade, it is unavoidable, and to act with decision and firmness when he is under the necessity of opposing their wishes.

But to return to the furnaces. It may be supposed that the quantity of cinder produced by a furnace is very great, when it is recollected that the weight of the materials put in is 36 tons in the twelve hours, whilst the iron produced in the same time weighs only 6 tons. The weight of the cinder will not, however, by any means balance the account, it having been found that there is a loss of weight, in the process of smelting, greater in amount than the quantity of coke used; that is, from 36 tons of materials put in at the tunnel head, the total process at the bottom in cinder, iron, and ashes, will not exceed 20 tons. The deficiency is occasioned in the process of combustion by the escape of oxygen, carbon, &c., from the mine and limestone, as well as from the coke.

Still the quantity of cinder continually accumulating is so great, as sometimes to occasion considerable expense in its disposal. The situations in Wales are generally very favourable for this object, being upon elevated ground. The cinders being carried in the direction of the declivity, and formed into a horizontal terrace, soon acquire, from the nature of the ground, a very great thickness, the road remaining level. Large ridges or hillocks of cinder are thus produced, called cinder *tips;* and often, from their great extent and elevated position, form a remarkable, though dreary, feature in the aspect of the country. Where the works are situated on a flat ground, without any great fall in the immediate neighbourhood, this facility in the removal of the cinders is not afforded, and a serious item of expense is consequently incurred. In one or two instances, they are obliged to be taken about two miles from the furnaces before they can be disposed of.

The pig iron produced in the operation of smelting is of very various qualities, according to the purpose for which it is wanted, and the circumstances under which it is manufactured. It may be divided, first, into foundry iron and forge iron; the former being used in the state of pigs, for casting; the latter being only applicable to the manufacture of bar iron. The reason of this is, that, from its nature, it is too thick, when melted, to adapt itself to the shape of the mould, and, when cold, is too weak and brittle to be serviceable as cast iron, even if the other objection did not exist.

But the foundry iron comes first to be described. There are three qualities of it,—first, second, and third.

No. 1 foundry iron differs in its chemical composition from the other sorts, by containing more carbon. It is, indeed, combined with as much carbon as it is capable of holding; and to effect this combination in its full extent, the coke containing the fibrous appearance of charcoal, or the purest carbon, is selected. The tendency of this combination is to render the iron soft, and to make it very fluid when melted, so that it will run into the finest and most delicate mouldings. It is used for small and ornamental castings, and anything that requires a minute and perfect adaptation to the shape of the mould. It is distinguished in its appearance by great smoothness on the face or surface of the pig; and in the fracture it exhibits a large, dark, bright, open grain, intermixed with dead spots of a lighter colour and closer texture. When broken, the pig does not ring, but sounds rather like lead, falling dull and dead upon the block over which it is broken. It is also so soft as to yield readily to the chisel. In running from the furnace, the surface of the melted metal is smooth and dull, breaking occasionally into streaks and cracks of a darker and brighter red. When it is highly carbonized, the pigs and the cinder are frequently covered with small bright black laminæ of a substance called kish. It is a pure carburet of iron, or black lead, and evinces an excess of carbon in the pig.

No. 2 foundry iron is less carbonized than No. 1; not so soft, closer grained and more regular in the fracture, not so fluid when melted, nor so smooth on the face of the pig; it is, however, harder and stronger, and is preferred for all the less delicate parts of machinery, where strength and durability are required.

These two sorts are all that are recognized in some places as foundry iron. Their being combined with so large a dose of carbon and oxygen renders them unfit for remanufacture into bars; but iron of the next quality, or No. 3, having less foreign admixture in its composition, is destined indifferently for the forge or the foundry. It is used extensively for castings where great strength is required, or in situations where it is to be exposed to constant wear and tear, such as tram plates, heavy shafts, and wheels, cylinders for steam-engines and many descriptions of heavy work. It is selected for these purposes from being still harder than No. 2, and possessing so great a degree of toughness as well as hardness as to make very strong and durable castings. In appearance it differs from No. 2, in the same way as that does from No. 1, being closer grained and more regular, and darker when broken. From its appearance, it is often called dark grey iron; by which term it is, indeed, as well known as by that of No. 3.

The next quality, *bright* iron, is never called foundry iron, although used extensively for large castings. It possesses great strength and hardness, but not fluidity enough to adapt itself to intricate or minute mouldings. It derives its name from its appearance, which is of a lighter colour and brighter lustre than that which has hitherto been described.

Mottled iron is used exclusively for the purposes of the forge, as it is too thick and brittle for the foundry. It is smooth in the fracture, hardly exhibiting any grain, and appears to be compounded of two qualities imperfectly combined, being spotted or mottled with grey and white.

White iron is supposed to contain a very small portion of carbon—less than any other sort of pig iron. It is totally unfit for casting, and is sometimes so thick as hardly to run into the pig moulds, although they are purposely made very large; and so brittle, that the largest and most unwieldy pigs may be readily broken by a blow with a sledge-hammer. It is too hard to yield in any degree to the chisel. The colour of the fracture is a silvery white; shining and smooth in its texture, with a foliated or crystallized structure.

Thus we have six distinct gradations of pig iron, produced under different circumstances in the blast furnace:—No. 1 and No. 2 foundry, No. 3 foundry or dark grey; bright, mottled, and white. The difference in the properties and appearance of these sorts has been attempted to be described; but any description must be imperfect, unless illustrated by reference to specimens. Accuracy in determining the precise quality of any particular specimen is only to be attained by experience; for when one sort is approaching to the next either below it or above it, the shades of difference are so minute as to make it difficult to determine its proper rank. For instance, we often hear iron spoken of as good bright or indifferent dark, or perhaps as second foundry, but so good that it may do as first. Experience also is necessary as to the local differences in the appearance of the pig; for foundry iron, especially, is found to vary materially in appearance at different works, the quality being the same.

All these six descriptions of pig iron contain oxygen and carbon. The carbon exists in the greatest proportion in the No. 1 foundry iron; and in the least in the white iron last described; its proportion being gradually diminished in the intermediate stages. Its tendency seems to be, to give a softness and toughness to the pig, so that, as far as carbon is concerned, the purer the iron is when run from the furnace, the less fit it is for foundry purposes.

In describing the management of a furnace, and the selection of the materials, there has been no reference to a discovery made some time ago, and recently brought into very general application. Messrs. Hill and Co., of the Plymouth works, near Merthyr, obtained a patent many years ago for the use of forge and refinery cinder, as a substitute for mine, in the furnace. These materials are the scoria or dross produced in the different operations of the forge and the refinery hereafter to be described. It is an oxide of iron, with but little foreign matter, and therefore containing a great proportion of iron, frequently 60 or 70 per cent. It had not been generally used before for any purpose; for although it was known to contain a large proportion of iron, all attempts to smelt it effectively and economically had failed. It was thought to be so prejudicial to the working of a furnace, and the quality of the iron produced, as to render its extensive application impracticable. The effect it produced was to make the furnace burn, although a light burden was used. The twyeres could not be kept strong; the cinder became black, and the iron of a very inferior quality, being entirely white and very thick in running out of the furnace. Under all these discouraging circumstances, it was thought that no substitution of forge or refinery cinder for mine could be advantageously made, and the cinder was consequently laid aside as entirely worthless.

The contrivance of Messrs. Hill and Co. consisted in mixing the cinder with argillaceous matter, so as to form a more complete imitation of the ore in its natural state. A portion of the shale or clunch adhering to the natural ore when first raised, was to be put into the furnace with every charge of cinder. This combination was to make the material less rich, or leaner, as it is termed, and thereby to prevent the injurious effect before described of the burning of the furnace. The experiment succeeded, and a patent was obtained, which promised to be very lucrative. It was, however, soon invaded. An action was brought for the infringement of the patent, which was successfully defended, a prior use of the system in question having been proved. Thus, then, every iron master had it in his power to avail himself of his large stores of cinder, the accumulation perhaps of many years, in any quantity or proportion that he might find expedient. Many were the experiments made, and numberless the tons of bad iron produced in consequence. It was thought that the substitution, even in small proportions, of a cheap for an expensive material, must more than counterbalance all the disadvantages that would arise in quality, &c.; but time and experience sobered down these anticipations, and counteracted these erroneous impressions. The general opinion of the application of cinder in Wales now is, that it can be advantageously used only to a certain extent, and with great care. Indeed, it is thought to be very fair work if the constant production of the cinder at the forge and refineries can be used at the furnaces as it is made, so that the large stores before collected may, still be in part at least, preserved, to be made available at some future time when the manufacture of iron has undergone further improvement.

The use of cinder certainly deteriorates the quality of the iron. It rarely produces foundry iron, even when mixed in small proportions with mine; and when the proportion is increased, or when it is used entirely by itself, the pig produced is not of a clear bright white colour, or compact solid texture, but of a dirty dull colour, very rough and uneven on the surface, and somewhat porous in its internal structure. In the subsequent processes of conversion into bar iron, there is a greater loss of weight in pig produced from cinder than from mine, with also a certain deterioration of quality in the finished bar. All these circumstances show that the greatest care must be taken to ensure the advantageous application of cinder. It should be remembered that these remarks are only applicable to Wales; the cinder in Staffordshire having been more extensively and profitably applied.

There is little doubt that the time will come when this material will be found much more valuable than it can now be considered; that when chemical science has made further advances, a more effectual method will be discovered of separating the metal, which is known to exist in a very large proportion, and combined with so few impurities. We must be content, however, to proceed gradually. When we look back to the process of manufacturing iron twenty years ago, we have every reason to be satisfied with the progress which has been made in the knowledge and improvement of the subject; and we may confidently anticipate that the next twenty years may be equally marked by advancement. It is true that many schemes projected by scientific and experienced men have failed; that many favourite speculations, which have appeared most plausible in the closet or laboratory, have been incapable of being followed up in practice on a large scale. But this want of success should by no means dishearten us. The very failures themselves lead us on to more accurate knowledge and correct results, and thus pave the way, slowly it is true, but surely also, to ultimate success and certainty.

Our present want of knowledge is remarkably displayed in the different operations of converting pig iron into malleable, or wrought iron. Pig iron is commonly supposed to be a combination of the pure metal with carbon and oxygen; bar iron is the same metal freed from these impurities. It is not ascertained in what proportions oxygen exists in the pig; but we know that the carbon is more abundant in proportion as the iron is soft and tough. Thus then we are struck with this apparent contradiction, that the purer the iron is in the state of pig, as far at least as carbon is concerned, and in that respect the more it resembles malleable iron in its chemical properties, the more removed it becomes from it in its appearance and mechanical properties; the white iron of the furnace being, as we have seen, the hardest and most brittle that can be produced. It is, however, so difficult to follow up chemical analysis and obtain results with minute accuracy, in a process requiring intense heat, that hitherto the phenomena attendant upon the refining of pig iron, and its conversion into bars, may be said rather to be guessed at than perfectly explained.

The operation of refining the pig iron is performed in small, low furnaces, called refineries. They are about three feet square at the base in the inside. The bottom of the hearth is of fire brick, and the front, back, and sides, of cast iron. The castings used for the sides are made hollow, and so contrived as to allow the passage of a constant stream of water through them. This contrivance is necessary as a precaution against the intense heat of the fire, which would otherwise soon burn away, and destroy the sides of the refinery. Near the top of this square are three holes in the side, for the introduction of the blast pipes. Refineries are of two kinds, according as the blast is applied on both sides or only on one. In the former case, they are called double fires; and in the latter, single. The double fire being larger than the single, and having a more ample supply of blast, will make a much greater quantity of refined metal. It would have been therefore universally preferred, if it had not been thought to carry on the process of refining at a greater expense of iron and coke than the single fire; that is, in the technical language of the trade, 'to work to a worse yield.' This may be the case under peculiar circumstances of materials; but generally it will be found, that, all other things being equal, the greater the quantity produced in one fire, instead of distributing the production between two, the greater will be the economy of fuel; for a portion of heat will always be lost at the surface and sides of the fire; and therefore the smaller the fire, the greater will be the proportion of surface and consequent loss of heat. But the yield of iron in the refinery is of more consequence than the yield of coke, inasmuch as the former material is much more costly than the latter. If, therefore, the yield of iron is worse in the double fire than in the single one, the latter ought to be preferred, in spite of the greater loss of coke. This, however, is not generally the case; and the double refineries are consequently the most commonly in use. They are furnished with three small twyeres on each side, the pipes being about an inch in diameter, and the pressure of the blast the same as for the furnace, viz. from 1¾lb. to 2½lbs. or even 3lbs. on the square inch. The twyeres are protected by a conical case of wrought iron, projecting a little into the fire, and made hollow, or double, so as to allow of the constant circulation of a stream of cold water. These are called water twyeres, and are found necessary to keep the sides of the refinery cool, and the twyere pipes from being burned. Water twyeres are also occasionally used at the smelting furnace, when it is working hot and there is a propensity to burn, and they are then of much advantage in checking the heat of the furnace and preserving the masonry of the sides.

The refinery is furnished with iron doors at the back, but is open in front; and when the doors behind are closed, it looks not unlike an old-fashioned kitchen fire-place, though by no means so approachable, for the heat thrown out is too great for any one but the workmen who are accustomed to it, to come near. The whole is surmounted by a low, wide, square chimney of brick-work, the entire edifice not being more than 18 to 20 feet high. In front, the workman is protected from the weather by a shed coming forward from the fire. There is a hole at the bottom of the hearth in front, for running out the metal, similar to that in the furnace. It communicates by a short channel with an oblong flat mould of cast iron, about 20 feet long by 2 broad. This is placed over a cistern of water, with the surface of which it is in contact, and is thus kept cool, and chills the metal as it runs into it. It is necessary to cast the mould very thick, to provide against the frequent cracking to which it is liable, from the unequal contraction and expansion of the iron.

The process of refining consists in separating a portion of the carbon from the pig, and thus reducing the iron to a greater degree of purity preparatory to the subsequent operations which it has to undergo. This is effected by keeping the pigs in the state of fusion for some time, exposed to a very great heat and a strong blast. How the change is produced, what is the quantity of carbon separated, and combined in what proportion with oxygen, are rather subjects of speculation than demonstrated facts. It would appear that there is a certain combination of carbon and oxygen in the pig more favourable than any other for the process of refining, for dark grey pigs will produce a much better quality of refined metal than mottled or white, though it might be supposed, from the latter being combined with less carbon than the former, that they would the more readily part with what they do contain. The white pig, in its chemical properties, as far as we know them, approaches very nearly to the refined metal. In its appearance, also, and mechanical properties it is very similar to it. The plate of metal run into the refinery mould is very brittle, and easily broken into convenient pieces for use at the forge. In its fracture, it presents the same bright silvery whiteness that has been described in the white pig. With all this apparent similarity, white iron is disliked by the refiner, as occasioning more trouble in working, and producing refined metal of a worse quality than dark grey, bright, or mottled pigs; and it will be seen afterwards that the white pig cannot be wholly substituted for refined metal at the forge. There is then an essential difference in the composition of the iron in these two states, though what this difference is has not hitherto been accurately ascertained.

The refiner selects his materials according to the quality of the iron wanted. The best quality is made from the dark grey pig, or No. 3, and the inferior sorts from bright, mottled, and white, in their order. The very worst white iron cannot be used by itself in the refinery, being too thick to be readily run out, and consequently clogging up and setting in the hearth. It is got rid of by being mixed with pigs of a better quality, by which means little inconvenience is occasioned to the refiner.

From the time the pigs are put into the refinery, it requires about two hours before they are in a proper state to run out. Thus, the refiner will run out his mould of metal six times in his turn of twelve hours; and as there is always a double set of men, to avoid the loss of time and fuel consequent upon allowing the fires to go out, the refineries will continue at this rate from the Monday morning to the Saturday night. The weight of each plate of metal is about a ton. The quantity then produced in a double fire in the week will be from sixty to seventy tons. Let us now see at what expense of material it is produced, or, in technical language, what are the refinery yields.

The yield of iron to the ton of refined metal, like every thing else in the trade, varies according to good or bad management, to the quality of the pigs, and also to the quality of the coke. Dark grey pigs, with well carbonized coke, will sometimes work to a yield of 2¼ cwt., *i.e.* 22¼ cwt. of pigs will only be required to produce the ton of refined metal. More will be required with the inferior qualities of pig; and 23 cwt. will not probably be too much to state as the average quantity of pig to the ton of refined metal in Wales. This deficiency of weight is more than balanced by the quantity of cinder produced, showing the combination of a portion of the iron with oxygen and other impurities. At each running out of the refined metal, a quantity of the cinder comes with it, and being lighter than the metal, it floats on the top, and detaches itself as it cools. It is an oxide of iron, and, as has been seen, is now duly appreciated as a valuable substitute for mine at the furnaces. From an actual trial, carefully made during one week at two refineries, the following results were obtained:—

	Tons.	Cwt.
Pigs used - - - -	151	7
Refined metal produced	135	0
Showing a loss of -	16	7

from which it appears that the yield was 2 cwt. 1 qr. 22 lbs., or that 1 ton 2 cwt. 1 qr. 22 lbs. of pig iron was used to make the ton of metal. During the above period, the refinery cinder produced was 31 tons 4 cwt. which, it will be observed, more than balances the waste of the pig iron by 14 tons 17 cwt., showing a combination of iron with extraneous matter to that extent. The cinder, therefore, in this instance, would contain rather more than 50 per cent. of iron.

The quantity of coal used to the ton of metal is not great, ten or twelve cwt. being sufficient. It is used in the state of coke at the refinery; but the most satisfactory way of stating the yield is to give it in the coal, as some qualities will produce a greater quantity of coke than others. The running out a mould of refined iron, or *metal* as it is called for shortness, is a brilliant and beautiful spectacle. The impetuosity of the stream as it issues from the hearth when first opened, the hissing of the liquid metal, the beautiful sparks of ignited iron fantastically dancing in all directions, and afterwards the sluggish progress of the cinder bubbling up, and frequently rising into grotesque forms, cannot fail to be striking and interesting to the observer, however unacquainted he may be with the chemical and scientific solution of the phenomena he is witnessing.

The refiners, like the furnace men, are paid on the quantity of metal produced. It requires considerable experience and skill to be a good refiner. Their occupation also is one of great exertion, and occasional exposure to an intense heat. Their business consists in putting the charge of pigs on the fire, which they do by opening the iron doors at the back; in attending to the progress of the melting, supplying the fire with coke from time to time, and frequently stirring it up to equalize the heat in all parts of the hearth; in attending to the twyeres, and taking care that the circulation of the water continues uninterrupted; in running out the metal when it is ready; and finally, in raising the plate from the mould, when it has a little cooled, by means of a lever, and wheeling it forwards beyond his shed, removing the cinder, and preparing the mould for the reception of the next supply of metal. The metal is weighed by a person appointed for the purpose, who keeps a separate account of the work of each refiner, to be carried to his credit in the pay book.

Having now got through the business of the furnace and the refinery, the various operations of the forge come next under our notice. The forge and mill are perhaps the most interesting department of an iron work. In what has been hitherto before us, there has been no succession of active business brought palpably to the view of the spectator. It is true that things are constantly progressing, but the proceeds are only occasionally brought to light. '*A sow of pigs*' is cast at the furnace every twelve hours, and then all is comparatively quiet again. A plate of metal is run out at the refinery only at intervals, The continued action is carried on in secret as it were, out of our sight, and beyond our observation. We see the rough materials put into the furnace at the tunnel head, and are told that such and such combinations and results are to follow; but, unfortunately, we cannot ourselves observe these operations, and we must therefore content ourselves with a partial and imperfect contemplation of the progress of the manufacture so far.

In the forge and mill, on the contrary, all is bustle and activity;—nothing is left to itself;—all is under the constant observation of the workman; and we can watch the progress of converting the refined metal into bars, through all its different states and stages.

Steam power here, as with the furnaces, is in most general use; convenient situations affording an ample supply of water being extremely rare. But as it is not so important to have an uninterrupted power for the forge as it is for the furnace, water power might be applicable to the former, though it would be rejected for the latter purpose. Stoppage at the forge is not attended with the fatal consequences that would result at the furnace. It is an inconvenience rather than a positive injury; merely a loss of production, a hinderance to the progress of the work.

Supposing then that steam power is the primum mobile at the forge, and that one engine is used, let us inquire what it has to do. The forge consists, we will say, of a hammer and two pair of rollers, (or *rolls*, as they are termed, the workman being called the roller,) with a pair or two of strong shears to cut the bars. We will not stop to describe these now, as they will come again under our observation. We will assume also, that the mill contains two pair of rolls of fourteen inches diameter, for making large sizes of bolts and bars; two pair of ten inches, as an intermediate size; and two or three pair only seven inches in diameter, for rolling the smallest sizes of iron. The mill also, as well as the forge, should be provided with strong shears, for cutting the bars. If nail rods are required to be made, there must be the proper machinery for them also—viz. a pair of rolls and a pair of slitters, as they are called. To conclude, a heavy and powerful lathe is necessary, for the purpose of turning the iron rolls. The engine then will be required to put in motion nine pair of rolls, the hammer, shears, and lathe. To effect these objects, an engine with a steam cylinder of forty-five inches will be required. The work to be done by this engine is of a peculiar kind; the strain, or the force and friction to be overcome, being at one time very great, and at another comparatively nothing. If it has only the machinery to keep in motion, which is occasionally the case during short intervals, it has of course little resistance to overcome. If, on the other hand, there is a bar passing through every pair of rolls at the same time, the resistance becomes so great, that if it were continued instead of being temporary, the engine would be staggered and finally stopped. This great variation ought to be avoided as much as possible by the workmen, who should so contrive as to keep the work of the engine tolerably regular, neither allowing the rolls to remain long idle, nor supplying them all with bars at the same time and in quick succession. This equalization of power is also provided for necessarily by other means. It is well known that all engines that communicate power by means of a crank must be furnished with a fly wheel, to carry the crank over the centres. This they do by their momentum; and if it were not for the fly wheel, the engine would be liable to stop at the end of every stroke; that is, whenever the piston and the crank get to their lowest point of depression or their highest point of elevation. At these points the power of the engine is nothing, as it has no leverage upon which to act in the crank. At the intermediate parts of the ascending and descending stroke the power varies, being the greatest at the half stroke, when the crank presents the longest lever to the connecting rod, and proportionably smaller as it approaches the top or bottom.

This irregularity of power is common to all engines working with a crank, and they are all therefore provided with a fly wheel. But when, in addition to this unavoidable variation in the action of an engine, it has to perform work of an intermitting kind—to resist great and sudden strains, that come at intervals, and last for only a short time, the fly wheel becomes eminently useful. In engines of this description, therefore, it is made unusually large and heavy, weighing perhaps 8, 10 or 12 tons, and of the diameter of 16 feet, the weight being disposed as much at the circumference as is consistent with the strength of the wheel. The speed at which it is propelled is also very much greater than in ordinary cases, being 70, 80, and even 100 revolutions in the minute—so fast, that the spokes or radii of the wheel are sometimes not discernible. The momentum of such a mass of iron moving at so great a velocity, may readily be conceived to be tremendous, and to be a most effectual coadjutor to the engine in carrying it through sudden strains. Indeed, hardly any force that could be opposed to it would be sufficient to stop it all at once. So irresistible is its power, that in case of any sudden impediment, too great for the machinery to surmount, some part of it must give way, and as these cases will sometimes occur, it is contrived to make a subordinate part of the machinery weaker than the rest, so that, by breaking, it saves the more valuable parts from injury, and is itself easily replaced.

As may be supposed, all the machinery of a forge is obliged to be particularly firm and strong. Very heavy cast iron plates are imbedded in masonry underground, to form a firm foundation. These beds are furnished with grooves and other conveniences, by which the uprights or sides of the rolls are immoveably secured. The different sets of rolls require to be turned at different speeds, and a number of wheels and shafts are therefore necessary, which are carried chiefly under ground for the greater accommodation of the work. Thus there is almost as much weight of machinery under ground as above; and the spectator will at first be at a loss to trace the connexion from the engine to the more distant parts of the machinery.

The rolls are cast solid; and to provide for the great and constant wear they have to sustain from the pressure of the bar, as it passes through them, they are made of bright iron, as being the hardest quality that is consistent with a proper degree of strength. Now it is found that in very heavy castings the body of the iron is not uniformly firm and solid throughout. The outside may not, and probably will not, betray this defect, as it cools and hardens before the rest; but the shrinking of the iron within, as it cools, occasions small holes and a partial honeycomb texture, which of course is prejudicial in all cases. It is particularly so in rolls, which have the outside taken off in turning, and which ought, when finished, to present an uniformly smooth and firm surface. The founder, however, has a means of obviating this unsoundness of texture. The mould of the roll is sunk in the cast house in a perpendicular direction below the surface, and above it is a second mould or head, as it is called, which, when that of the roll is filled, receives an additional quantity of the melted metal. The founder introduces a bar through this head into the body of the roll, with which he gently stirs the iron as long as it is sufficiently fluid to admit of his doing so. The deficiency occasioned by the shrinking of the iron in the body of the roll is thus supplied from above, and the whole casting is sound and solid throughout.

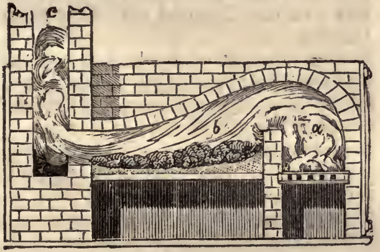
In turning so large a body, and one composed of so hard a material, a very slow motion is necessary, otherwise the steel tools would soon become so hot as to lose their edge. This is accordingly provided for by a succession of large and small wheels, which reduce the speed at the lathe to about a revolution and a half in a minute.

From what has been stated of the number of shafts and wheels in the machinery of a forge and mill, each of which must have its axles or bearings, it may be supposed that the friction to be overcome is of itself enormous. It is increased from the necessity of all these axles and bearings being large and strong; and the only means there are of keeping it at all within bounds are therefore anxiously resorted to. The first of these is to have all the machinery constructed and put together with great accuracy; the wheels correctly centred, perfectly true, and in line with each other; the shafts carefully levelled, and in line also; and the rolls exactly parallel. The next is to have brass bearings for all the necks of the rolls, the axles of the wheels, and the ends of the shafts,—the friction occasioned by the rubbing of two different metals being well known to be much less than that of two pieces of the same metal. The third of these means is, to keep all the points of friction well oiled and perfectly cool. If the axle of a wheel or neck of a roll be suffered to become hot, the friction is prodigiously increased at once, and the parts in question begin rapidly to rub and wear against each other; thus producing a double evil,—the immediate one of increasing the work of the engine, and the more remote, though not less important one, of bringing the machinery out of line or level by the unequal wearing of its parts.

In describing the manufacture of bars, we shall have to encounter many technical terms, all of which will be noticed and explained as they occur; not that it is necessary to introduce them all for the purposes of clear definition to the general reader, but it is surely desirable that those who interest themselves in any subject should be made acquainted with the terms in which they would hear that subject explained by those immediately engaged in it.

The first grand process at the forge is the puddling, an operation by which the oxygen and carbon are still further and more completely separated from the iron than could be accomplished in the refinery. It is performed in a reverberatory furnace, called a puddling furnace, of which a section is annexed, in *fig.* 5, to give an idea of its structure.

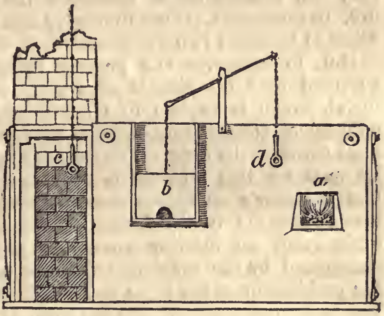
Fig. 5.



In this figure, *a* is the grate, supplied with coal through an aperture in the side, called the stoke-hole, and furnished with bars at the bottom for the proper supply of air and escape of the ashes. *b* is the body of the furnace, where the refined metal is placed and exposed to the heat of the flames, which are drawn from the fire by the current of air over the little brick-work division between *a* and *b*, and are turned downwards again by the inclination of the roof, so as to curl and play upon the surface of the melted iron at *b*; they are then carried through the narrow part, or neck of the furnace, to the stack or chimney *c*. The chimney is carried up to the height of about 30 feet, and bound together at different points with iron, to keep it firmly together. There is a damper at the top of it, by which the puddler regulates the degree of draft (and consequently heat) to his furnace; for, during some parts of his operations, he wants a more intense heat than at others. The draft and heat of these furnaces are so great, that the flame is carried completely through to the top of the stack, where it comes in contact with the damper, which is frequently nearly red hot. The bottom of the furnace (*c*) was formerly always composed of sand, and occasionally is so still; but the most general plan is to construct it of a thick cast iron plate, which is preserved from fusion by a coat of the oxide of iron or cinder, which is formed in puddling. An artificial bottom is thus created, and found to answer better than one constructed upon sand.

Fig. 6 is an outline of the exterior of a puddling furnace, in which the whole side is of one or more plates of cast iron lined with brick, the two sides being connected by bars at the top, over the brickwork of the roof. *a* is the stoke-hole, so contrived as to be stopped with a piece of coal, which is used to equalize the heat, by preventing the ingress of air to the furnace, except through the bars at the bottom. *b* is the door, raised when necessary by the lever and chain *d*. *c* is the stack, where a portion of the chain is shown by which the damper is raised or lowered. The furnace, when first lighted, requires three or four hours before it is ready to be charged, or to receive a heat of metal, as it is called; that is, the proper quantity of refined iron.

Fig. 6.



The first department at the forge is the weighing out of these charges, and delivering them at the puddling furnaces. The general weight of the charge is about 3½ cwt., or from that to 4 cwt.; it cannot be stated with precision, as the practice varies at different works. Indeed, all the statements of quantity, and weight, and yield, that have hitherto been made, as well as those which will come under our discussion before we conclude, must necessarily be somewhat vague and imperfect. Certainly, no two works in Wales correspond exactly in the quality of their materials, the results of the different branches of their manufacture, and their mode of working. The attempt here is to establish a kind of average. If we were to ground our calculations, and confine our description to any one particular work, we should, in all probability, give a very unsatisfactory account of the general practice and the general results in Wales. As it is, errors may have been made as to the correct averages, for these are not always easy to obtain ; but however inaccurate the statements here made may be, considered as averages, they are, nevertheless, points that have been selected between two extremes.

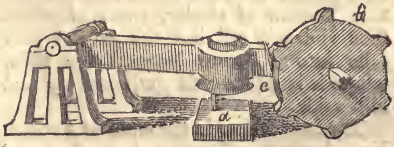
But, to return. The puddler being supplied with his charge of 4 cwt. of metal, which is broken into small and convenient pieces, puts it into his furnace through the door. The instrument he uses for this purpose is something like a baker's wooden shovel. In all his operations he is assisted by his underhand, an inferior workman, not recognized by the master, but paid by the puddler out of his price for puddling. The metal being all put into the furnace, the door is shut down and carefully closed, to prevent the admission of air; as any air admitted, except through the body of the fire, tends to lessen the heat and derange the regular circulation of the current. In about half an hour the pieces of metal begin to melt, and then begin also the labours of the puddler. At the bottom of the door is a small hole, shaped like a scollop (shown in *fig.* 6), and only large enough for the puddler to introduce his tools and see the progress of his work. His first business is so to dispose the pieces of melting metal that those which are the least exposed to the action of the flame may be drawn more immediately under its influence, and that the whole quantity may be brought to the same state, and melted as nearly as possible together. If it is not so managed, that which is first melted begins to burn and waste before the other is ready; and the yield is, therefore, worse than when all goes on well together. When the whole is melted, the puddler, sometimes with a tool turned at the end like a hoe, and sometimes with a flat one, stirs it about diligently in all directions, exposing every part of it in turn to the action of the flame. In doing this he is obliged constantly to change his tools, which soon become red-hot, and are plunged, as they are withdrawn, into a vessel of water to cool them. The liquid mass heaves and boils whilst it is being stirred, showing the escape of an elastic fluid. After a time it becomes more and more thick, having a sort of curdy appearance as it is turned over, the points and corners of the small crumbs being of a bright glowing white heat, whilst the body of the mass looks cooler. When the iron is in this state, the workman says it is coming round to nature. The puddler still perseveres in stirring, or rather moving it about, till it is so thick and tenacious as to stick together and form into lumps. He then begins to '*ball it up*;' that is, to divide it into a certain number of portions, generally five or six, which he brings into a round form with his tools, making them as firm and compact as he can. In this state they are called puddler's balls or blooms, and the puddler has now finished his heat, as it is termed.

The number of heats that a puddler will work in the twelve hours, with the common puddling furnace, is from six to nine. In the course of the heat he occasionally throws in a little water, which, in his own language, brings the iron round to nature faster. He also uses a small quantity of the black oxide of iron, formed in the subsequent processes of the forge. This enables him to improve his yield, as it affords a portion of iron, and increases the weight of the produce of the furnace, on which weight he is paid. He has sometimes a premium for good yield, receiving an extra price when the proceeds of his furnace exceed a certain weight,—the quantity of metal used being in all cases the same. This is not, however, a very satisfactory mode of payment, as it holds out an inducement for the immoderate use of cinder, which injures the quality of the iron : it is also a temptation to the puddler to supply himself with metal by stealing it from the yard or from his neighbours' stock, and thus using more than the regular and authorized charge. These petty thefts are not difficult of execution, particularly at night ; and the temptation to commit them should always be withheld when it is possible to do so.

Iron masters, in the late depressed times, have been put very much on the *qui vive* for all possible projects of retrenchment and economy. Indeed, economy may be considered as the very essence and soul of their manufacture. One change to which they have recently turned their attention more than formerly, is the substitution of white pig iron for refined metal in the puddling furnace. As far as chemical analysis goes, the quality of the one differs very slightly, as we have seen, from that of the other. If, therefore, the white pig were found to answer at the forge as well as metal, the saving would be very great. In the first place, the 3 cwt. loss per ton in the refinery yield would be saved; this, supposing pig iron to be worth 3*l.*, is of itself nine shillings. To this is to be added, the wages of the refiner, the cost of the coke, and the charge for weighing and loading the metal; so that, altogether, we may put down the refined metal at 3*l.* 15*s.* per ton, supposing the pig as above to be 3*l.* The saving, therefore, being so great as fifteen shillings on the puddler's material, there is a great inducement for the substitution, provided it can be made without any correspondent disadvantage. This is the consideration; and the difficulties and disadvantages are by no means trifling. To put a case in its strongest colours it is best to make it an extreme one. Let us suppose, then, that white pig iron is exclusively used in the puddling furnace, without any admixture of refined metal. In the first place, the charge of pig works hot and fluid in the puddling furnace. It takes a long time to 'come round to nature,' and is, therefore, more laborious for the puddler, who requires a higher price for his work per ton. It will admit of little or no cinder being used, as its own deposit of cinder in the operation is great. By its great heat and fluidity in working, it burns through the artificial coating of cinder on the bottom of the furnace, and wears out the iron bottom very fast, occasioning much care and trouble to the puddler. As it deposits a greater quantity of cinder than metal does, it, of course, loses weight in proportion, and works to a bad yield. Probably, in this way, there is nearly 1 cwt. difference between pig and metal in the yield. All these are drawbacks, though not very material ones; but the chief disadvantage is the deterioration in the quality of the bar iron produced in this way. This mode of manufacture has uniformly a tendency to impair its strength and body. This is an argument which admits of no reply. The very same circumstances of flat demand and low prices, that force the cheap manufacture of iron, require also that the greatest attention be paid to its quality. If a work acquires a reputation for quality, it will at least have a preference in the market over others, if not an advantage in price; and in times of extraordinary depression, such as we have recently witnessed, it is essential to preserve this advantage, to maintain this preference; otherwise very much more is lost by the iron master being obliged to accumulate a stock of iron, or to force it into the market, than can be saved by the undue substitution of pig for metal. No doubt a portion of it may be advantageously used for common iron, although it is far from being the important saving that it would at first appear to be.

When the puddler has completed all his balls, his underhand proceeds to deliver them over to the shingler, or the roller; for, in some works, the process of shingling is omitted, the puddled ball being rolled at once into the rough bar. The shingling consists in giving the puddled balls a few blows with a very heavy hammer, which makes them more solid, and reduces them to an oblong shape, better calculated for going between the rolls. It also squeezes out a portion of the liquid cinder or oxide, which is separated from the pure iron in the puddling. The hammer, generally weighing about four tons, is represented in *fig.* 7, in which it appears as at rest, being supported by the upright bar *a.* When this bar is removed, the six little projections or arms in the solid wheel *b* raise the point of the hammer *c*, and let it fall again in the course of their revolution. From ten to twenty blows are generally sufficient to give the bloom its due form. Whilst under the action of the hammer, the sparks and pieces of cinder fly with great force in all directions, and the shingler or hammer-man is obliged to protect himself by very thick leather leggings and apron. The

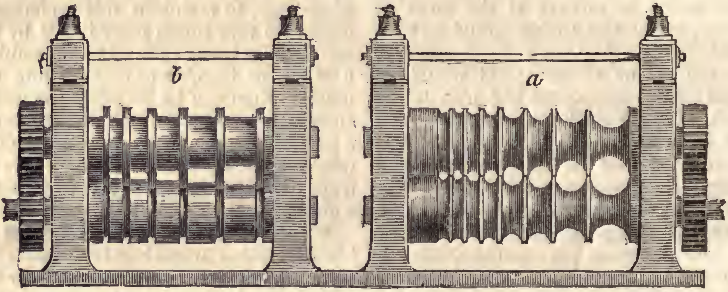
Fig. 7.



bloom itself hisses, and bubbles, and flames under the operation, showing that the escape of an elastic fluid is still going on. If properly puddled, it is brought to a firm and tolerably tenacious mass. Sometimes, when not well puddled, it does not adhere equally together, a portion appearing harder than the rest, and not amalgamating well with it. It is then turned back to the puddler, under the quaint denomination of a shadrach. This term has, no doubt, a scriptural derivation; the thing to which it is applied having come out of the fiery furnace unchanged, or, at least, not sufficiently changed from its previous nature. For every shadrach the puddler has a fine set down to him, which is deducted from his wages on the day of reckoning.

The roller takes the bloom from the shingler, and, whilst it is still hot, passes it through the puddle-rolls, which are shown in *fig*. 8. It is first put through the largest hole in the rolls at *a*, and then goes through the smaller ones in succession. It is received by a boy on the opposite side, called the catcher, and handed back by him, with a pair of tongs, over the rolls, to the roller, who, when he has reduced the size of the bar in the first pair of rolls, passes it through different grooves of the second. There it is reduced to a more accurate form, and to the required width and thickness. The pressure of the rolls upon the bar as it passes between them expels a further portion of cinder, some of which flies violently off, but the greater part falls into a hollow beneath the rolls, where it is afterwards gathered up and laid aside.

Fig. 8.



The iron is now in the state of a rough bar, having undergone a most signal change. The metal that was put into the puddling furnace was easily fusible, very hard, and very brittle; it has now become a long, slender bar of malleable iron, soft, tough, and hardly fusible; and this great change, it is supposed, is effected merely by the separation of a little oxygen and a minute portion of carbon from the pure iron. It must not, however, be supposed that the bar in this state is finished, or fit for sale; it is scaly and uneven on its surface, rough and imperfect on the edges, and unsound in the body, and therefore not yet calculated for the smith's use. It has still to undergo a further purification at the mill, the operations at the forge being now concluded.

At some works there is no forge-hammer, and the blooms are there compressed into an oblong form, or 'nobbled,' by the puddlers with a heavy iron bar, before they are taken out of the furnace. But as they are in this way very imperfectly formed, the first groove of the rolls is necessarily much larger than where a hammer is used. The puddler is paid on the weight of rough bars produced; and the weight of each furnace is, therefore, kept separate, an account being taken of each man's performance. The yield of the puddling furnace depends very much on the quality of the refined metal used, and the degree of licence that the workman has in the use of cinder. If he is allowed to use as much as he pleases, and is working upon good metal, the weight of the rough bars will sometimes be as great as that of the metal put into the furnace; but this is not to be desired, as it indicates an excessive use of cinder, and what is gained here is lost afterwards in the mill, as the rough bar is unsound, and contains still so great a portion of cinder as to lose weight considerably when again heated in the mill. 22 cwt. is about the usual quantity of metal required to make a ton of rough bars, supposing the puddler is allowed to use little or no cinder; and about 17 cwt. of coal is consumed to the ton of rough bars.

There is a species of puddling furnace, of which no mention has hitherto been made, but which may with propriety be noticed before we quit this part of the subject. In the process of puddling, as above described, there is an obvious loss of time from the point when the metal is first put in, to that when it is sufficiently heated for the puddler to begin his operations,—a period of from twenty minutes to half an hour. Now the time required to complete the heat is under an hour and three-quarters, the puddler usually finishing seven heats in his turn. The produce of these seven heats will be about 25 cwt.; so that, reckoning eleven turns in the week, the make of one furnace in a week is between thirteen and fourteen tons. But if half an hour in each heat could be saved, and the workman be kept regularly on without interruption, many more heats could be completed in the same time, and there would be a considerable saving in coal.

To this end there have been several contrivances for warming the fresh charge of metal whilst the preceding heat is in progress. One plan is, to make the flue rather wider, so as to form a sort of recess for the reception of the fresh charge, which is placed there by the puddler's underhand through a small door for the purpose, without any interruption to him, and, when his heat is finished, is drawn forward, and is ready for him to go on with, without any delay. The simplest method, however, yet used, is to make the body of the furnace longer than according to the old plan, and to have a second door, between that where the puddler works and the stack. This affords sufficient convenience and room for the succeeding charge of metal, which at the same time is so near the workman that, when he has completed the heat and sent the balls to the shingler, it can be instantly drawn to the scene of action, and, if put in at the right time, is just in the proper state. With these furnaces, nine heats can readily be worked by one man in twelve hours; and if, as is sometimes the case, the furnace is provided with three sets of men instead of two, (each set working eight hours out of the twenty-four, instead of twelve,) ten or even twelve heats may be finished in the twelve hours. The additional number of turns being, of course, attended with a proportionate increase in the weight of the produce, it follows that there must be a considerable economy of coal; for the quantity used at the furnace is only the same, or nearly the same, whether it be constructed on the old or on the new system.

The rough bars, when they come from the puddle rolls, are cut into lengths by a strong pair of shears, worked from the engine. In some works, they are cut hot, immediately after being rolled, and weighed afterwards; in others, they are laid aside in the first instance to cool, the work of each puddler being kept separate, and then weighed and sheared when cold. The first of these plans is, perhaps, rather more economical in labour, but the saving is not great; the other method affords the greatest facility of seeing and comparing the work of each puddler. The rough bars are of such sizes and cut into such lengths as are best adapted to the size of the finished bar wanted. They are generally 2, 3, or 4 inches wide, by ½ or ⅝ of an inch thick. These, when cut into the proper lengths, according to the sizes wanted, are wheeled to the balling or heating furnaces, and delivered to the pilers.

The construction and shape of the balling furnace is very similar to the puddling furnace. It is a reverberatory furnace, heated by a coal fire at the end, the flame of which is drawn on by the current of air, and turned downwards in its course to the flue by the inclination of the interior of the roof. Instead, however, of its having the iron bottom, with the protecting coat of cinder, as in the puddling furnace, it is of loose sand, renewed from time to time as it becomes uneven or wears away. The stack of the balling furnace is of the same height and proportions as that of the puddling furnace, and, like it, is furnished with a damper at the top to regulate the heat. A similarly constructed door at the side completes the resemblance.

The term balling furnace is not, in the present day, by any means an applicable one, as its use is simply to give a welding heat to an oblong pile of the rough bars, which are then to be reduced by the rolls to the shape of finished bars. The process is called indifferently 'balling' and 'heating,' the latter term correctly defining the operation; but, in Wales, the furnace is always designated as a balling furnace, and the workmen as ballers;

and we must therefore adhere to the commonly received nomenclature, however false may be the impression it conveys.

The business of the pilers, generally boys or women, is to pile up or place together the lengths of the rough bars, which are delivered to them from the shears. The pile generally consists of five or six of these pieces laid evenly one upon another, all being of the same length, so that one does not project beyond the rest. It is important that the bars should be flat and the pile laid smoothly, for wherever there is a projection or interstice, the iron will be more or less wasted in the balling furnace. This is shown by the appearance of the pile when drawn out of the furnace after being heated. All the corners and sharp edges are rounded, and if there are any pieces projecting beyond the rest, and not protected by the main body of the pile, they appear very much wasted by the action of the fire. Small bodies are, of course, much sooner heated than large ones; and when the proper degree of heat is attained in the balling furnace, the action of the fire afterwards is merely to waste and injure the iron. If, therefore, the pile, instead of being a compact body, is ragged at the sides and uneven at the ends, all the projections will be sufficiently heated long before the pile itself, and whilst it is acquiring the proper heat, they will be burning and wasting away. The post of the baller is not one of great labour, but it requires considerable experience, attention, and care. The point of time when the piles in his furnace are just ready for the roller, is a most critical one. If he takes them out too soon, they are not completely welded together, and do not make a smooth and compact bar; and, on the other hand, every minute that they are allowed to remain beyond the proper time is productive of injury and loss. The injury arises from the iron being burnt, as it is called, or over-heated, which causes it to be weak and brittle in the bar, sometimes to such a degree as rather to resemble cast than malleable iron. As a proof that the injury may be done in a very short time, it sometimes happens that the first two or three piles that are taken out of the balling furnace (the heat consisting, perhaps, of ten or twelve piles) are perfectly tough and good in the bar; whilst the same number taken out at the end of the heat, at an interval of a very few minutes, as fast as they can be successively passed through the rolls, will, perhaps, have suffered so much from being overheated as to break quite brittle, and be unfit for sale. A circumstance of this kind is not, by any means, of frequent occurrence; but as was done before, an extreme case is cited to show the effects in their strongest colours. This instance is quite sufficient to prove that much mischief may be done without great care on the part of the baller. It is his business not to take out the piles indiscriminately from the furnace as they present themselves, but to select those first which are the hottest and most likely to burn, either from having been put first into the furnace, or from being placed in a hotter part of it than the rest. He should also so put in his piles as to have them ready in their proper turn with the other balling furnaces, so that the succession may be kept up without any waiting either on the part of the baller or roller. He is restricted in the number of piles he puts into the furnace, a regular scale being provided for him according to the weight of each pile; if they are small, he puts in perhaps twelve or sixteen, as a small bar is so soon rolled that no injury is found to arise from the last of the piles waiting in the furnace. The number is diminished as they become heavier; and when very large, only four or five are put in.

The waste in the balling furnace is considerable, and, unlike the puddling furnace, the greater part of the cinder runs off the pile in the furnace, and thus separates itself from the iron without mechanical force. As the pile is attaining its greatest heat, the cinder first forms a sort of glaze over its surface, and then flows down the bottom of the furnace, which is purposely made inclined, to a small outlet at the end opposite to the grate. It is beneficial to the iron, by protecting the pile from being burnt, filling up the interstices between the rough bars, and preventing the flame from acting upon the interior. Its benefit in this way is proved by the circumstance, that a bar is frequently burnt at one end, and quite uninjured at the other; and, upon investigation, it will be found that, in this case, the burnt end has been upon a higher elevation in the balling furnace than the other. The cinder has run from the upper end of the pile, and left it to the action of the flame; whilst the lower end, having been amply supplied with its due covering, has been protected.

The balling being the last branch of the manufacture of bars in which there is a waste of the material, the yield is of more importance here than in any previous operation, the material being more valuable. The yield is generally tried separately on the iron rolled at the large rolls and that produced at the small ones. With the large sizes the yield is better: that is, the waste is less than with small iron; for, as has been seen before, the loss in the furnace is proportionably greater as the size of the pile is smaller. With the ordinary sizes of bars, as they occur in the large rolls, the yield may be about 1¾ cwt., the ton of finished bars being produced from 21¾ cwt. of rough bars. With the smaller sizes the yield rises considerably above 2 cwt.; so that, to take all the sizes of bars as they are produced, the yield will probably be about 2¼ cwt. on the average.

Small iron is not rolled from piles like the larger sizes, but from billets or single pieces of bars, which are cut into convenient lengths, according to the size of the finished bar wanted. Where billets are used, the baller can very much increase the work of his furnace, by putting in a fresh billet for every one he draws out, instead of waiting till the whole furnace is drawn. He is enabled to do this, as, instead of drawing the hot pile to the rolls, he throws the billet to the roller with his tongs, without moving far from his place. He has, therefore, sufficient time upon his hands, before the roller has finished that bar, to put in his fresh billet,—especially as a billet is put into the furnace much more expeditiously than a pile would be, which requires to be put in with care, to prevent its different pieces from being displaced.

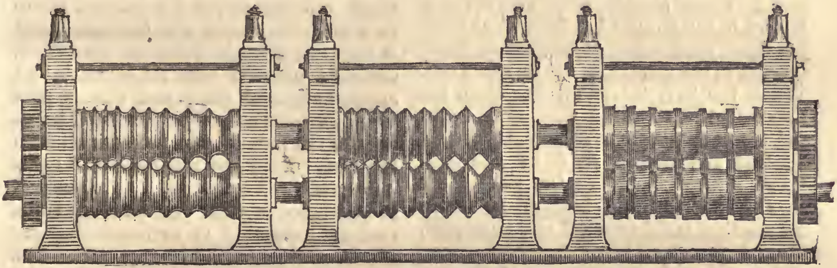


Fig. 9. *Fig.* 10. *Fig.* 11.

The last operation in the manufacture of bars is the rolling. The variety of sizes is very great, but may all be divided into three heads: rounds or bolts, squares, and flats. *Figures* 9, 10, 11 represent three pair of rolls; the first for round iron, the second for squares, and the last for flats. These are what are called the finishing rolls, for before the pile is brought to them, it is reduced to a size somewhat approaching to that required, by the roughing rolls, which are larger than the finishing rolls, and provided with wider grooves. The pile is passed through several of these, each rather smaller than the preceding one, and by this means reduced from its original form to that of a solid bar, the various layers of which it is formed being firmly welded together, and the remaining portion of cinder and impurity being thoroughly expelled.

There is a sort of rest or small bench in front of the roughing rolls to support one end of the bar, whilst the roller holds it by the other in his tongs and pushes it through the grooves: it is received by a man on the other side, called the catcher, who returns it over the top roll. It is handed backwards and forwards with as much expedition as possible, that it may not be allowed to cool, for if much time is lost it becomes too cold and hard to be reduced to the required form by the pressure of the rolls, and must be heated again before it can be finished. The number of layers in the pile produce a fibre in the bar that adds very much to its strength and toughness. However perfect the weld may be, this fibre is always perceptible in good iron.

In rolling flat bars, the layers of the pile are kept horizontal, that the fibre may intersect the bar in its breadth, and not edgeways as it were,—like *fig.* 12 rather than *fig.* 13. The section or end of a bar is here represented, in which there are six layers or strata, the pile

Fig. 12.

Fig. 13.

from which it was made having consisted of six pieces of rough bar. In the first of these figures, the workman has kept the bar in the right position throughout; in the other it has been turned on its edge, producing a transverse grain. It will be readily seen that the fibre in the first bar is much more favourably disposed for strength than that in the second, just as a deal plank is stronger when the grain corresponds with its flat surface than when it intersects its smallest diameter. In rolling square bars no precaution of this kind is necessary; but the experienced smith, if he wishes to make the most of his iron, will always work it with a due regard to the direction of the pile. However true the rolls may be turned, there will always be a little space between them which will prevent the angles of the square bar formed at their junction, from being so perfect as those formed in the moulding of the roll itself. When the bar, therefore, has been reduced to the required size, it is again put through the same groove, turning it so that the angles shall be changed, those formed before at the sides being now at the top and bottom, by which means they are sharpened and corrected. Round iron also, being formed between the two semicircular grooves of the two rolls, is liable to the same imperfection unless it is passed several times through the last hole; and even this repetition does not succeed, unless the bar, during its progress, be held in its position by the roller; otherwise it will twist round and adapt itself to the same situation in the rolls that it before occupied, the streak or finn, as it is called, still remaining. There are generally three sizes of rolls, as has been stated before —the largest about 14 to 16 inches diameter, the middle 10, and the small rolls 7—and to produce the same speed to the bar in passing through these different sized rolls, they must of course be made to revolve more quickly in proportion as the circumference is decreased. But this is not all that is necessary, for the small iron is required to be rolled at a greater speed than large sizes, as it becomes cold so much sooner. About 70 revolutions a minute are considered a good speed for the large rolls, 140 for the middle sized rolls, and 230 or 240 for the small ones, which will be found on calculation to give them a considerably greater velocity than the others. After being rolled, all that remains is, that the bars have the ends cut off by powerful shears worked by the engine, when they are ready for shipment. They are, however, previously straightened by boys on a long bench of cast iron, and stamped with some letter or device to distinguish the works where they are made. Small iron is put up in bundles of half a hundred, or a hundred weight each, which gives it a neater appearance, and more convenient form for removal. Notwithstanding the hardness of the kind of iron selected for the rolls, they are found to wear very fast from the pressure of the hot bars passing through them—that is to say, the surface becomes rough, and the angles blunt and irregular,—and when this is the case, the manufactured bar is necessarily rough and imperfect. It is not of great importance for the larger sizes to be a little uneven on the surface, but it is very much so to have the small iron perfectly smooth and accurate in its appearance and size; and this is provided for by producing an artificial hardness in the iron of which the small rolls are cast. They are what is called case-hardened in the casting, that is, instead of being cast in sand like the large rolls, and the generality of castings, they are run in a thick solid iron mould. The effect is to cool the iron suddenly on the outside, or chill it, and thereby to give it the hardness and appearance of white iron on the surface, whilst the inside is dark grey or bright. It is thus sufficiently strong to sustain the strain to which it is to be exposed, which it would not be if it were cast entirely of white iron. The surface being infinitely more hard than the inside, the turning it, and cutting the necessary groves in the latter, is a very tedious process, but when finished it retains its polished surface for a long time, and effects so great an improvement in the appearance of the work done, as amply to compensate for the extra expense and trouble in its manufacture. The very small sizes of iron are generally rolled in long lengths, sometimes as much as 40 feet, and afterwards cut into two or three lengths for the convenience of removal. They look better rolled in this way than in short lengths, and at the same time are less trouble to the roller, who can roll a long piece almost as readily as he can one of half the length. The manufacture of common bar iron has now been described in all its different stages. The Welsh iron masters confine themselves more to this regular trade than those of Staffordshire, who, from their situation and longer standing in the trade, have a constant demand for a great variety of articles on which they get an extra profit. Of these articles we may mention slit nail rods, boiler plates, and sheet iron of all sorts, hoop iron, spade iron, &c., as some of the most important. They also roll angle iron, wrought iron rails for roads, &c. These branches of the trade of course require extra attention, and are sometimes troublesome from their hindering the regular progress of the work, but they have hitherto been a source of great profit—greater than they are ever likely to be again, for they are now becoming much more general than they have been, and will probably be extensively entered into in Wales before very long. Indeed at present nail rods and boiler plates are regularly made for sale at some of the Welsh works; the first to a great extent, the last only in a less degree. The manufacture of nail rods is performed in a very easy and expeditious manner. It consists in rolling a flat bar five or six inches wide, by the thickness required in the rod, say a quarter of an inch, and then, while it is yet hot, passing it between steel rollers, or cutters that intersect each other. It is drawn in by them as they revolve, and cut into twenty or thirty small rods according to the width of the cutters. The rods are completed at once, and merely require to be straightened and put up in bundles. As may be expected, they will not bear a comparison in appearance with rolled iron, as they are always more or less ragged at the edges, and rough and imperfect in their general execution, but they answer very well for the manufacture of nails, and are infinitely cheaper than rolled iron of the same size would be. The waste of iron in the balling furnaces is so great, and the process of rolling so slow with the very small sizes, that the cost is prodigiously increased, and the slitting mill is therefore an admirable expedient for obtaining small iron at a low price. Hoop iron is rolled in the same manner as bars, except that the rolls are perfectly plain instead of being grooved. They are brought nearer to each other by a screw, at each successive time that the hoop is passed between them, till it is reduced to the required thickness. Boiler plates and sheet iron are also rolled between plain rolls, which should be case-hardened if the work is required to be turned out well. Boiler plates are frequently very heavy—as much as 2 cwt. each,—and when this is the case the work is very laborious for the rollers, of whom an additional number is required. The iron for them is prepared by making a pile of rough bars which is heated in a puddling or balling furnace and brought under the forge hammer, where, by repeated blows, it is beaten into a solid slab of about two or three inches thick and nearly square, long and broad, according to the weight and shape of the boiler plate for which it is destined. It then requires to be again heated, as it has become too cold under the hammer to be rolled at the same heat: when heated again it is rolled to the proper thickness, the rolls being brought nearer to each other by screws every time it passes between them. It is also brought to the required shape by passing it through the rolls in different directions, sometimes lengthways, and sometimes with the side or one corner foremost. A skilful roller will in this way bring it very nearly to whatever dimensions are wanted, so that the ragged and uneven edges which are afterwards to be cut off shall amount to as trifling a sum as possible.

There is a great difference in the quality of bar iron, which has not yet been explained. It varies in this respect as much as almost any other manufactured article, and, without great care on the part of the manufacturer, will lose its reputation in the market as well as most other commodities. The iron produced in different districts is naturally different in its quality, and that of Wales has its peculiar and distinguishing properties. The foundry iron and the bars of Wales differ in the same way from the same descriptions elsewhere: they are both remarkable for strength. The Welsh foundry iron is, therefore, esteemed for all castings where great strength is required. It has been asserted that this advantage is counterbalanced by a defect, and that, though the Welsh pig iron is undoubtedly strong, it will not run into the fine delicate castings that can be made of Staffordshire iron, and, in addition to this, that it is liable to shrink unequally in cooling, to draw, as it is called, forming an imperfect and unsound casting. We have a strong argument against the first of these objections in the fact, that a great deal of Welsh foundry iron has actually been sent to Staffordshire for the purpose of being run into saucepans, nails, and other small castings for which a very fluid iron is necessary. In reply to the second objection, namely, that Welsh iron makes imperfect and unsound castings, it may be stated that it has been used in the execution of government contracts for cannon with great advantage. This could hardly be the case if the allegation were valid, for it is well known that cannon are required to be perfectly sound and accurate, and any unsoundness in the body must either be detected in the boring, or lead to failure in the proving of the gun.

Nearly the same may be said of the bar as of the pig iron of Wales. It is very hard and strong, not working so easily under the smith's hammer as a softer iron, and therefore is frequently found fault with by the smith, who would prefer an inferior iron because it would give him less trouble. This description applies most forcibly to the iron of the south-eastern part of the Welsh district, that of the north and west not being so hard. The two great defects of bar iron are its being red short, or cold short; the former term is applied to iron that cracks when bent or punched at a red heat; it is generally very strong when cold, but the difficulty of working it is a great objection in the market—not but that it may be readily worked with care, as it is generally only at one degree of heat that the imperfection shows itself, but it is not every smith that will give himself the trouble to find out and avoid this particular heat; and it is certainly an advantage, all other things being equal, that iron should work readily at any temperature. Cold short iron, on the contrary, is wrought without difficulty when hot, but is weak and brittle cold. The method of trying the quality of iron, is to nick a bar at one side with a chisel, and then to break it, or double it down, as the case may be, at the notch. If the iron is cold short, it will break off at once with a blow of the sledge hammer. The fracture will be bright and shining, the texture large grained, with little or no appearance of fibre; in fact, it will very much resemble foundry iron in its appearance, and sometimes will be almost as brittle. Any iron may be brought to this state by being overheated in the balling furnace, and that which is naturally inclined to be cold short must be heated with great care to prevent the evil. If, upon trial, the bar should be of good quality, instead of breaking short off, it will bend double, and those portions of it to the depth of the notch on both sides will separate a little from the body of the bar and split up just as a piece of fresh ash stick would do, and will exhibit a clear, distinct, silky fibre. If this appearance is shown on the trial of the bar cold, and if it is then taken to the smith's shop and bent double at a cherry-red heat, first in the direction of the pile, and then at right angles to it, without being at all cracked on the outer side of the bend, it may safely be pronounced to be of excellent quality, neither red short nor cold short. There are some works in Wales where the iron has a tendency to be red short, and others where the opposite quality is most to be dreaded. A cold short iron is generally produced from a lean ore, that is, one containing only a small per centage of iron, and at several works in South Wales it is found advantageous to mix the rich red hepatic ore of Lancashire and Cumberland with the poorer iron stone of their own district. The mixture gives strength to the iron, and prevents it from being cold short. The Lancashire ore is an oxide of iron containing few impurities, and producing as much as 75 per cent. of iron. It does not require roasting, but is put into the furnace in the state in which it is brought from the mine. If smelted by itself, it would produce a very red short iron, and it is, therefore, only when mixed that it can be advantageously used.

There are three qualities of bar iron regularly recognised in the trade; common iron, best, and best best, or chain cable iron. The manufacture of the first of these, or common iron, is what has hitherto been described. Best iron, as it produces a higher price, is more expensive in the manufacture, and requires greater care in the selection of the materials. The refined metal used by the puddlers for best iron should be made of dark grey pigs, selected for the purpose. Best metal differs from common by being more brittle, and when broken its fracture is of a more shining and silvery white. The texture is also more compact and less broken and interrupted by air-bubbles. This quality of metal is puddled by itself without any mixture of pig, nor is the puddler allowed to use any cinder in his furnace. By these precautions a stronger and tougher rough bar is obtained, and the quality of the finished bar is proportionably better and more regular. Scrap bars are frequently used with best rough bars in the balling furnace. The scrap bar is composed of the short imperfect pieces that are cut off the ends of the finished bars, In a large work they form an important amount, and are collected and either piled up carefully together to be heated and rolled at once into a bar, or if they are too small to be so arranged, they are put into a puddling furnace, and at a welding heat formed into a ball which is shingled and rolled like common puddled iron. Scrap bars are of a strong compact quality, and produce very good finished iron when mixed with best rough bars. Cable bolts are differently made at different works, according to the strength and other peculiarities of the material.—In all cases they are made of carefully selected materials, and have more work upon them than common iron—that is to say, have been wholly or in part piled, heated, and rolled a second time. This extra process always very much improves the quality, and a bar of inferior common finished iron, if cut into lengths, piled and rolled again, will be found perhaps of best quality merely from having undergone this additional process. It will possess more fibre and consequently be stronger and tougher than it was before. Cable bolts, being intended entirely to resist a longitudinal strain, should possess this toughness and fibrous texture in an eminent degree, and any inequality or variation should be sedulously avoided, for one defective link in the chain would be as destructive as if the whole were weak. The strength of cable iron is proved by stretching a short piece of bar (or of the manufactured chain) in a machine for the purpose, till it break, and noting down the precise weight required to pull it in two. It is surprising how much a good bar will stretch before it separates—for instance, a piece of inch and quarter bolt, of about two feet six inches long, will sometimes be lengthened six inches, or twenty per cent., before it breaks. In the beginning of the experiment the little oxidized portions of the outside will scale off and drop down; and just before the bar breaks, the point where it is going to separate will be shown by a considerable contraction in the bar. The broken ends will be quite hot, latent heat being evolved by the texture of the iron having become closer, and the fibre appears harsher, smaller, and less silky than before the trial. The following table shows the proof which cable iron ought to bear in the trial without breaking.

Inches.	Tons.	Tons.
1	19	17.15
1⅛	26	23
1¼	32	27.10
1⅜	38	35
1½	44	39
1⅝	52	44.10

The first column shows the diameter of the bar; the second the required proof of the manufactured chain; and the third, the proof of the bar before it is manufactured into the chain. Thus an inch bar ought to bear a weight of seventeen tons and three-quarters without breaking, and when made into a chain it ought to sustain nineteen tons. Charcoal iron is another variety in the manufactured article that is made to a certain extent in Wales, but only at a few works. It receives its name from an extra process of refining to which the iron is subjected, and in which charcoal is used instead of coke. In this second refining the iron loses its fluidity in the same way as it does in the puddling furnace—and indeed the charcoal refining is not altogether an additional process, but rather a substitution for that of puddling.—The bloom when it is taken out of the charcoal fire is put under a heavy hammer and beaten down to a flat cake, in which state it is called stamped iron. It is then broken up into small pieces, piled, heated, and again put under the hammer, and reduced to a regularly shaped slab of about a hundred pounds weight. The slab so formed is sold to the tin-plate manufacturers to be rolled down into thin sheets, and afterwards tinned. It is particularly tough and strong iron, and much harder than that made in the common way. Charcoal iron is used also for other purposes, the principal of which is the manufacture of horse-nail rods, for which the strongest and toughest material is required. Every branch of the Welsh iron master's trade has now been described. All that has been attempted has been a plain straight-forward delineation of the practical part of the subject before us, rather than a chemical or scientific treatise; and if the matters that have been treated of have been so explained as to be clearly understood, the object will have been attained.

It may perhaps be interesting here, to look back for a moment to the various yields of which mention has been made at different times, and to form a calculation of the total consumption of the different materials to make a ton of bar iron. It should be stated that, in speaking generally of bar iron, common iron is to be understood; and it is necessary to make this remark here, as the manufacture of best and cable iron, requiring an extra process, is of course attended with an extra expense of material, and in all calculations of the yield of bar iron, all the current sizes made at the three different sizes of rolls should be taken into the account. It would be fallacious to make the calculation on the larger sizes only, as the result with those would be much more favourable than with the small sizes, and an average of the whole forge should therefore be taken as the fairest and most correct result. In the first place, then, let us establish the quantity of pig iron required to make a ton of bars, and for this purpose it will be necessary to follow it through all the different stages of the manufacture. The refinery is the first of these; and we have seen that there the yield of pig iron to the ton of metal is from 2 to 3 cwt., and we will therefore assume as an average that 22½ cwt. of pig is taken. The next stage is the puddling, in which we will say that 21½ cwt. of refined metal is consumed for the production of a ton of the rough bars. 22 cwt. was before stated as the average puddler's yield, but this was on the supposition that little or no cinder is used, and for common iron a pretty free use of cinder may be allowed. But the 21½ cwt. of refined metal will be found on calculation to be equal to 24.188 cwt. of pig iron; and this is therefore the yield of pig iron to the ton of rough bars. The third and last process in which there is a waste of the material is the balling, and here it was stated that the waste per ton was about 2¼ cwt. which we will therefore take as an average. By pursuing the calculation, we shall see that supposing one ton of rough bars equal to 24.188 cwt. of pigs, 22¼ cwt. of rough bars will be equal to 26.909 cwt. of the pigs, which will be the quantity necessary for the production of a ton of bar iron, the yields being as above stated. The above figures, when reduced from the decimal to quarters and pounds, will be 1 ton 6 cwt. 3 quarters and 19lbs. To continue the subject, we will now endeavour in the same way to trace down the yield of coal, mine, and limestone, and ascertain the total consumption of all the materials. Supposing 4¾ tons of coal to be used at the furnace for the ton of pigs, including the engine and mine kilns, the 1 ton 6 cwt. 3 quarters and 19lbs., as above, or, stating it decimally, 1.345 of pig iron will require 6.378 tons of coal, or 6 tons 7 cwt. 2 quarters and 6 lbs. reducing the decimal to cwt., quarters, and pounds. In addition to this, we have to take the consumption of coal at the refinery, the puddling furnace and the balling furnace, including what is used at the forge engine. The consumption of coal at the refinery has been stated as about 10 cwt. to the ton of metal; but as 1.222 of metal is taken to the ton of bars, the coal must be calculated on this quantity, and will therefore be .611, or rather more than 12 cwt. The third item of coal to come into the account is what is used at the forge, including the puddling and balling furnaces and the engine. This may be taken at once, and will be found to be about 38 cwt. on the ton of finished iron. We have therefore to add together the three sums of

first... 6.378 tons used at the furnace
secondly 611 „ „ refinery
thirdly 1.90 „ „ forge and mill
tons cwt. qr. lbs.
Total.. 8.889 ....or 8 17 3 3

of coal to the ton of bars. The calculation of the consumption of iron stone is very simple, that of pigs having been ascertained. Three tons of mine being assigned as the yield to the ton of pigs, 4.035, or rather more than four tons, will be the amount required as the yield of iron stone to finished bars. In the same way, supposing 21 cwt. of limestone is used to the ton of pigs, 1.415 will appear as the proportion of limestone to bars. It will be seen from the foregoing observations, that in the manufacture of foundry iron, the great object is not to produce pure iron, but a compound of iron with carbon; and the greater the proportion of carbon, the better will be the quality of the pig. In wrought iron, on the contrary, the aim is, to attain to the greatest possible purity, any admixture of a foreign substance being found disadvantageous. Two eminent chemists (Bergman and Meyer) found that by treating cold short iron with sulphuric acid, a white powder was separated, which they discovered to be phosphuret of iron, but the same result did not attend the experiment if the iron operated upon was not cold short. Hence it would appear that this defect is to be attributed to the presence of phosphorus. The same chemists also pronounced that silica, as well as carbon and oxygen, enters into the composition of cast iron. It is curious that such slight chemical differences should be attended by so wide a difference in the properties of iron; and this remark is in no instance more forcibly illustrated than in the composition of steel. Steel is produced by the combination of carbon with pure iron in so small a proportion as the $\frac{1}{300}$th part. Again, plumbago, black lead as it is called, or the kish that has been described as being produced in the furnace in the smelting of foundry iron, is also a compound of carbon and iron, though in different proportions.

The iron trade in Wales was formerly a source of great profit, and a few very large fortunes have been made in it; but like many other branches of our commerce, the production of iron has latterly been so excessively extended, as to force down prices beyond anything that could have been anticipated. By this means the profits of the iron master have not only been extinguished for the last few years, but his anticipations as to future gains have been, to say the least, very much moderated, and he can now only expect to realize even a small profit on his investments by the very strictest attention to economy and management in all the departments of his trade. To justify these remarks it may be stated, that in the year 1825 the current price of common bar iron at the shipping port was 14*l.* per ton; and that now, in July 1831, the same article is selling for 5*l.* 5*s.* per ton. The different points of reduction between these two extremes, with the occasional checks and revivals in the price, are shown by the following list of prices from 1824 to the present time.

		Price of Bar Iron per Ton.		
September,	1824	£9	0	0
November	,,	10	0	0
January	1825	12	0	0
March	,,	14	0	0
August	,,	12	0	0
October	,,	10	0	0
May	1826	9	0	0
October	,,	8	10	0
November	,,	9	0	0
February	1827	8	10	0
May	,,	8	0	0
August	,,	8	10	0
September	,,	9	0	0
December	,,	£8	10	0
February	1828	8	0	0
May	,,	7	10	0
October	,,	8	0	0
December	,,	7	10	0
January	1829	7	0	0
April	,,	6	10	0
May	,,	6	5	0
June	,,	6	10	0
September	,,	6	0	0
October	,,	5	15	0
December	,,	5	10	0
March	1830	5	5	0
April	,,	5	15	0
May	,,	6	0	0
October	,,	5	10	0
January	1831	5	5	0
April	,,	5	10	0
June	,,	5	5	0

A prodigious increase of the make in 1825 was the natural consequence of the excessive prices of that period, and likewise the natural cause amongst others of the subsequent depression. The quantity of iron now made is probably greater than it has ever been, for it is found that in an extensive establishment like an iron work, the general charges are so heavy that low prices are only to be met by increasing the productiveness of the work. Thus the evil operates to its own extension; and it has been only by the opening made in the increase of our foreign trade, that markets have been found for all the iron that has been manufactured. The foreign demand, it is to be hoped, will still continue, but whether its extension is likely to continue as it has hitherto done, is a very problematical point, for iron works are establishing rapidly in North America and elsewhere. And the Welsh and Staffordshire iron masters are at this moment actually employed to their own destruction, in the execution of castings, &c., for a very large establishment that is forming under the auspices of a public company in France. One of the chief directors and shareholders in this company is Marshal Soult, hitherto better known in a military than in a commercial capacity. The works are erecting at Alais, in the province of Languedoc, not far from Montpellier. The iron stone and coal ore are said to be of excellent quality and most abundant—so much so, that it is confidently anticipated that pig iron will be made there at half the price that it can now be manufactured at in Great

Britain under the most favourable circumstances. The great drawback is the situation of the works, which will be thirty-five miles from the Rhone, the nearest navigable river, and forty from the sea. Until a facility is afforded by the establishment of a rail-road or canal, this circumstance will occasion a charge in carriage that will more than double the cost of the iron.

It may be interesting here to give the comparative quantities of iron manufactured in Great Britain at different periods, as stated in the British Almanac of 1829, from which the precise increase in the production is seen up to 1827.—

Anno	Iron made in Great Britain. Tons.	No. of Furnaces.
1740	17,000	59
1788	68,000	85
1796	125,000	121
1806	250,000	
1820	400,000	
1827	690,000	284

By this table we find that the make of 1827 is prodigiously above any previous year. The following is a statement of the distribution of this quantity in the proportions in which it was produced at the different iron districts.

	Tons.	Furnaces.
South Wales	272,000	90
Staffordshire	216,000	95
Shropshire	78,000	31
Yorkshire	43,000	24
Scotland	36,500	18
North Wales	24,000	12
Derbyshire	20,500	14

Of this quantity three-tenths is calculated to be foundry iron. This table shows that the Welsh furnaces are considerably more productive, as to quantity, than those of any other districts; and the difference would, probably, be even greater at the present time, as the average make of the furnaces in Wales has certainly increased since 1827. The following is a list of the quantity of iron sent down from some of the principal works in the Merthyr district, by the Glamorganshire Canal, in 1828. The particulars are supposed to be not all of them perfectly correct, though they are probably not far from the truth. They do not precisely establish the make of the different works, as they only, of course, include the iron sent to the shipping port, and can take no account of home consumption, or increase and decrease of stocks at the works.

	Tons.
Cyfarthfa and Hirwen works, Messrs. Crawshay and Co.	25,412
Dowlais . . Guest and Co.	25,020
Plymouth . Hill and Co.	14,500
Pen y Darran, Foreman and Co.	10,805
Aberdare	9,262
Gadlys	598
Bute	177
Total	85,774

In 1829, the total quantity sent down the Glamorganshire Canal was 88,000 tons; and in 1830 it was rather reduced again, the quantity being 87,364 tons, distributed in the following proportions amongst the different works.

	Tons.
Dowlais	29,621
Cyfarthfa, &c.	21,312
Pen y Darran	12,582
Plymouth	13,046
Aberdare	7,248
Blakemore and Co.	2,891
Brown and Co.	664
Total	87,364

The above works do not comprise half the South Wales district, the shipments from the port of Newport being greater than those from Cardiff. The returns of iron by the Monmouthshire Canal to Newport, are for

	Tons.
1829	108,000
1830	106,000

This superiority on the part of Newport to Cardiff, was by no means the case some years ago, but latterly the works of Monmouthshire have been much increased, and have given a population and an importance to that district that was before unknown. Indeed the face of nature has been entirely changed in some places in the space of a few years, by the establishment of new works. Romantic vallies, that before were rarely traversed by a human being, are now intersected by rail-roads, and studded with rows of workmen's houses. The flourishing woods that clothed the sides of the hills, and in the winter sheltered innumerable woodcocks, are now cut down for pit timber, or blackened by smoke, which prevents the former tenants from resuming their visits; and the clear mountain streams that teemed with life, and afforded a never-failing resource to the fisherman, are now thickened and poisoned by the mineral waters that drain into them.

The statistical inquirer may perhaps be curious to learn some particulars as to the number of people supported by the manufacture of iron in South Wales. These particulars are not to be obtained with facility, from the circumstance of there being many master workmen, or contractors, at every work, who employ a number of workmen under them, whose names are not returned in the pay books. From the best information that could be obtained on this subject, the following is a statement of the number employed on a work where there are five furnaces, and a forge and mill capable of manufacturing about two hundred tons of bar-iron weekly. Each particular class of labour is here kept separate, and the number of women and boys is given as well as that of the men, from which it will be observed that the employment for the former at iron-works is not very extensive.

	Men.	Women.	Boys.
Colliers, including road-men, horse-tenders, and sundry labourers	280	0	27
Miners, including stacking and loading the mine, road-men, horse-tenders, and sundry labourers	395	40	73
Furnaces, &c., including furnace-labour, viz., keepers, fillers, refiners, cokers, pig-weighers, engineers, fitters-up, moulders, smiths, carpenters, sawyers, stable-men, brick-makers, masons, machine-men, carriers, &c. &c.	257	39	3
Forge and mill, viz., puddlers, shinglers, rollers, catchers, straighteners, smiths, ballers, engineers, bar-weighers, clerks, &c., &c.	145	5	55
Agents, overlookers, and others, not included in the above	31	0	0
TOTALS	1108	84	191

From the above statement it appears that five furnaces, with a corresponding establishment for the manufacture of bar-iron, provide *direct* employment for near fourteen hundred individuals. Supposing in round numbers that a work of this size produces a twentieth of the iron made in South Wales and Monmouthshire, which supposition will not be far from the truth, and supposing, likewise, that the number of work-people here stated affords a tolerably fair average, the iron-works in this district give direct employment to about twenty-eight thousand people, to say nothing of the wives and families who derive their support from the labour of the men, and the much larger number who are necessarily employed and maintained in a variety of ways in every populous district.

It will be seen by a reference to the canal returns of bar-iron sent to Newport and Cardiff, that a work producing about two hundred tons a week may fairly be stated to form a twentieth of the whole production of South Wales, and this calculation is confirmed by the following table of the number of furnaces, which shows a proportion of nearly one to twenty in a work consisting of five furnaces compared with the total number.

	No. of Furnaces in blast.	No. of Furnaces out of blast.	Total.
Dowlais Iron-works—Guest and Co.	9	3	12
Cyfarthfa—Crawshay and Sons	9	0	9
Hirwen	4	0	4
Plymouth—Hill and Co.	5	2	7
Pen y Darran—Thompson, Foreman, and Co.	5	0	5
Romney and Bute Works	2	2	4
Sir Howey and Ebbw Vale Works—Harfords, Davies, and Co.	6	1	7
Nant y Glo—Bailey, Brothers	7	0	7
Tredegar—Thompson, Foreman, and Co.	5	0	5
Aberdare	3	3	6
Abersychan—British Iron Company	3	2	5
Varteg Hill—Kenricks and Co.	5	0	5
Blaenafon—Hills and Wheeley	4	0	4
Beaufort—Kendal, Bevan, and Co.	3	1	4
Clydach—Frere and Co.	3	0	3
The Race—C. H. Leigh	1	2	3
Carried forward	74	16	90

	No. of Furnaces in blast.	No. of Furnaces out of blast.	Total.
Brought forward	74	16	90
Pentwyn—Hunt, Brothers, and Co.	2	0	2
Coalbrook Vale—Brewers	1	1	2
Blaina—Jones and Co.	2	0	2
Yniscedwin—Crane and Co.	2	0	2
Maesteg	2	0	2
Pontrhyd y Ven—Reynolds and Co.	2	0	2
Vigors	2	0	2
Pentyrch—R. Blakemore	1	0	1
Gadlys—Bryant	1	0	1
Ryddry	0	1	1
Cefn Crubur	1	0	1
TOTAL	90	18	108