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MALLEABLE CAST IRON

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BY

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M.I.MAR.E.

SECOND EDITION, REVISED

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PREFACE TO THE FIRST EDITION.

The subject of this work is one that has hitherto been neglected in our technical literature, and the following pages have been written in response to numerous enquiries for reliable information concerning the characteristics of the material and the process of production as carried out in this country.

Under the *nom de plume* of "P. I. Giron" I have already contributed various articles on the subject to the *Mechanical World* and the *Practical Engineer*, and to the Editors of these well-known journals I am indebted for encouragement and also for permission to make use of some of the information that has already appeared in their columns.

I take this opportunity of thanking many friends, engineers and ironfounders, for aiding me with useful suggestions. The excellent photographs of typical Pig Irons (S. C. M. brand) were supplied by Mr. F. F. Sharpe, Wolverhampton, and the accompanying analyses by the Seaton Carew Iron Co., West Hartlepool.

S. J. P.

Leicester, 1908.

PREFACE TO THE SECOND EDITION

Owing to the progress that has been made in malleable iron-founding since the first edition of this book was issued, I have considered it advisable to revise the contents so as to include information concerning the more modern and scientific methods of production, thus bringing the book up to date and adding considerably to its practical value. The section on Mixing by Analysis is based on successful experience in this system of mixing metals, and in preparing the section on Heat-measuring Instruments I am indebted to the Cambridge Scientific Instrument Co., Ltd., for reviewing the manuscript for suitable illustrations.

S. J. P.

London, 1919.

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MALLEABLE CAST IRON

INTRODUCTORY

A WELL-KNOWN authority on malleable castings has said: "There is really little information available outside of the foundries most interested, and it may as well be said also, very little within. The founder is not going to increase the difficulties in his sales if he can help it, and the inspecting engineer, not being able to check the process from his own understanding, cannot act as intelligently as he really should."

There is a deal of truth in the statement, and it is probably owing to the general ignorance on the subject that malleable cast iron is frequently condemned as being unreliable. As a matter of fact, it is as reliable as any other metal or alloy, provided always that due regard is paid to the circumstances under which it is produced. So little is this understood, however, that it is not an unusual thing for people to send ordinary grey iron castings to be "made malleable."

There is practically no branch of engineering, using the term in its widest sense, in which it cannot be used to advantage. It is rapidly superseding steel for many purposes where steel was formerly considered indispensable; and although a lingering spirit of conservatism still regards it with suspicion, and hinders its more general adoption, there is every reason to believe that before long it will take a higher place than it now occupies in the somewhat limited list of materials that the engineer has to draw upon.

The use of cast iron in this country dates from the fourteenth century; but it was only towards the latter end of the sixteenth century, during the progressive reign of Queen Elizabeth, that ironfounding became an established industry, and although it may be assumed that in the meantime experiments were carried out with a view to producing a softer and more ductile iron with equal facility, it was over one hundred years afterwards that the problem of producing a malleable iron casting was solved.

The credit for this must be given to the famous French chemist Réaumur, the inventor of the system of thermometer graduation which bears his name, and it was in 1722 that he announced his discovery that by heating iron castings packed in red ore the iron was softened much more rapidly than by any other means.

For nearly another century no further progress of development is recorded until 1804, when Samuel Lucas, a Sheffield ironfounder, took out a patent for "a method of separating impurities from crude or cast iron without fusing or melting it, and of rendering the same malleable and proper for several purposes for which forged and rolled iron is now used; and also by the same method of improving articles manufactured of cast iron, and thereby rendering cast or crude iron applicable to a variety of new and useful purposes."

According to the scanty information available it appears that the castings were packed in iron ore or metallic oxides ground to powder, "intense heat being necessary to effect a union of the carbon with the ore or other packing." From this it will be seen that Lucas actually patented the process discovered by Réaumur nearly a century earlier.

A few years later Seth Boyden, an ironfounder of Newark, New Jersey, U.S.A., working on information he had received from England, succeeded in producing malleable castings from American pig iron, and although his process was practically the same as that of Lucas, the quality of castings was different owing to the native pig iron from which they were made being practically free from sulphur.

At this time the malleable castings made in both countries were small, and when larger work was attempted the annealing was still found to be a delicate operation, easily affected by slight variations in the quality of the pig iron, while the high contraction of the most suitable pig irons caused shrinkage flaws that could not be eliminated by methods then known to founders. From then until near the end of the nineteenth century progress was slow and tentative. Metallurgists were either not consulted, or were not interested, and developments made were carried out by experiments conducted by rule of thumb and guesswork.

For many years the production of malleable castings was confined to small and comparatively unimportant details, and the possibilities of the material were neither appreciated nor exploited as they should have been. One great hindrance to the progress of the industry was the inordinate jealousy between firms engaged in the business, who covered the process with an absurd cloak of mystery and fiercely resented friendly offers of outside assistance in improving their methods, and incidentally the quality of their castings. With the memorable cycle boom there came a huge demand and a good market for malleable castings suitable for the trade. Naturally prices soon rose and many new malleable foundries were started; but the castings on the whole were far inferior in quality and not sufficiently reliable, and the amount of castings scrapped and returned to the makers soon became so excessive that many had to shut down. Very few firms could be relied on to produce castings of uniform quality, and consequently the demand soon exceeded the supply. Some of the larger cycle firms set up their own foundries, and under the supervision of skilled metallurgists, some of whom were imported from the continent, the production of malleable castings on a more scientific basis was justified by a great improvement in the quality and reliability of the material. It is true that strict secrecy was still maintained regarding the actual details, and to outsiders very little information was available; but with the spread of technical education, and the independent investigations of metallurgists at Sheffield and elsewhere, the walls of prejudice were broken down, and finally the works chemist became a necessity in places where he would previously have been regarded as an intruder. With the development of the motor car industry the utility of malleable castings became still more evident, and is now appreciated at its true value, which in an unprecedented demand for munitions of war was at once recognised and made use of to the fullest extent.

In one respect progress has lagged somewhat, and that is in the melting process. Speaking generally, the methods in use in this country are behind those in vogue in the United States, where probably 90 per cent. of the world's output is produced. This preponderance is due to the greater popularity and consequently wider application of the material, and the readiness with which the American ironfounders adapted themselves to the demand by specialising on a large scale to ensure a rapid and constant supply of castings to their customers.

In Great Britain a row of crucible furnaces, a cupola, or, in a very few places, an air furnace, constitutes the entire melting equipment. Under these conditions the output is necessarily small, and annealing ovens are kept open for several days until there is a supply of castings sufficient to fill them. This means that in most cases the customer would have to wait ten or fourteen days for a small batch of castings—or even a single casting—that should not take more than five or six days to deliver.

Although the crucible method of melting is still adopted very largely in this country, in America it has long been discarded as being too slow and costly, and even the cupola, in spite of its low cost of upkeep, is not considered to be as successful as the air furnace for the production of castings of good quality, while in large foundries they have adopted open-hearth furnaces similar to those used for steel melting. These huge furnaces are run continuously day and night all the year round, except for necessary repairs at intervals, and as this ensures a steady supply of castings to the annealing ovens there is no waiting and consequently no cause for complaint or prejudice on the part of the customer.

Efforts directed towards reducing the cost of melting have so far met with but little success. For ordinary purposes the cupola still remains the cheapest and most economical furnace, the cost of repairs and upkeep being much lower than that of the open-hearth and reverberatory furnaces, and the rate of melting is much quicker. Most recent experiments made with a view to greater economy in the consumption of fuel have been concerned with crucible furnaces. Oil and gas have been tried as substitutes for coke, and with some success so far as actual melting is concerned, but the intense heat generated by these fuels has such a destructive effect on the crucibles and the lining of the furnaces, both expensive items, that the saving in cost of fuel is largely discounted. This is unfortunate, since it has been proved conclusively that when iron for malleable castings is melted in a gas or oil furnace, and especially the latter, the castings are much sounder and more free from impurities than those obtained by any other method, and if properly annealed they possess a tensile strength and ductility combined that cannot be equalled by any other process. It is therefore extremely probable that future improvements in melting and greater economy in fuel will be reached along those lines. The most economical crucible furnace of this type at present is the regenerative furnace, in which the fuel is utilised and applied as in the open-hearth furnace. These furnaces hold five or six crucibles each, and are constructed with gas and air ports through which the products of combustion sweep round the crucibles, first in one direction and then in another, the direction of flow being reversed every twenty minutes or so. The best results are obtained when there is a sufficient number of furnaces to justify the installation of a fairly large gas producer, since they are more economical than the smaller ones, but even then the cost of repairs to linings, and the renewal of crucibles, is excessively high in most cases.

Malleable cast iron is really a form of steel, and not, as is sometimes supposed, of wrought iron. In other words, it is cast iron of a special composition from which a certain amount of carbon has been extracted; this is practically a definition of cast steel, and the castings have many characteristics in common. That part of the process which is known as annealing is misnamed; annealing can be accomplished by the action of heat only; but when the castings are packed in ore, or any other suitable decarbonising material, whether the object is precipitation or partial elimination of the carbon content, the process becomes one of conversion. The heat is only necessary to open out the structure of the casting so as to allow the oxygen to penetrate, and the carbon, in the form of carbon dioxide, to escape. As, however, the term "annealing" is in general use, it has been retained for the purposes of this work in order to avoid misunderstanding.

Many failures have been traced to the following causes:—

(*a*) Treating the material as for wrought iron or steel and attempting to forge or weld it. The castings are not amenable to this treatment, although they can to a limited extent be hammered or swaged in order to slightly reduce the area or to elongate a plain casting that is a trifle short of the required dimension, but even this must be done with great care, preferably with a succession of light blows, as it soon causes disintegration, and the quality of the iron rapidly deteriorates under the operation if prolonged or roughly carried out.

(*b*) Heating the castings for hardening or other purposes and cooling off by quenching suddenly in cold water. The sudden strain thrown on the crystalline structure of the casting by this treatment causes it to "shatter," *i.e.*, to split open in all directions, but chiefly in the direction of the long axis of the crystals. These cracks are sometimes very minute, and not discovered until failure occurs under working conditions, when they are attributed to other causes. For any other operation for which it may be necessary to heat the casting it should be allowed to cool slowly buried in ashes, dry sand, or annealing ore.

(*c*) Subjecting the castings to a temperature beyond the critical point at which the nature of iron undergoes a complete change, by which a soft, ductile casting is changed into a stronger but harder one, causing difficulty in machining and otherwise rendering it unsuitable for the purpose for which it was originally intended.

The critical temperature referred to has not been fixed definitely, there being a slight difference in the result obtained by different observers; but as near as can be ascertained it is about 1,250° F.

FOUNDRY PRACTICE

Melting

To a casual onlooker a moulding shop devoted to the production of malleable castings presents an appearance identical with those in which grey iron castings are made, but although the principles of ironfounding apply equally to both processes there are essential differences in the mixing and melting, the preparation of moulds and cores to suit the special characteristics of white iron, and the gating and feeding of the castings; and while for grey iron considerable latitude is permissible in all these particulars, a more precise, methodical system is indispensable for the production of malleable castings; and this is principally the reason why moulders experienced in grey iron work are not much use in a malleable foundry, where any disregard of fundamental principles is fatal to success.

For commercial purposes the various grades of pig iron are numbered 1 to 8. Nos. 1 to 4 are grey iron of varying degrees of structure, No. 1 being the softest; these are all used, singly or in different proportions, in the production of ordinary castings. The remainder, Nos. 5 to 8, are only suitable for malleable castings, and are better known by classification of names, thus :—

No. 5	Grey
No. 6	Soft mottled.
No. 7	Hard mottled.
No. 8	White.

This nomenclature is derived from the appearance of the fracture, the "mottle" being due to the appearance of the graphitic or free carbon, the quantity of which diminishes until in white iron the carbon is almost wholly combined.

The following analysis of these pig irons is derived from various sources:—

	C.C.	G.C.	Si.	Mn.	S.	P.
Soft mottled .	·67 to 1·82	2·64 to 2·93	1·50 to 3·06	·60 to 1·03	·145 to 1·14	·93 to 1·50
Hard mottled	1·08 to 1·30	1·11 to 2·90	·70 to 2·17	·55 to 1·33	·16 to 1·48	1·16 to 1·48
White . .	2·46 to 3·10	·66 to ·90	·50 to 1·12	·55 to 2·72	·180 to 2·52	·91 to 1·18

To meet special requirements, and for high class crucible work where absolute uniformity is desirable, there are three intermediate grades of pig iron, known as grey, medium mottled, and spotted white, so that the founder has the choice of six varieties, any one of which may be used instead of a mixture of two or more of the others. In this way the nature of the resultant casting is always the same, and is consequently amenable to exactly the same conditions of temperature and duration of the anneal; the process of manufacture is thus to a certain extent standardised; this would not be possible if a mixture were used, for although the contents of each kind of pig iron may be known, the analysis of the combined metal will show considerable variation. In the selection of iron preference is always given to that which contains the lowest percentage of sulphur, for reasons already stated, and the fracture of the pig should present a clean, sound structure. In some classes of iron there will be found flakes of a brownish material, resembling spiegel in appearance and of a very undesirable character. It is more refractory than the iron in which it is found, and in consequence is to be found in the subsequent castings, where it is a source of weakness, and a casting of uniform thickness tested to destruction will invariably break at this point under a strain that would not materially affect a sound casting. Needless to say, iron of this description is not used except for a low class of work in which homogeneity is not a first consideration.

The pig iron in general use is made in two sizes, known as medium and small, being defined by the area of the section. These have been adopted principally for the convenience of the crucible melting, the capacity of a crucible being unsuited to the larger sections.

The three methods of melting employed in this country are crucible, cupola, and air furnace. The crucible method was the one first adopted for malleable castings, the trade at the time being chiefly confined to the manufacture of smallware, such as buckles, door-keys and lock tumblers. As the demand for larger castings became general this method soon proved inconvenient and expensive, and founders turned to the cupola as being more economical and better suited to cope with the demand. This did not, however, improve the quality of the work; on the contrary there was a perceptible depreciation. A few founders having an exceptionally large output made use of the air furnace, which is superior in effect to the cupola, although it is not nearly so economical in working, and for this reason the cupola is still the most widely used of all furnaces.

Up to the present time there is no method of melting which produces castings of such excellent quality as the crucible. The pot furnace shown in fig. 1 is used for this purpose. It consists of a rectangular cast iron casing resting on a stool which supports a lining of firebricks and also the firebars as shown; these are of wrought iron 1¼ inches square. A heavy cast plate fits inside the casing at the top and rests on the bricks, and the square hole in the centre through which the crucible and fuel are introduced is covered with a loose lid which has a ring fitted to facilitate removal. The whole arrangement is sunk in a pit so that the top is level with or only slightly raised above the floor line; this is for convenience in placing and withdrawing the crucibles. The ashpit is covered with a grating which fulfils the double purpose of a

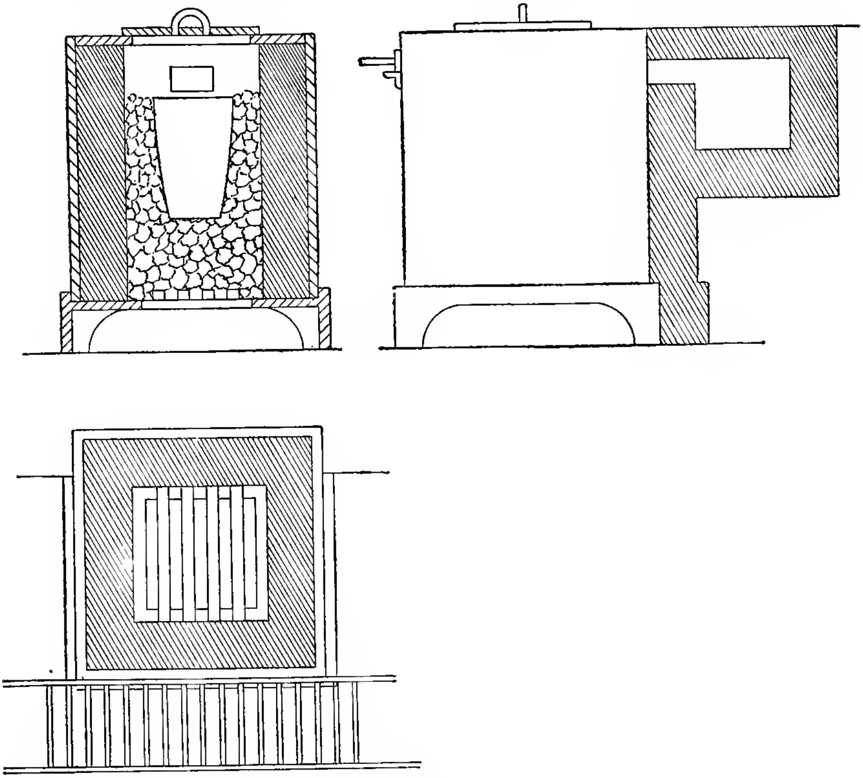


Fig. 1.—Crucible or pot furnace.

working platform which allows the dirt and skimmings to fall through before the crucible is taken to the moulds.

The working of this furnace is very simple. A fire is laid at the bottom and covered with 12 inches of good, hard foundry coke, free from sulphur (the latter condition is absolutely essential to produce really good malleable castings), and the lid of the furnace is closed in order to ensure a keen draught and ignite the coke to incandescence. The crucibles used are of plumbago, and are identical with those used by brass-founders. They vary in capacity, but the most useful size holds about 50 lbs. of melted iron. The charge consists of refined pig iron (small), broken into pieces about 8 inches long, and hard scrap, gates, runners and small feeders, broken into suitable pieces.

It may be said that no two foundries are agreed as to what constitutes the best mixtures for different kinds of work ; it is a matter on which personal opinion is sharply divided, and each founder claims for his "special" mixture virtues possessed by no other. The following mixtures have invariably given satisfactory results, and are typical of all the others, and if they have any special merit it lies in the addition of soft scrap, the inclusion of which will be regarded by many as rank heresy, but the efficaceous results of which are undeniable. The table is divided into two classes, general and special; for the former it is necessary to use up the hard scrap that would otherwise accumulate, but for the latter it is left out to ensure a uniform quality of iron :—

Class or work.	General.	Special.
Very thin light castings . .	Soft mottled 4 Hard scrap . 1	Grey or Soft mottled
Light castings, not less than ¼″ thick.	Soft mottled 3 Hard scrap . 2	Soft mottled

Class or work.	General.		Special.
Sections up to 1¼"	Soft mottled	2½	Medium mottled
	White . .	1	
	Hard scrap .	1½	
	or		
	Hard mottled	3½	
	Hard scrap .	1½	
Sections up to 2¼"	Soft mottled	2	Hard mottled
	White . .	1	
	Hard scrap .	2	
	or		
	Hard mottled	3	
	Hard scrap .	2	
Sections up to 3½" and over .	As above.		Spotted white

10 per cent. of soft scrap to be added to each charge.

As soon as the layer of coke at the bottom of the furnace is burnt through and has reached a state of incandescence, more coke is added until the bed on which the crucible is placed is sufficiently high to bring the top edge of the crucible level with the centre line of the flue. The space surrounding the crucible is now packed with coke, tightly rammed down, the lid is laid over the hole and the edges luted with wet sand to prevent the admission of cold air, which would be detrimental to good draught.

The first charge consists of pig iron only, and when this has begun to melt, which will be in about an hour from the time the crucible was put in, the lid may be removed and a further supply of pig and scrap added; before doing this it will be necessary to raise the crucible to its original position, as it will have sunk as the coke burns away. By gripping the crucible with the tongs and lifting it the coke surrounding it falls underneath and forms a fresh bed, and more coke is then packed round the sides as before; the furnace is then sealed up again for half an hour, at the end of which more coke and iron are added; this is repeated half-hourly until the crucible is almost full of molten iron in a highly incandescent state. Under normal conditions this takes about three hours, and when once the iron is thoroughly melted it should be withdrawn immediately, as if left too long in the furnace it gets burnt and is difficult to anneal. It is necessary to bring the iron to a very high temperature to ensure a thorough mixing of the different qualities, and consequently this must be done even if a "cool" metal is required for castings of heavy section, as it can be allowed to cool down after withdrawal.

There are other special forms of crucible furnaces. Some of these are heated by gas and in others the combustion is assisted by an air blast in the ashpit. On the whole, however, they have no outstanding advantages over the one described, which, for all practical purposes, has not yet been superseded. Two things must be borne in mind in working these furnaces. The fuel must not be allowed to come in contact with the molten iron, and for very best work the crucible should be fitted with a lid of fireclay, luted to prevent the iron from absorbing any of those deleterious gases for which it has an affinity. Where a number of furnaces are required they are placed in a row parallel with the main flue and opening into it. Some of the large firms in this country who make a speciality of high-class work have as many as fifty or more arranged on this system. A space of 6 inches should be allowed between each furnace to facilitate repairs and, if necessary, removal without interfering with those on either side. Dampers are fitted behind each draught hole, so that only the furnaces in actual operation are in communication with the main flue. The necessity for this will be better understood when it is stated that the furnaces are worked continuously. As soon as the crucible is withdrawn the fire-bars are cleaned, a fresh bed of coke made up, and the same crucible put in again as soon as possible. The lid should be put on to retain the heat in the lining of the furnace, and by doing this the subsequent " heats " will melt the iron in about two hours, so that by charging the furnaces in the early morning it is possible to get five heats a day. The life of a crucible under these circumstances is from thirty to fifty heats according to quality and care in handling.

Unless the crucibles are properly annealed before being put in the furnace for the first time they will invariably crack or chip badly on being exposed to the intense heat. As a precaution against this they should always be stored in a warm, dry place, such as in a core stove or on racks immediately over the furnaces. A few hours before they are required for melting purposes they are put over a slow fire and filled with hot ashes. This latter precaution is often neglected, with the result that the difference in temperature between the outside and the inside of the crucible causes unequal expansion and subsequent chipping which the process is intended to prevent. Another good way is to place the crucible over the fire with the bottom upwards, thus warming up the inner and outer surfaces simultaneously. These are methods adopted when the crucible is required for a furnace already heated up, but when circumstances will allow, the best way is to place the crucible in a newly-lighted furnace and allow both to heat up gradually together. Plumbago is a bad conductor of heat, and the more slowly the preliminary heating is effected, the less the likelihood of chipping or cracking. The life of the crucibles will be considerably prolonged if immediately after use they are put into a drying furnace or other suitable place where the cooling down will be gradual. By carefully observing the foregoing rules, even with crucibles that have already been used, they will stand a considerably greater number of heats than would otherwise be the case. Some makes are more susceptible to sudden changes of temperature than others.

Although the cupola is not generally regarded as being entirely satisfactory for melting iron required for malleable castings, it is more extensively used than any other form of furnace in this country. It is economical to work, the cost of maintenance is comparatively low, and its efficiency as a melter is indisputable. The objections to its use are that, as the iron is in actual contact with the fuel, it absorbs any deleterious matter that may be contained therein, such as sulphur, etc., and also that, owing to the rapidity of the melting, it is possible to burn the iron and so produce hard finished castings.

The first of these objections is the most important one. It is difficult to obtain coke which is absolutely free from those impurities for which iron in a melted state has an unfortunate affinity, but by the exercise of a little discretion in choosing the fuel the resulting castings will be of a quality that will meet all requirements for "general work," and it is under this heading that the bulk of the castings produced are included.

The second objection may be overcome by systematically regulating the blast so that the iron does not melt too rapidly ; a pressure of 4 to 5 ozs. is ample, and this should always be checked by a pressure gauge on the blast pipe near the tuyere. In the present-day mania for "hustling" there is a temptation to melt as quickly as possible; but this is absolutely fatal to the production of good malleable castings. After the blast is turned on there should be an interval of twenty minutes before the iron is down, after which the blast may be slightly checked, being then regulated as the melting proceeds, so that the iron comes out just hot enough to pour into the lightest moulds without premature chilling, and the iron must be kept flowing as long as possible without stopping up, so as to preclude the possibility of burning or oxidising the iron accumulated at the bottom of the cupola. All ladles are to be well lined with a refractory mixture of red sand and fireclay (3 to 1) and thoroughly dried for some hours before use in a suitable furnace; for this purpose the muffle is generally utilised, as it is usually empty at the time, and the ladles can be kept hot until the moment they are required in order to prevent chilling the first iron tapped into them and the formation of a heavy "skull," as it is called. This is a shell of iron formed on the inside of the ladle, and is produced either by the ladle not being warmed up sufficiently, or by the molten iron being burnt or oxidised. When this happens it adheres to the sides of the ladle in such quantities as to considerably reduce the capacity, which decreases with each ladleful poured.

It is customary to use the first iron down for the heaviest castings, as the metal is not then quite as hot and fluid as it will be later. The term fluid is used comparatively, as the metal flows more freely from the tapping hole than grey iron. It is whiter, and falls into the ladle with a distinct splash, giving off a constant shower of sparks, this being continued for some time in the ladle, and the metal must not be poured until it has subsided; when for castings that are thin and likely to chill or set quickly it must be poured at once, keeping the gate full until the metal reaches the top of the feeder. For all castings not less than 1 inch in thickness at the lightest section the moment for pouring is judged by the appearance of the surface of the metal. This has another peculiar characteristic which distinguishes it from ordinary cast iron, for when first drawn from the furnace the metal has the appearance of boiling gently; there is no ebullition, but the surface has a marbled appearance which is constantly changing—it is as if two distinct metals were in chemical conflict. This activity gradually ceases, and the metal is poured, quickly and steadily as soon as it becomes quiescent, any delay will result in cold-laps and mis-run castings. For all classes of work the pouring is stopped as soon as the metal is level with the top of the mould; a shovelful of floor sand is then thrown on the gate and pressed down with the foot;

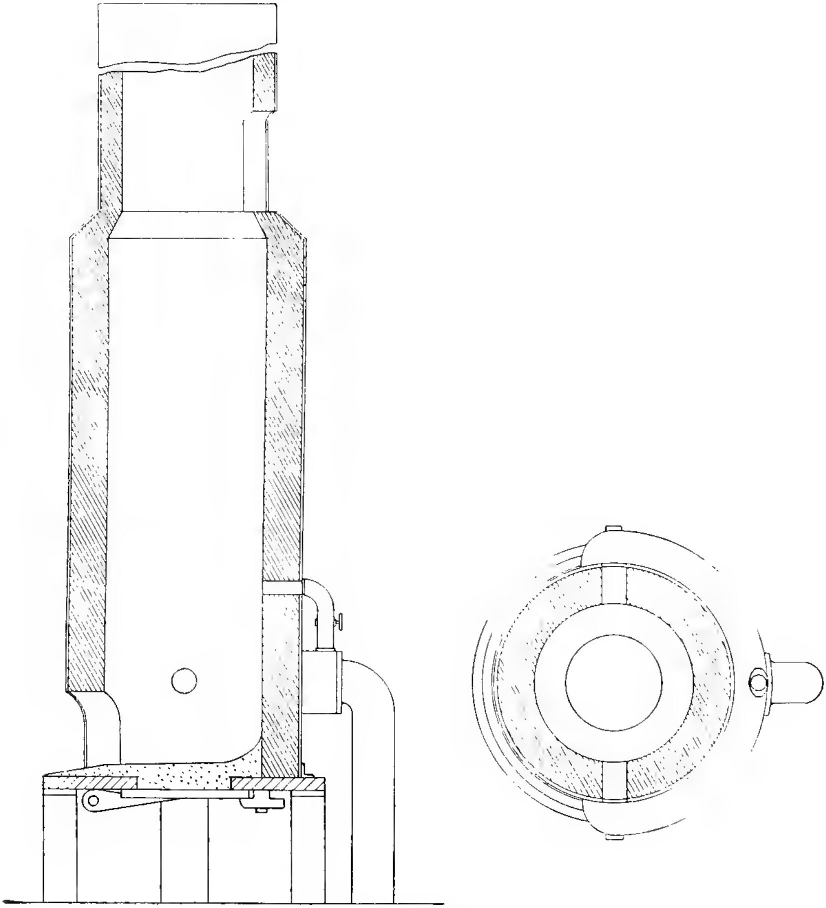


Fig. 2.—Cupola.

this is to prevent regurgitation owing to the back pressure of the feeders, which are gradually filled up with hot metal from a hand ladle. No time should be lost in doing this, or a crust will be formed on the surface which will prevent the feeder from acting properly.

The cupola is a furnace which admits of little variation in design, yet it is so susceptible to minor influences that it is next to impossible to standardise the various items which go to make it effective. The ratio of height to the diameter, of iron to fuel, of blast pipe area to tuyere area, of blast to charge, are all governed by the "personal element," and also by locality and atmospheric conditions. The same cupola, worked by different furnacemen, each of whom is an experienced melter, will give widely different results even with the same quality of pig iron and fuel, and the difference in the behaviour of the metal when the barometer is high and when it is low is sometimes perplexing to a degree. Under these circumstances the cupola described here and shown in fig. 2 is only typical, and though it has always given satisfaction it might possibly not do so under different conditions. The principal dimensions are:—

Height of charging door above bottom	12 feet
Height of tuyeres above bottom ...	15 inches
Diameter outside	3 feet 6 inches
Diameter inside	2 feet 6 inches
Diameter of blast pipe	8 inches
Diameter of main tuyeres	4½ inches
Diameter of monkey tuyere	2½ inches
Pressure of blast	4 to 5 ozs.
Weight of iron melted per hour ...	2 tons
Coke consumed per ton of iron ...	4 cwts.

The blast is supplied by a positive rotary blower, and the monkey tuyere can be shut off by means of a butterfly valve when not required.

The lining from the bottom plate up to the shoulder below the charging door consists of best quality firebrick blocks, moulded to correct size and shape. They are carefully laid without the use of a trowel, each block being dipped first in a bucket of clean water and then in a very thin mixture of fireclay and laid in its place. The efficacy of this method will be appreciated when it is stated that a lining laid in this manner will outlast three or four linings laid in the ordinary way with about $\frac{3}{8}$ inch of thick fireclay between each brick.

The deterioration and destruction of the lining takes place chiefly round the melting zone, in this case about 18 inches above the level of the tuyeres, and this must be patched up daily with some refractory material such as gannister, or a mixture of fireclay and ground firebricks. Fireclay alone is useless for the purpose, as having little or no cohesiveness it crumbles and falls away under the influence of heat.

The tuyere blocks are of ordinary cast iron, and are not secured to the shell in any way, being laid as one of the bricks, and as the inner end is 2 inches away from the inner circumference of the lining, it does not burn away, and therefore need not be protected or cooled in any way.

A brisk fire is kept burning on the bed for twenty-four hours after lining, and the cupola is then ready for melting.

A drop bottom is provided, and this has many advantages over the old-fashion plate bottom, not only because of the facilities it offers for cleaning out at the end of the heat, but it also renders it more accessible for repairing, and owing to the greater ingress for air the furnace cools down much quicker, and can be sooner got ready for use again. It is sometimes objected that rapid cooling is a disadvantage, as being liable to set up contraction strains and crack the lining; but this objection does not hold good in practice, sudden strains being prevented by leaving the mass of coke and slag dropped at the end of the heat in a partly quenched state, so that all air entering the cupola for the first two or three hours is heated. The drop bottom is hinged beneath the breast door, so that it acts as a screen when knocking down the slag through the breast door, and also as a measure of precaution in case of accidental dropping during the melting, in which case the molten iron is prevented from splashing amongst the moulders engaged in filling their ladles.

The bottom being in position, secured by the trigger, a bed of well-rammed floor sand is made up on it about 3 inches thick at the centre, sloping from every direction towards the centre of the breast door, where the tapping hole will be made. About four hours before the blast is put on, a good coal fire is started, and as soon as this burns freely it is covered with a layer of coke about 1 foot thick; the breast opening is then filled in with suitable pieces of coke, a piece of 1½-inch gaspipe being laid on the bottom to form the tapping hole. The interstices are then filled with floor sand, well damped to make it cohesive, applied by throwing; the space round the pipe is packed with stiff fireclay, and the breast door or plate put in position; this does not fit close up to the shell, but stands back about 2 inches, leaving sufficient space for a further supply of floor sand to be rammed down to effectually seal the opening. The pipe is now withdrawn, and the aperture made wider at the front so that it will firmly hold the stopping.

A further supply of coke is now added through the charging door until it reaches about 18 inches above the level of the tuyeres, and when this has burnt through the charges are put in the following order: Pig iron, scrap, coke—the proportion being 6 cwts. pig and scrap to 1¼ cwt. of good hard coke;

these are laid alternately until the charging door is reached; a handful of limestone, broken small, is thrown on each charge of iron, and is the most efficient flux.

The mixtures suggested for charging the crucible furnace will also apply to the cupola, and the weight of each charge of iron includes the addition of 10 per cent. clean, sound, annealed scrap. It was at one time considered that the latter had an injurious effect on the castings, and it was rigorously excluded; the defects ascribed to it were probably due to other causes, as it has been found in modern practice that the addition of a limited proportion sensibly improves the ultimate ductility of the material, while not materially affecting the tensile strength. As the melting proceeds the amount of coke in each charge is gradually reduced, and at the end of two hours less than 1 cwt. will suffice.

Unless for experimental purposes, nothing else must be put into a cupola used for malleable cast iron, or the results, although perhaps not apparent in the casting, will ultimately affect the character of the annealed article to a considerable extent, and for this the quality of the pig iron may be unjustly blamed. It is necessary to emphasise this point, as there is a temptation to take advantage of the apparent economy and run in a few charges of common iron for moulding boxes, patterns, etc. If this is done first it will affect the whole of the "malleable" charges put on afterwards, and if put on at the end the castings, instead of being grey iron, will be mottled, or even in many cases white, and wholly unsuitable. Where there is only one cupola a separate day should be assigned to such common iron castings as may be required and to making annealing pans, the cupola being thoroughly cleaned out before using it for malleable castings again.

The importance of using a supply of good coke is imperative, as it is absolutely necessary for the production of good ductile castings that the iron, in addition to containing the smallest percentage of sulphur, should also be kept from contact with that deleterious matter during the process of melting. Good coke can always be judged by its appearance, being a bright metallic grey, free from the iridescent colours that proclaim the presence of sulphur; it is hard, and will not easily crush under the weight imposed upon it in the cupola, while the pieces are larger and free from dust or breeze when broken, and permit a free blast through the cupola which cannot be obtained with small, cheap fuel or composite coke; gas coke must not be used under any circumstances; not only is it too soft and ashy, but it generally contains an intolerable amount of sulphur.

A good idea of the quality of the iron may be obtained by watching its behaviour as soon as it is tapped out. If the marbled effect previously alluded to is in the form of large, bold curves it indicates a hard mixture, and *vice versâ;* small convolutions are a sure sign of soft metal, so that for important castings, if there is any doubt as to the suitability of the metal or the nature of the charge, it is advisable to tap a small quantity into a hand ladle and note the appearance of the surface.

The use of the air furnace for the production of malleable iron castings in this country is extremely limited; probably there are not more than half a dozen in operation at the present time. The objections to its more general adoption are that it is more costly than the cupola; the cost of maintenance is higher, and only a large output will make it commercially practicable, and while the superior quality of the castings up to a certain size is indisputable, the cost of production calls for a higher selling price than manufacturers generally are prepared to pay. Under these circumstances, and considering the fact that the difference between air furnace and cupola castings made from European pig iron is not nearly so marked as in those made from American low-sulphur pig, this form of furnace is not likely to become popular in this country; but as it comes within the scope of this work, some description of the furnace and its working is necessary.

Fig. 3 shows what is known as the camel-back type of furnace, and it will be seen that it is only a variation on the old-fashioned puddling furnace. It is built of firebrick and well braced together with buckstaves and tie rods, and is constructed with a chimney at the end furthest away from the firegrate to carry away waste gases and promote a keen natural draught, upon which the air furnace depends for good melting. To prepare the furnace a bed of 3 or 4 inches of sand, well rammed down, is made up on the bottom, which slopes downwards towards the chimney end, where it is dished out to form what is called the bath, to receive the molten iron. The entire charge for the heat, pig and scrap, is placed on this bed just behind the bridge, this being the hottest part of furnaces of this type when at work; the charging door is then sealed up and the fire started, the fuel for which should be as free from sulphur as it is possible to obtain it; any good bituminous or long-flaming coal will do provided it does not leave too much ash to choke the draught through the firebars. As it passes over the charge the flame is deflected downwards, so that the iron after melting is kept hot in the bath until tapping takes place; this is done at the hole shown at the bottom of the bath.

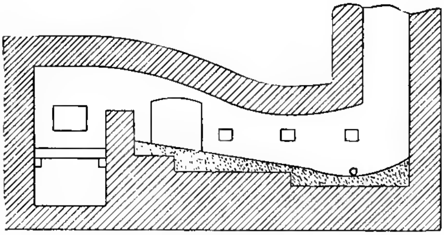


Fig. 3.—Air furnace. Camel-back type.

The charge begins to melt freely about two hours after the fire is started, and is ready for tapping in from five to six hours, according to the nature and weight of the charge. During the whole period of melting the fire must be carefully attended to so that the iron will melt regularly and continuously until it is all down. It is considered good practice to keep up the heat and allow the iron to remain in the bath for at least half an hour after the last of the charge is melted, in order to ensure a thorough mixing of the various contents, and arrangements are made so that the whole charge may be drawn off without stopping up. The rate of melting is watched through the observation holes, and these are opened as seldom as possible, to prevent checking the draught by the admission of cold air. In charging the pig iron the alternate layers are laid crosswise, and not touching sideways, so that the products of combustion may have free play to melt quickly and evenly.

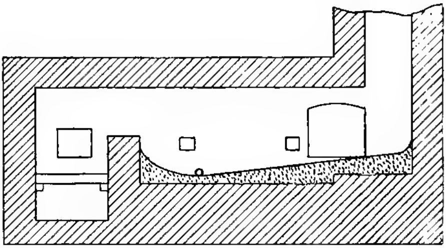


FIG. 4.—Air furnace. Straight roof type.

Fig. 4 shows another type of air furnace in which the charge is introduced at the bottom of the chimney, and the bath is made up immediately behind the bridge; the conditions of working are similar to those already given, and neither type can be said to possess any particular advantage over the other. Each has its its votaries, and local conditions may possibly have something to do with choice in the matter. In each case the area of the firegrate is usually about four times that of the chimney or flue. Like the cupola, the air furnace requires patching daily at those parts where the cutting action of the gases is most destructive, which is generally along the slag line. The sand bottom is also repaired, not necessarily renewed, for each heat. The ratio of coal consumed to iron melted for the entire heat averages about 1 to 3; it is seldom less than 1 to 4, and this ratio can only be obtained under the most favourable circumstances. The chief advantages of the air furnace over the cupola are that it produces a larger body of metal that can be tapped at one operation, and owing to the fact that the iron does not come in contact with the fuel while melting, it does not absorb any deleterious matter, but on the contrary it is subjected to a refining action which, amongst other things, reduces the amount of sulphur content, thus giving a stronger iron than it would be possible to produce in a cupola. These are eminently desirable qualifications, but for the general run of malleable castings they are not imperative, as the weight of a single casting seldom exceeds 12 cwts., while the amount of sulphur abstracted from European pig irons is not sufficient to justify the increased cost of production by this means, except for special classes of work, and as the demand for these is a limited one, the output is chiefly confined to crucible furnaces, in which it is produced under similar conditions and with better results.

MOULDING

Any of the recognised moulding sands which are in general use in this country are suitable for malleable castings, and it is considered good practice to use plenty of new sand in the facing, which should be freshly mixed daily. Excessive moisture, both in this and in the black sand used for filling, should be avoided, only just sufficient being added to give the necessary cohesiveness, which is tested by squeezing in the hand. Wet sand will pack much closer than dry; this reduces the porosity or permeability and causes blowholes. On the other hand, if too dry it is difficult to work, being too weak to withstand drawing the pattern, especially if any thin walls of sand form part of the mould, while during the pouring of the metal patches of the sand will become detached and cause scabbing.

The amount of coal dust to be added to the facing varies considerably in different foundries, but for a medium class of work the following is reliable :—

New sand	10 parts
Old sand	6 parts
Coal dust	1 part

For light castings $\frac{1}{2}$ part coal dust is sufficient, and for heavy work the proportion is increased to $1\frac{1}{2}$ or 2 parts, the latter being used for thick, solid castings. For thin castings, not exceeding $\frac{3}{16}$ inch in thickness, it is better not to use any coal dust at the points furthest away from the runners, so as to lessen the risk of mis-running.

As the use of plumbago is only intended to give a clean surface, its use in a malleable foundry is restricted to such work as pipes, high pressure fittings, pistons, etc., that have to undergo minute inspection before annealing. Whether it is used or not will make no difference in the appearance of the finished casting after it has been annealed.

The method adopted for feeding grey iron castings in order to prevent the formation of shrink-holes consists in working or ramming the semi-fluid metal by means of thin iron rods introduced into the mould through the risers or other special openings, the operation being continued until the metal has set to such an extent that it is no longer possible. This process is not applicable to malleable castings on account of the rapidity of cooling and the considerably higher rate of contraction. There seems to be much confusion of ideas as to the meaning of the terms "contraction" and "shrinkage," and they are often used synonymously by writers on foundry matters, with the result that many of their statements are somewhat vague and misleading. The terms are interdependent, but are not interchangeable. By "contraction" is meant the reduction in the linear dimensions of the casting due to cooling; in other words, it is the difference between the dimensions of the mould, or pattern, and those of the casting. "Shrinkage" applies to the structure of the metal, and refers to the contraction of the crystals of which the iron is composed. During the period of cooling the crystals at the surface are the first to become fixed, and as congelation proceeds the others are gradually drawn away from the centre of the mass, leaving a cavity technically known as a shrink-hole, and it is to prevent the formation of this cavity that feeding is resorted to. In malleable iron castings this is done by means of a large head of metal situated immediately over the highest point of the part or parts of the casting where shrink-holes are most likely to form, or where, owing to a difference of the

Malleable Pig Iron.—Grey.

Approximate Analysis.

Graphitic carbon, 2·90 per cent. ; combined carbon, ·92 per cent. ; silicon, 1·35 per cent. ; sulphur, ·121 per cent.; phosphorus, ·05 per cent.; manganese, ·40 per cent.

section, and consequently in the rate of cooling, one part of the casting is likely to pull apart from the other. The fluid metal in the head or feeder flows by gravity into the interior of the casting and replaces that which has been drawn towards the surface, giving a sound section not attainable by any other means. In some cases, where there is a danger of pulling owing to abrupt change of section, it is not always possible to place a feeder at the desired point, and then it becomes necessary to make use of a chill. This is a block of cast iron shaped to the outline of that part of the casting to which it is applied, so that when the fluid metal comes in contact with it cooling proceeds rapidly, and there is then not sufficient difference in the temperature of the section to cause a flaw at the junction. Chills are only used for small castings or for larger ones in which the section is comparatively thin; for heavier work they aggravate the cause of shrink-holes, and feeders must be used.

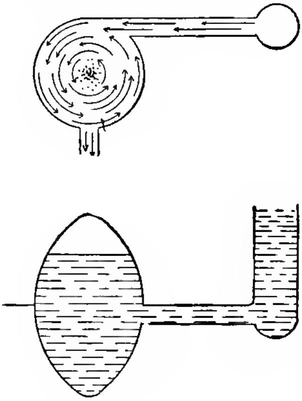


FIG. 5.—Spinner—correct.

The use of the "spinner," or "whirling gate" as it is sometimes called, is not a universal practice in malleable iron founding, and this probably accounts for the number of dirty castings that are sent out, as it is undoubtedly the best way of securing the admission of clean, sound metal into the mould. The action of the spinner is shown in fig. 5, in which it will be seen that the metal enters the circular space at a tangent, setting up a whirling motion and by centripetal force keeping all floating impurities in the centre, while in the meantime the clean iron is running into the mould. The runner leading into the mould must not be cut as in fig. 6, or the spinner will be inoperative, and the metal together with the floating impurities will be carried directly into the mould.

An alternative method of running clean iron is to make use of what are called fin-gates (fig. 7). These are formed by cutting a number of wide, shallow channels leading from a deeper one to the mould, the idea being to leave only sufficient space to allow the clean metal to enter while the passage of impurities is arrested. It is open to the objection that, as the passage is so restricted, the metal is prematurely chilled and therefore likely to cause mis-run castings; it is therefore only suitable for thin, flat castings where a spinning gate could not be conveniently introduced, and can only be used with very hot metal.

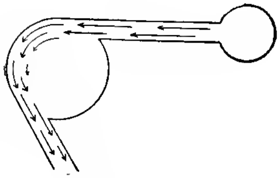


Fig. 6.—Spinner—incorrect.

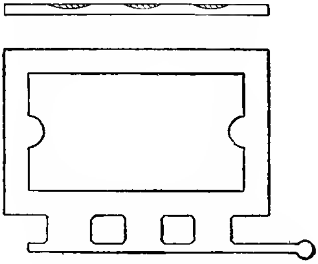


Fig. 7.—Fin-gates.

The many different classes of work done in malleable call for as many different methods of moulding, and as the weight of the castings varies from one quarter of an ounce to half a ton, it is obvious that what is suitable for one will not do for another. There is, however, one thing common to all methods, and that is, the necessity for feeding to counteract the shrinkage of the crystals.

Taking the lightest castings first, which include such articles as key blanks, hinges, light machine parts for typewriters, sewing machines, etc., these are usually made up into a spray, and are moulded on a plaster oddside by boys. To do this a number of metal patterns are made sufficient to fill a 10-inch by 8-inch snap flask. Each pattern has its own feeder, which comes between it and the gate, which runs down the centre of the flask; rapping holes are drilled or cast in the gate, and steady pins of smooth iron or brass wire are fitted for the purpose of giving an even lift when drawing the spray from the mould. The complete spray may be either cast all in one piece or have the various parts soldered together according to circumstances, and in any case it is finished off smooth all over with the file and emery cloth, and given plenty of taper or draught so that no dressing of the mould will be required (fig. 8).

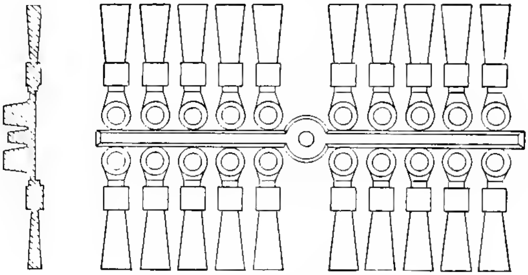


FIG. 8.—A spray of patterns.

The plaster oddside is made by first filling one half of a flask with floor sand, rammed down and strickled off level with the top; the spray is bedded down in this with the bottom upward and the sand dressed round it to form a parting line; a rough wooden box having sides 2 inches deep and 1 inch in thickness, through which a number of long nails are driven is placed over the flask, and quickly filled with plaster-of-paris mixed with clean water to the consistency of thick cream; this is allowed to set for thirty minutes, when it may be removed, the long nails acting as lifters to prevent the plaster from falling out of the box, and battens across the bottom take off the effect of ramming. The face of the oddside, which is a plaster cast of the top half of the spray, is scraped clean and trimmed with a sharp knife, and then varnished with three coats of shellac varnish, mixed with plenty of red lead; this gives it a smooth, hard surface and prevents the sand from adhering when rammed up.

To mould from this the oddside is placed on a bench with the spray in position, the bottom half of the snap flask is laid on it with pins fitting in sockets fitted to the box, and sufficient facing sand is thrown in to cover the spray, filling up with floor sand, the whole being rammed up by means of dollies or double-ended wooden rammers; the moulder uses two of these, one in each hand, using first the "peg" end, and finishing off with the flat end and a strickle. Flask and oddside are then turned over, and the latter is lifted off, leaving the spray in the flask, the surface is dusted over with parting sand, and the top half fitted on and filled with sand as before, the down gate is cut with a piece of thin tubing about 1 inch in diameter. The operation of moulding is then completed, and after the spray is taken out, the mould is laid on the floor and the flask removed. The method is remarkably expeditious, and so little skill is required that a boy of sixteen can complete a mould in considerably less time than it takes to describe it.

A spray of larger castings, moulded in the same way, is shown in fig. 9.

When the number of castings required from a certain pattern is small and not sufficient to justify the expense of making up a spray and plaster oddside they can be cheaply moulded under the above conditions by working them loose on a sand oddside in the following manner. One half of the flask is filled with floor sand and levelled off as in the previous case, a strip of wood or metal called a "ridge" is laid down the centre to form the gate, and the patterns arranged on either side in a suitable manner, allowing sufficient room between the centre gate and the pattern to introduce a feeder: when the patterns are properly bedded in the other half of the flask is placed in position and filled in with floor sand to which has been added a handful of powdered resin; this is rammed up very hard, and when removed it is a replica of a plaster cast; it is placed on an iron coreplate, and, after removing the snap flask, it is put in the core-stove or other hot place until heated through; this causes the resin to melt and bind the mass together on cooling again. The moulding is done by boys, but a little more experience is required than for spray moulding, as will be understood from the following description of the method:—

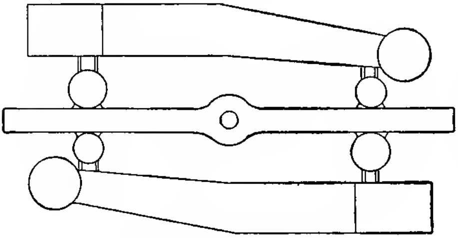


FIG. 9.—Large spray.

The top half of the flask, being the one in which the oddside was made, is clipped round it in its original position, the patterns are laid in their places together with the centre gate, the bottom half of the flask is fitted in its place and, after applying parting sand, is filled up with facing and floor sand as before and rammed up. The whole thing is now rolled over and the upper half containing the oddside is lifted off, leaving the pattern in the bottom flask. At this point it is necessary to add feeders to the mould, and this is done by means of small truncated cones of wood or metal, and which are generally stocked in different sizes to suit the different classes of work; one of these "knobs" is laid between each pattern and the ridge, the top half of the flask is then put on, rammed up, and the down gate cut, and on being taken off again it is necessary, after taking out the patterns, to cut the gates leading from the ridge; this should be done on the top flask in which the feeder is situated, the gates being wide and shallow so as to allow free flow of the metal and at the same time prevent the ingress of dirt.

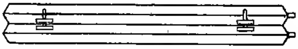


Fig. 10.—Tub moulding boxes.

A third way of dealing with small castings is known as "tub" moulding, and by this method as many as 100 to 150 castings are moulded in each box; the work is done by men who are experienced in this particular class of work. The "tub" boxes are 2 ft. × 1 ft. × 2 in., of the shape shown in fig. 10, and are all interchangeable. A top side is rammed up with a mixture of sand and resin, forming an oddside from which all the moulds are then made, as in the last instance, with the exception that there are no knobs introduced for feeders, instead of which there are three ridges leading from one end of the box and connected together at the end by a cross strip; these are all laid in position on the oddside to form channels in the top from which shallow gates are led from either side to each of the castings. Fig. 11 shows a tub mould ready for closing, and when this is done the boxes are clamped between

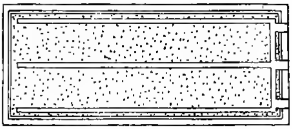


Fig. 11.—Gating for tub mould.

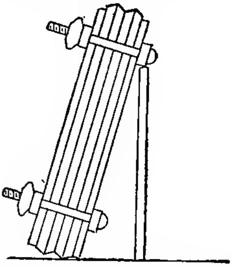


Fig. 12.—Ready for pouring.

flat hardwood boards, secured by wooden screws and stood on end ready for pouring (fig. 12). It will be seen that in this case the centre channel, in which the metal is poured, and also the side channels, all act as feeders, and an expert tub moulder can turn out a huge quantity of castings in a day. The castings requiring the greatest pressure of feed are placed at the lower end of the box, and *vice versâ*.

Castings which are too heavy to mould by any of the foregoing methods, that is to say, those weighing from 1 lb. upwards, are made on plates, moulding machines, or in the orthodox manner on bench or floor, according to suitability of pattern and number of castings required, and these will be better illustrated by examples showing the particular method of gating and feeding required for malleable castings.

Plate moulding is carried out in several ways, according to whether the castings required are a standard pattern in continual use or only odd fifties or hundreds. They are seldom used for lifts exceeding 1½ inch, as beyond this a simple moulding machine is in every way more suitable. The plates are of wood for small quantities and odd work, with the patterns fixed on with ordinary wood screws. The moulding is done:—

(1) From a single plate on which the bottom flask is rammed up, the top being rammed up on a plain board. These are only suitable for castings having one side flat.

(2) From a single plate on which the top and bottom flasks are rammed up separately but closed reversibly. This is suitable for patterns having one flat side, or which is made in halves, each half being exactly similar in outline.

(3) From two separate plates, on which the corresponding halves of a split pattern, not necessarily alike, are fitted so as to register when the flasks, one off each plate, are closed.

(4) From one plate having corresponding half patterns on each side.

As the preparation of these plates belongs to the pattern shop, and will be described in another chapter, it is only necessary here to describe the manipulation of them in the foundry. In each case very little skill is required, and as the necessary runners and feeders are fixed on the plate, the work can be done by youths, and with very little training they are capable of a large output.

Taking the single plate first, the top flask is fitted on to this with the pins passing through lugs on the plate; the box is then rammed up, levelled off with a strickle and vented with a fine wire, and the gate cut with a piece of tube as before; flask and plate are then rolled over, and the plate is lightly rapped in all directions and lifted off. The bottom flask is then laid on a plain flat board, rammed up and strickled and laid in position on the floor; the top is then fitted on and the flasks removed.

In the second case both flasks are rammed up from the same plate, but in closing the mould the top is reversed so that similar impressions are at the opposite ends of each box. In each of these cases only one worker is required, but in the third the moulders work in pairs, one moulding the top and the other one the bottom.

In all cases the vent wire should be freely used and the mould laid on a thin bed of loose sand.

When the number of castings required justifies the preparation of a special cast plate having the corresponding halves of the patterns on opposite sides, this is fitted between the top and bottom flasks, being brought into register by the pins, which must be parallel, passing through holes in the plate exactly in line with those in the top flask.

When using moulding machines for malleable castings it should be noticed that those of the " presser " type give very unsatisfactory results, and independent power rammers are very little better, while with a well designed machine, fitted up with properly made patterns, the use of vibrators or any means of rapping should be wholly unnecessary. The operation of moulding is carried out exactly as for plates.

When only a few castings are required they are worked loose. If small, several of them are moulded in one box around a central feeder, as shown in fig. 13, and the moulders should always have a stock of feeder and spinner patterns (fig. 14) at hand from which they can select those most suitable for the class of work they happen to be engaged upon. As a rule it will be found that the most convenient way of adjusting these is that shown in fig. 13, and for castings averaging 1½ lbs. each the feeder is simply a truncated cone, which does not communicate with the surface of the mould; but for heavier castings the feeder shown in fig. 15 is better. As will be seen, this is a conical block of wood the length of which is equal to the depth from the top of the pattern to the top edge of the box, so that when the mould is dressed off with a straight-edge the feeder can be withdrawn before opening the box again to draw patterns and

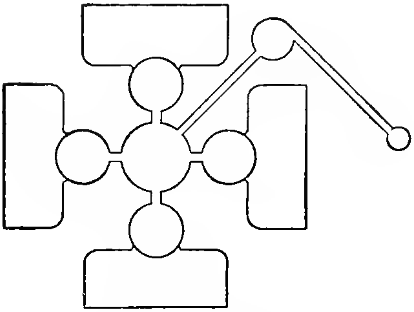


Fig. 13.—Central feeder.

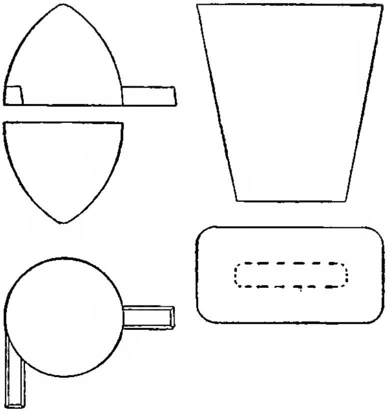


Fig. 14.—Spinner and feeder patterns.

finish the mould. The sand in the bottom box immediately under the feeder should be spooned out to a depth of ½ inch or so, so that the first wash of metal entering the feeder, which will be chilled by contact with the sand, remains below the level of the runners, and a flow of hot metal through the runners is secured; it also helps to maintain the fluidity of the feeder when the mould is full, and so prolong the action as much as possible. This important point should be aimed at in every case, as it is the only way in which perfect homogeneity of the castings can be secured, and, in combination with the use of the spinner, it was until recently a jealously guarded secret of success in malleable founding. Owing to the migrations of peripatetic moulders, the secret is now an open one, but owing to the intense conservatism of founders generally, together with a strong disinclination to melt the necessary amount of metal, the proper use of these two adjuncts is still restricted to comparatively few firms. These are, however, the most progressive, and the quality of their work is sufficient testimony to the advantage gained.

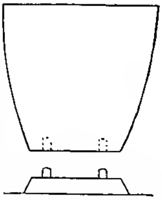


Fig. 15.—Feeder for large castings.

So far the class of work described does not call for a very high order of intelligence on the part of the moulder, but when we come to castings large enough to be moulded singly, and which sometimes contain abrupt and extreme changes of section, then considerable skill and judgment are required to overcome difficulties which are almost negligible in smaller work. To be able to locate the exact spot at which feeders should be placed to be most effective, and also the most suitable point at which the gate and runners are to be cut, is an accomplishment only acquired by years of experience in the production of castings of every description; and as each form of casting requires different treatment it is only possible within the limits of this work to give examples of typical castings, and as these are taken from actual practice they will serve to illustrate the principles laid down and at the same time suggest the lines upon which any other form of mould may be constructed.

A general rule to be observed is to gate low and feed at the highest point; but this only applies to plain work in which no conflicting stresses are caused by unequal section and the contraction is not restrained in any way. This can be better explained by describing the method of moulding a 6-inch cube, and although this may appear to be as simple a casting as it is possible to make—and it possibly is in grey iron—it will be found by experiment that any attempt to produce a sound homogeneous cube by methods other than the one described will result in a huge shrink-hole in the centre, as well as an accumulation of slag and other "matter out of place" in the upper surface.

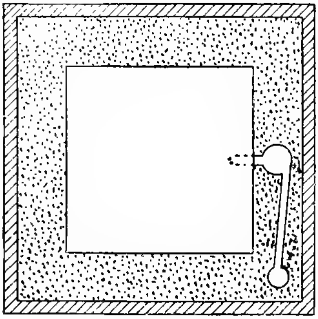


Fig. 16.—Gating for cube.

Ten-inch boxes will be found most suitable for the purpose, and as these are usually 3 inches deep, four of them will be required. A three-part box, with a middle part 6 inches deep, would be better, but this is not essential. The first box part is laid on a board together with a spinner, as in fig. 16. This is rammed up, strickled off, and vented thoroughly, and then turned over, dusted over with parting sand, and placed in position on the floor to receive the middle part and the pattern, which is laid in the centre of the box together with a knob over the spinner. Ramming up and using strong facing sand, this part is finished off level with the top of the pattern, parting sand applied, and the top part fitted on and rammed up. The down-gate is cut in one corner with a thin tube, passing down to the bottom part. The mould is now ready for finishing, and on removing the top part an impression of the pattern will be seen, in the centre of which a hole is cut right through for the feeder, tapering outwards from 2 inches diameter to 4 inches diameter towards the top of the mould; this is laid on one side and the pattern drawn from the middle part, which is also lifted off, turned over to take out the spinning knob, and put aside. The spinner pattern is drawn from the bottom part and the runners completed by cutting to connect with the down-gate in one direction and with the bottom of the mould as shown by the impression of the pattern. The box parts are re-assembled, and additional height added to the feeder by means of a ring lined with sand placed over the centre. The mould is then ready for pouring (fig. 17).

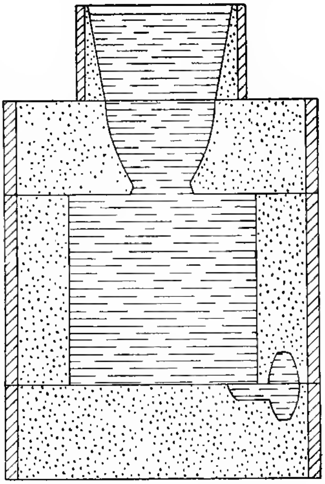


Fig. 17.—Cube mould complete.

Just previous to this a "spot" of metal should be poured down the gate and left to cool, so that when the time comes to fill the mould the downward stream impinges on the "spot" and flows off without dislodging any sand that might possibly be carried past the "spinner" and cause a dirty patch in the surface of the casting. The pouring is done slowly as soon as the iron is "quiet," the down-gate being kept full until the metal reaches the top of the box; the gate is then stopped up with a handful of floor sand pressed down with the foot, and sufficient "hot" metal poured into the ring to fill it. The weight of metal necessary to feed the casting properly will be about three-fourths that of the finished casting.

The feeder is not broken off until cold, as it is not likely to start a crack in a casting of this description. If the feeder is knocked off too soon after pouring there is always danger of bleeding taking place owing to the centre being kept in a semi-fluid state by the heat of the mass; this would nullify the purpose of feeding, which should be maintained until the casting has "set" right through, and the result would be an ugly spongy hole in the top of the casting (fig. 18). On the other hand, if knocked off when the metal has congealed throughout but is still red-hot, the feeder will probably break off at some unexpected spot, leaving 4 or 5 lbs. of metal to be removed in the dressing (fig. 19). In cutting the hole for feeder the sand nearest the casting is always chamfered off so as to form a neck at which the feeder will break off when cold, and if this precaution is neglected it will almost invariably break off as shown in fig. 20.

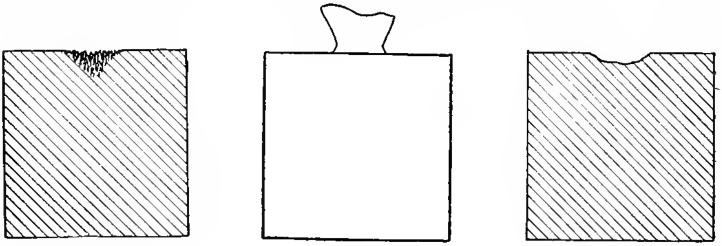


FIG. 18. FIG. 19. FIG. 20.

Broken feeders.

Before proceeding further on the subject of moulding it will be as well to draw attention to the fact that a blunt wire should always be used for venting. The passage formed by a pointed wire is firmly sealed up when the mould is sleeked, and the gases can only escape by percolating slowly through the sand; this is sure to cause blowholes. By using a blunt wire, only a very thin wall of sand lies between the interior of the mould and the passage, and, even if this is not broken down by the pressure, the resistance to the escape of gases is very slight.

To mould a plain ring of the description shown in fig. 21 appears equally simple, but there is only one way in which it can be successfully accomplished, and the method of gating and feeding again decides whether the resultant casting will be sound or scrap, assuming the mould to be well vented.

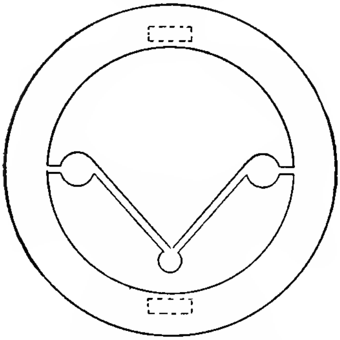


Fig. 21.—Moulding a ring—correct.

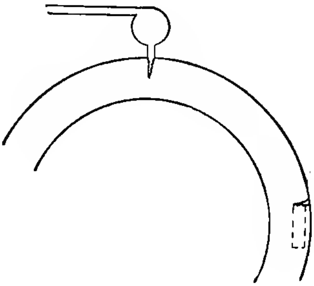


Fig. 22.—Incorrect.

It must be borne in mind that in circular castings of this class there is during the cooling of the metal a point at which the contraction of the ring is resisted to a certain extent by that part of the mould which is inside, and the pull is transferred to the outer edge of the ring, where it acts circumferentially, and if anywhere on the outer edge there is a soft or weak spot the crystals at that point will be torn apart, forming a pull or sear (fig. 22). It is evident, then, that the outer circumference should be of an even temperature all round, and if the runner is situated at any point on this circumference it will, being slightly hotter than the rest of the casting, form the weak spot at which the sear will occur. To prevent this the metal is always run from the inside, as shown, where the results of contraction are reversed and there is no danger of anything of the kind happening, and the use of two runners, each with its own spinner, enables the mould to be filled quickly without the possibility of "cold laps" or mis-run edges that might otherwise be formed, owing to the metal having to flow from a single gate all round the ring, the mean circumference of which is equal to a straight casting, the length of which would be three times the mean diameter of the ring; for the same reason two feeders are employed, each of which is sufficient to feed one half of the casting, and at the surface of which it should have an area equal to the section of metal in the ring. The object in placing the feeders nearer the inside edge is also to prevent weakening the outer edge during contraction.

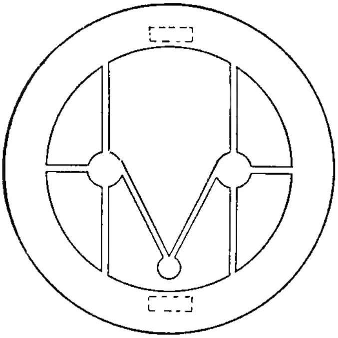


Fig. 23.—Gating a light ring.

In the case of a lighter form of ring of the same diameter, having thin edges or surrounded by teeth as in a sprocket, it becomes a question of filling the mould as quickly as possible with hot metal in order to prevent the thin edge or the points of the teeth from being mis-run, and it then becomes necessary to employ a number of runners by which the iron enters the mould at several places at once (fig. 23), quickly uniting and filling the mould without appreciable loss of heat. Two feeders, as in the previous instance, will be suitable for this casting. A weaker facing sand—*i.e.*, one containing a small proportion of coal dust—will also help to prevent mis-running. If the casting is of a particularly light section it will be necessary to run the metal through two gates simultaneously.

To mould a pipe or pipe connection calls for an amount of skill which marks the expert. Pipes of this material, though seldom more than 4 feet 6 inches in length, may be as much as 18 inches, or even more, in diameter, and when required to stand a working pressure of perhaps 150 lbs. per square inch, tested to 300 lbs. by hydrostatic pressure, with a thickness of $\frac{5}{8}$ inch or at most $\frac{3}{4}$ inch, it will be understood that considerable care is necessary to ensure a sound casting absolutely free from porosity or cold shuts, and most moulders will get them "fuzzy" along the upper surface; this is due to either or a combination of two causes—the mould, or core, or both, may be improperly dried and warmed, or the metal may be allowed to cool too far before pouring, and in any case proper gating and disposition of feeders cannot in any way be expected to rectify matters. In moulding a pipe 3 feet 6 inches long and 10 inches in diameter, which may be taken as an average size, it should be gated at each end and on opposite sides of the parting line as shown in fig. 24, although it is possible to get good results by means of two gates on one side (fig. 25). Four feeders are used, one on the top of each flange to ensure soundness at the

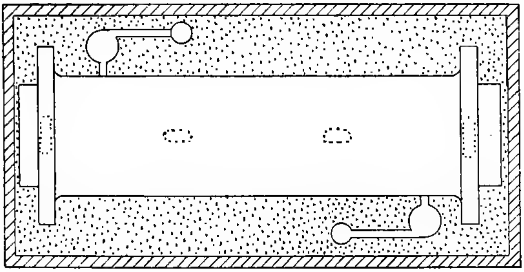


FIG. 24.—Pipe mould: gates.

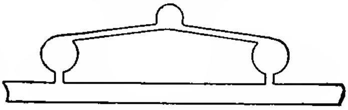


FIG. 25.—Twin gates.

neck, and the other two on the body of the pipe as shown in fig. 26, to feed that part, and also to act as risers for any dirt or scum floating on the surface of the iron.

A crush core must be used, made up of red sand mixed with a liberal quantity of sawdust; the cinders, etc., in the centre forming a "heart" not less than 5 inches in diameter, and the whole well stiffened with iron rods about $\frac{3}{8}$ inch square. It is made at least three days before required, thoroughly dried, and painted over with two coats only of plumbago and water, applied with a soft brush; it is placed in position immediately before pouring, and must be quite hot at the time.

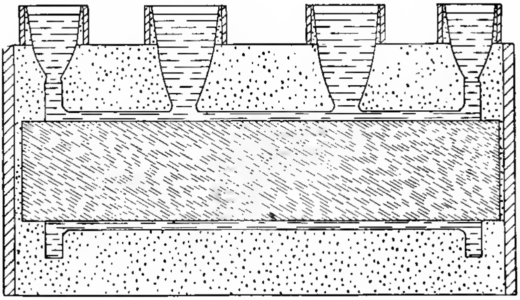


FIG. 26.—Pipe mould: feeders.

The mould is laid on a cinder-bed, with a short length of 2-inch pipe leading from it to atmosphere to carry off the gases rapidly; the bottom half is rammed up fairly hard and, when placed on the cinder bed, is well vented with a blunt vent wire pushed right down into the cinders; oblique vents are also made along the surface of the parting about 2 inches from the side of the box; they are connected by a longitudinal channel from which other short channels are cut at right angles leading to the edge of the box. The top half is rammed up harder so that there will be no danger of knocking out, but must be well ventilated between the feeders; the entire mould is dusted over with plumbago, lightly sleeked over, and thoroughly surface dried with hot plates, so that when closed immediately before pouring it feels quite hot when touched with the knuckles.

The metal for pouring should be taken at the middle of the heat and have a preponderance of soft mottled or grey in the mixture; the condition at the time of pouring should be "hot"; pour as quickly as the gating will allow until the iron in the feeders is level with the top of the box, then add more weights, put on rims 6 inches deep and fill up with more "hot feed."

As a casting of this description does not require muffling, it is left in the mould for at least twelve hours, the feeders being knocked off from four to five hours after pouring. If the foregoing conditions are fulfilled and the metal is clean the chances are all in favour of a good casting; if, however, metal and mould are cool and venting inefficiently done, then, when the rising metal flows over from each side across the top of the core, it will set almost immediately, and all impurities will be trapped there, while cold shuts are almost certain to occur. The method of gating and feeding a bend of the same diameter is shown in fig. 27.

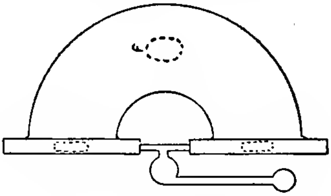


FIG. 27.—Bends: gates and feeders.

In contrast with the pipe previously described, fig. 28 shows a heavy air-pump lever which can be moulded in the same box. Here we have a section which is solid throughout, the cores in the bosses being too small in proportion to the bulk of casting to have any appreciable effect, and as there are no flanges or other projections to grip the mould it is only necessary to see that the high shrinkage incidental to solid castings of this description is counteracted by properly placed feeders of ample dimensions. The difference in bulk between the bosses and the stalk of the lever is comparatively slight, but it is nevertheless sufficient to cause shrinkage of the crystals at the junction in the relatively short space of time that elapses between the final setting of each, and as there are three of these bosses, it will be necessary to place a feeder over each of them, so that as shrinkage takes place the metal in these sinks by gravitation to make up the amount necessary to secure homogeneity. The preparation of the mould does not call for such elaborate care as is necessary for a pipe, and the facing sand contains a greater proportion of coal dust, the surface being further protected by a good sleeking of plumbago. The venting must be ample; in fact, within reasonable limits, it cannot be overdone for malleable castings of this description. The iron, poured from both ends of the mould as shown, should be in that state of fluidity known as "medium," as there is very little risk of chilling or cold shuts and there are no thin sections to run up, while the shrinkage is reduced to a minimum. It will be necessary to pour steadily to avoid scabbing, and the feeders are filled up with "very hot" metal as soon as possible after the mould is full.

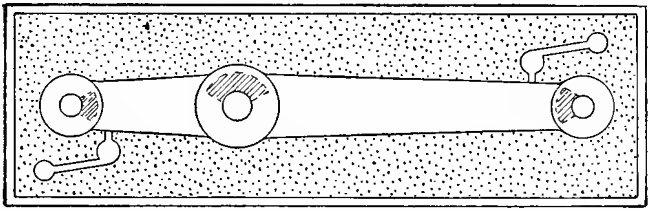


FIG. 28.—Moulding a pump lever.

Probably one of the heaviest castings made in malleable iron is a jawstock for stone-breaking machinery, of which fig. 29 is an example. This weighs about 12 cwts. and requires for casting purposes, including feeders, nearly 15 cwts. of metal. The mould is prepared as for the pump rod, except that greater care is necessary to make up a solid, though well vented, bottom part on account of the heavy pressure of metal, and also to use plenty of weights on the top when pouring, as the lifting power of a body of metal of this size is very considerable. As will be seen in the illustration, it is gated at one end only, the runners being led through two separate spinners; three feeders are used, being placed as shown, and each of these should contain not less than 1 cwt. of iron, and as a mass of metal of this description takes some time to set, it is necessary to cut the feeders full at the neck so that there may be no risk of setting at this point until sufficient make-up has been supplied to the interior of the casting; for the same reason, the feeder rims should be put on and quickly filled with very hot metal immediately pouring ceases and the mould is full.

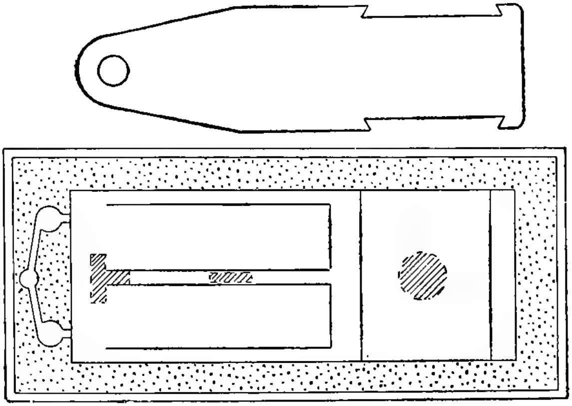


Fig. 29.—Moulding a jawstock.

The iron for the casting itself should not be too hot; on the contrary, it is better on the "dull" side, and if too hot when tapped it is advisable to throw some parting sand over the surface of the metal in the ladle while waiting until the proper consistency is reached; this forms a "skin" on the surface, which prevents oxidisation and also holds together all loose pieces of slag and dirt that are left in the ladle after skimming and prevents them from being carried into the mould when pouring, the metal coming up clean from beneath the skin, which is left in the ladle.

No attempt must be made to knock off the feeders for at least eight hours after the cast, or "bleeding" will occur owing to the centre still being in a semi-fluid state; when this happens it may be stopped by applying a cold metal surface, such as the face of a flat rammer, to the spot immediately; this chills the metal sufficiently to stop the "bleeding," but there is almost sure to be an ugly "shrink-hole" at this part owing to the action of the feeder being prematurely stopped. The casting had better be left in the mould for three or four days, but may be lifted or loosened in twenty-four hours, to accelerate the rate of cooling.

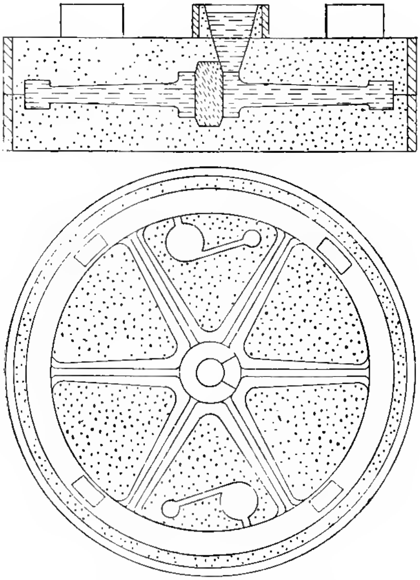


Fig. 30.—Moulding a wheel.

Fig. 30 shows the best method of moulding a large wheel, the type of which is a familiar one; the operation of moulding is in itself a simple one, and subsequent difficulties due to structural strains will be considerably minimised by using a mixture of iron containing rather more annealed scrap, say 12 per cent. It will be seen that there are four feeders on the rim—this is assuming the wheel to be 3 feet or more in diameter; for smaller wheels down to 2 feet diameter three feeders will suffice, placed between alternate pairs of arms. Wheels between 1 and 2 feet in diameter should have only two feeders, placed between opposite pairs of arms, and for all sizes below 1 foot diameter, one feeder will suffice.

The metal at the time of pouring should be "medium hot," and as soon as it has become sufficiently set to allow the feeders to be knocked off without "bleeding" the casting must be put into a well-heated muffle without delay.

Although, owing to its simplicity of design, an elevator bucket seems an easy casting to make, there is usually a very high percentage of wasters in this class of work on account of the lightness of the section and the large superficial area of the mould; the thickness of the metal is seldom more than $\frac{3}{16}$ inch, and frequently only $\frac{1}{8}$ inch, so that cold shuts and mis-run castings are numerous unless the mould can be filled very quickly, and if the runners are too large a considerable amount of dirt will find its way into the mould; on account of the light section a spinning gate is impracticable, while a horizontal fin-gate sufficiently shallow to check the dirt would not fill the mould quickly enough. A method adopted with much success is that shown in fig. 31: the iron is poured down the riser as shown; this is done quickly with very hot, clean, well-skimmed metal, to receive which the mould must be thoroughly well vented. It is, in fact, a vertical fin-gate which also acts as a feeder, and which by gravitation causes the metal to rush into the mould and fill it rapidly, the impurities floating at the surface of the metal in the feeder.

In all castings of comparatively light section in which there are sharp corners or angles, as in fig. 32, there is always a danger of the crystals being torn apart on cooling, owing to the resistance of the intervening sand, and in this case the moulder cuts away sufficient sand to form a "fin" across the corners as shown; the rupture will then occur in the fin, which is ground or cut out of the finished casting.

Strictly speaking all malleable castings should be muffled in the same way as steel castings, and for the same reason, viz., to relieve the tension due to cooling strains, but in general practice it is only found to be necessary in certain classes of work which experience shows will be likely to fracture spontaneously if cooled down quickly, and amongst these may be mentioned wheels of every description; thin flat plates, especially circular discs, including pistons; and intricate or complicated castings in which the section of metal varies considerably. The tension in some of these is so excessive that it is by no means unusual for a casting to fracture in several places even two or three days after being taken out of the muffle. This is due to being removed too soon, before the molecules of iron have had sufficient time to adjust themselves. On the other hand, castings having unequal sections will fracture in transit from the mould to the muffle if exposed to

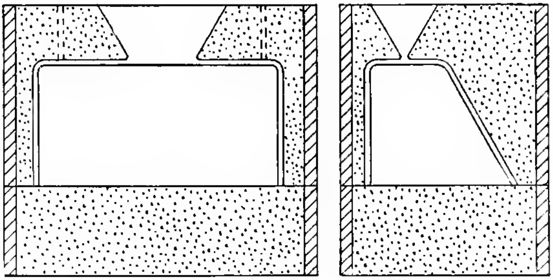


Fig. 31.—Mould for elevator buckets.

cold winds or draughts in the interval, so that the muffle door should always be inside the moulding shop, and should be so conveniently placed that castings from any part of the floor can be transferred to it in the shortest possible space of time.

As in all furnaces of this description, the design is to a great extent a matter of personal opinion, as well as being governed by such causes as locality and position of flue, capacity, and class of work for which required. The muffle described here will be found well adapted for the general run of malleable castings, but where there is a continuous output of work ranging from very heavy to very light it is better to divide the work into two classes and provide a muffle for each, as the heavy work will require muffling for a considerably longer period than the light work, and owing to the heavy scaling which takes place when the process is prolonged, the lighter castings may be reduced to worthlessness if treated with the heavier class.

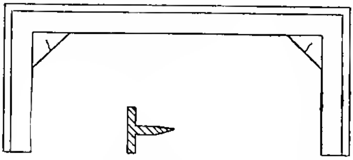


Fig. 32.—Moulder's fin.

It is, of course, possible to obviate this to a certain extent by placing the light work as far away from the fire as possible—that is to say, close to the door—but when this is done there is the additional risk of fracture owing to the rush of cold air which enters at this end each time the door is opened.

Prolonged muffling, even for light castings, is an advantage rather than otherwise, but to accomplish this without the inevitable scaling would require a special incandescent oven which could be sealed up so as to render it practically gas-tight, and this is impracticable for the purpose referred to.

As before stated, the duration of the muffling varies with the size of the casting and the nature of the strains. The temperature of the muffle when the castings are put into it should not be less than 1,500° F., and for light work no further firing will be necessary and the damper may be shut, the castings being left to cool down with the muffle, from which they may be removed in about ten or twelve hours. For heavy castings the fire must be made up immediately they are all in the muffle, and again in about two hours, and shortly afterwards the damper may be shut and the temperature allowed to fall gradually and the castings allowed to remain in the muffle as long as possible, which generally means until just before the muffle is again required.

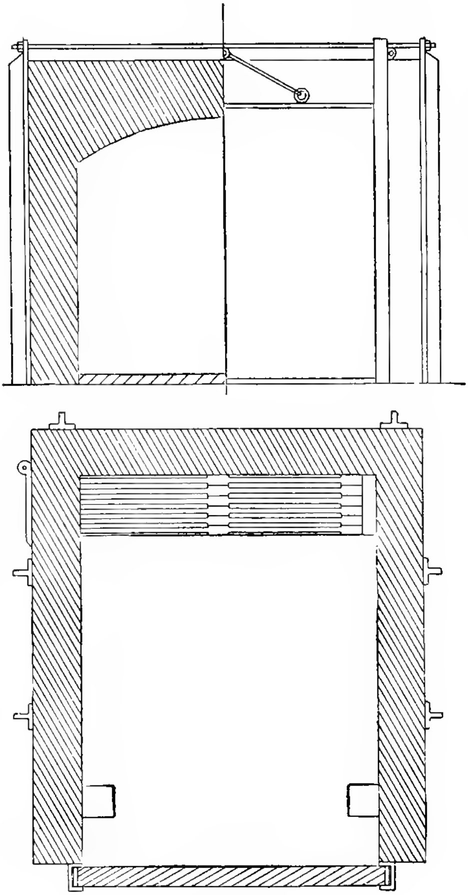
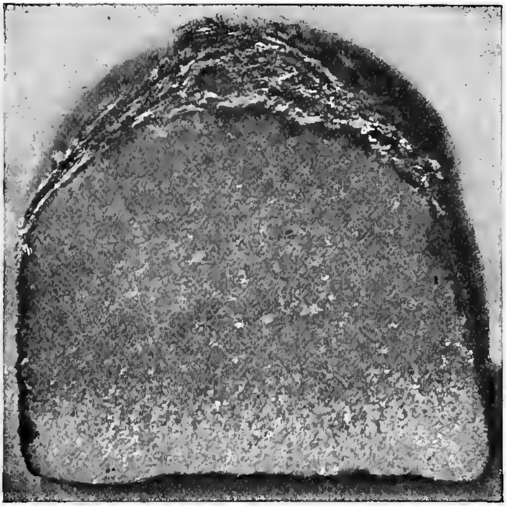


FIG. 33.—Muffle.

In all cases, heavy or light, the castings must be screened from cold winds from the time of their removal from the muffle until they are cold, or the local strains caused by unequal temperature will probably cause them to fly. Fig. 33 shows details of a useful form of muffle which was specially designed tò facilitate the placing



Malleable Pig Iron.—Soft Mottled.

Approximate Analysis.

Graphitic carbon, 2·50 per cent.; combined carbon, 1·24 per cent.; silicon, ·98 per cent.; sulphur, ·143 per cent.; phosphorus, ·05 per cent.; manganese, ·40 per cent.

and removal of large castings; the smaller ones are easily attended to, but to manipulate half a ton of red-hot metal, such as a piston for instance, is a matter which calls for every convenience in order that it may be expeditiously done; for this reason the bottom of the furnace is level with the floor line, so as to present no obstruction and to do away with the necessity for lifting heavy work, as would be required in the case of a muffle with a raised floor. The bottom is covered with cast iron plates 2 inches thick and 1 foot 6 inches square. Long plates were tried at first, but it was found that they buckled badly under the heat and made an uneven floor that was not conducive to easy working; the cost of renewal owing to burning away at the fire end was also excessive in comparison with the slabs which replaced them, only those at the fire line requiring periodical renewal. Two flues are provided so that the heat may be distributed throughout the furnace or drawn to one side if necessary by closing one damper and leaving the other open. This arrangement is very useful when some of the castings require muffling for more than the usual period, as they may be laid along one side so as to leave room for a fresh consignment on the other. In order to retain the heat as much as possible, the door should not be raised any higher than is necessary to admit the casting, and when they are all in, the joint round the edge of the door may with advantage be luted with wet sand. The temperature must be carefully regulated by means of the dampers, or the muffle will act as an air furnace, and melting will commence at the hottest parts.

COREMAKING

There are two main principles to be kept in view in the preparation of cores for malleable castings: they must be well vented, and must be made up so as to offer the least possible resistance to compression, so that the casting is free to contract in cooling without undue strain being thrown upon the crystals of which it is composed. The general use of waxwire has considerably simplified matters with regard to the first named, and is now regarded by malleable ironfounders as indispensable for small cores, while for larger ones an open centre of cinders or straw-rope, together with a liberal addition of sawdust and chopped hay to the sand used for the body of the core, provides ample escape for the gases, and at the same time it will yield to the pressure of the contracting metal. All large cores should contain not less than one part sawdust to five parts of red sand in bulk, with just sufficient powdered resin to ensure binding—about 1 in 30. Cores that are not large enough for a cinder or straw centre are made up with a larger proportion of sawdust, and as they are only rammed up sufficiently to hold together when damp, a little more resin must be added so that they can be safely handled after they are dried.

The drying must be done thoroughly, as nothing is more conducive to blowholes than an improperly dried core. The reason for this is obvious when it is remembered that the core is formed to meet conditions exactly opposite to those required in making the mould; in the latter case the molten metal is surrounded by sand and the opportunities for the escape of steam and gases are numerous, but with a core the state of affairs is reversed, and we have a body of sand surrounded by metal in which any bubbles formed by steam or gas are immediately imprisoned.

Steam bubbles are, of course, caused by moisture in the core, but there are others which have their origin in the rapid generation of gases evolved from substances used as binders mixed with the sand, and pastes for jointing cores made in halves, some of the special preparations sold for these purposes being particularly offensive in this respect, no matter how well vented a core may be.

The more loosely a core is made up the better it will serve its purpose (small cores are not rammed at all, the sand being merely pressed into a corebox with the hand), and consequently wires and rods dipped into a wash of fireclay are freely used to stiffen them and prevent them from breaking up under the pressure of the fluid iron. It is better to use a number of light rods than a few stronger ones, as the stiffening is then better distributed, and there is not so much risk of a portion of the core breaking away under the wash of the metal. This is the principle of reinforced concrete applied to the foundry practice.

The use of chaplets or stops for supporting cores, or preventing the tendency to float, is sparingly adopted, as the iron never fuses properly with that part of the chaplet which is embedded in it, even if it is tinned for the purpose, while the reaction caused by contact produces blowholes, and if by any other means the core can be held in its place it should be done in preference. If the use of supports is unavoidable it is better to make them of thin sheet iron, not more than $\frac{1}{32}$ inch thick or 21 gauge; these are bent into channel shape and placed as shown in fig. 34. They are easily fused into the metal of the casting, and are strong enough to serve their purpose until no longer required. Intricate cores, and others that are difficult to clean out of the castings, are coated with a wash of plumbago and water applied with a soft brush such as camel hair; this does not affect the venting, and will prevent the sand from adhering to the iron.

It is often necessary to cast special grids or frames to carry cores of a peculiar shape, and which cannot be extracted except by breaking them up inside the casting, and provided this is done before the castings are annealed, they may be cast of white iron, but if it is advisable to leave the core in until after annealing to prevent the casting from crushing or collapsing the frames must be of common grey iron, or they will become annealed with the casting, and this will render them difficult, if not impossible, to remove entirely. From the foregoing remarks it will be understood that to ensure soundness in cored castings it is absolutely essential that nothing should enter into the composition of the core but red sand, sawdust or chopped hay, and powdered resin, with cinders or straw rope in the centre of large ones. The ends of large cores that rest in the prints are packed in cinders or coke breeze so that the gases may have free escape after leaving the core. Loam cores are too close and unsuitable for malleable castings, and are consequently seldom, if ever, used for the purpose.

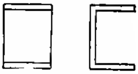


FIG. 34.—Chaplet.

ANNEALING

The problem of designing an annealing oven to be at once economical in consumption of fuel and efficient in results is one upon which more attention has been bestowed, more ingenuity exercised, and more money spent than on any other item in the entire process of manufacture. As a consequence some foundries have always several ovens of different types at work, and these are being continually altered in an attempt to attain greater efficiency. The size of the firegrate and the position of the flue have been varied in every conceivable manner ; gas and oil firing have been tried and found wanting, and the introduction of steam or air into the ashpit has only added to the cost of production without giving any improvement in the quality of the finished castings. No doubt some more economical type of oven will eventually be designed, but for the purposes of this book reference will only be made to those in general use which have up to the present proved equal or superior to those of more elaborate construction, which have not up to the present time justified the extra cost of building and maintenance.

It is essential that the oven should be :—

(1) Strongly built to withstand the alternate expansion and contraction due to a variation of nearly 1,700° F.

(2) That in order to attain an economical consumption of coal the area of the firegrate must be carefully considered in relation to the cubic capacity of the oven, and the ratio kept as low as possible.

(3) That the flues must be so situated as to maintain a fairly even temperature in all parts of the oven, while the full

area will only permit the escape of gases after thorough combustion.

(4) That when sealed up and at work there should be no possibility of heat escaping otherwise than by the flue; in other words, the structure must be practically gas-tight.

(5) That it must be capable of being operated independently of the adjoining ovens, and of being repaired without in any way interfering with the working of them.

(6) The foundations must be substantial enough to prevent subsidence and consequent cracking of the walls.

Whether they are built separately, in pairs, or in a continuous stack of three or more ovens depends on the class of work to be dealt with, and also on the output. In cases where the production of castings is only for special purposes, the demand being limited and intermittent, a small single oven shown in fig. 35 will be the most suitable. In this may be placed four tiers of five pans each, which may be round or square. An oven of this description measuring 5 feet 6 inches each way inside will hold about 30 cwts. of castings, more or less, according to class of work.

The capacity of this oven is so small that it is not necessary to have a firegrate at each end, as is usual in the larger ones; instead of this, two are shown at one end, the flue F being situated at the other. This is a most convenient arrangement, as the same stoke-hole is common to both grates. The entire structure rests upon ample foundations about 2 feet thick, more or less, according to the nature of the ground. The walls are of firebrick, the inside course being "best quality," *i.e.*, the most refractory obtainable. The arch has a spring of 9 inches, and is also of "best" brick in two courses, as this is the hottest part of the oven away from the fireline. In the centre of the arch a hole 6 inches square is left; this is covered with a firebrick slab when the oven is at

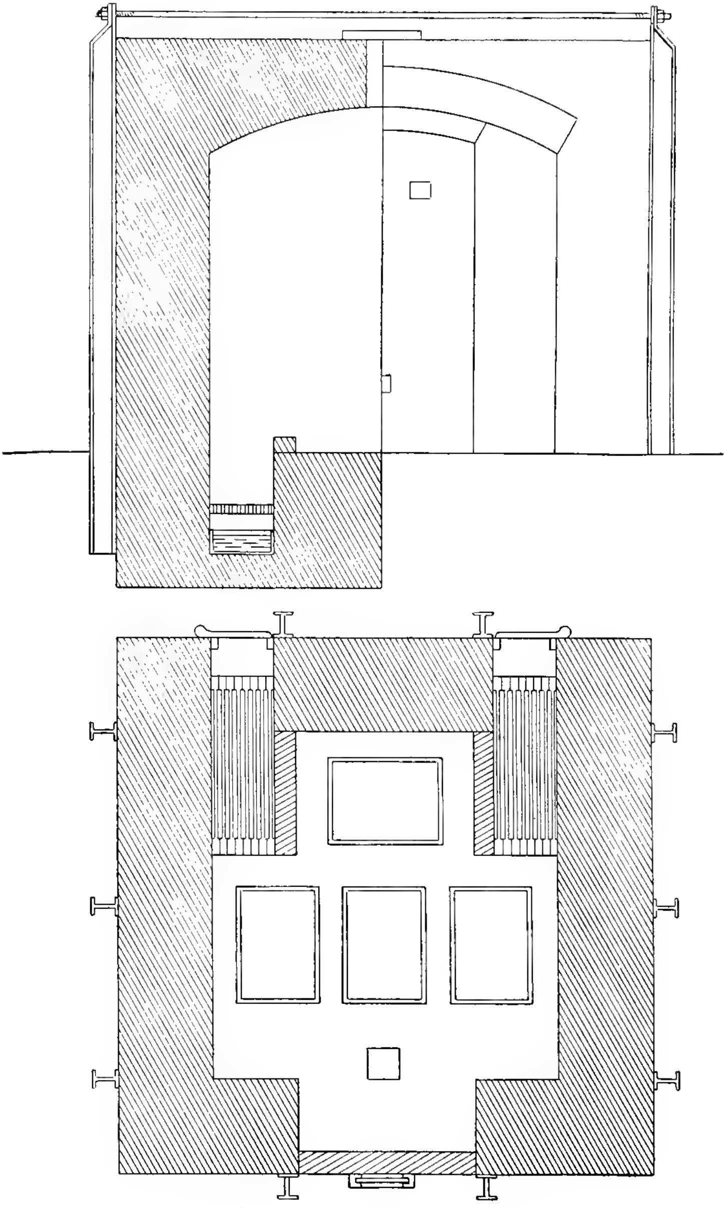


FIG. 35.—Annealing oven—30 cwts.

work, which is removed to allow the hot air to escape when cooling down, and also to ventilate the oven while the packing or repairing is going on. Instead of a slab, some designers prefer a tapered plug fitting into a corresponding hole in the arch, but although it adds to the expense, this method has no advantages to recommend it.

The oven is sealed up by building up a wall in the doorway with old firebricks, the mortar used for the purpose being made from foundry floor sand, mixed with a very small proportion of fireclay; this wall is generally termed a "wicket," and when completed the entire surface of it is plastered over with similar mortar. Two observation holes are left in the wicket, one about 6 inches from the top, and the other the same distance from the bottom; through the upper one the general appearance of the oven can be watched, and the lower one is used for ascertaining the amount of scale which has fallen from the pans. These holes should be closed with a taper firebrick plug, which is well luted with wet sand each time it is replaced. The customary method of stopping up the hole with a loose brick causes a considerable loss of heat, and makes an appreciable increase in the coal bill.

When the production is more regular and of greater variety, but supply limited, a pair of ovens, similar to the one shown in fig. 36, may be used, one of the pair being at work while the other is being discharged and refilled; these ovens can be packed with pans of different sizes, according to dimensions of castings, as shown in the drawing; the tiers are five in height, all the pans being 12 inches deep, and each oven holds approximately 4 tons of castings, according to size. The dimensions inside are 7 feet square and 6 feet 6 inches to top of arch.

The dividing wall in a pair of ovens should never be less than 18 inches in thickness, or the radiation will be so great that work in the idle oven can only be carried on under difficult conditions.

An ideal division would be formed by having two separate walls with an air space between; but this would add considerably to the cost of erection, as each wall would have to be the same thickness (18 inches), and for any effect this would have upon men accustomed to the work, the expense is not justified. Although these ovens are only slightly larger than the one previously described, the difference is sufficient to render it advisable to fire from both ends to secure an even temperature, and although it is by no means unusual to find ovens of this size fired from one end only, the results are not so uniform, and imperfectly annealed castings from the pans situated from the end furthest away from the fire are more often the rule than the exception.

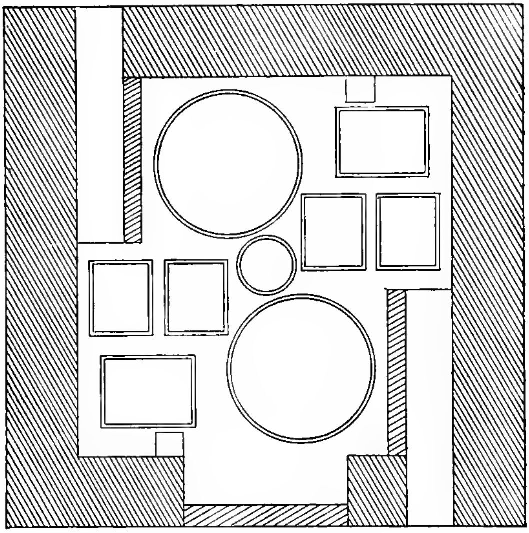


FIG. 36.—Annealing oven—4 tons.

When the output is large, the ovens may be built either in continuous stacks or in pairs, each pair of different dimensions to suit the different classes of work. The latter method is preferable on account of the unequal expansion of ovens of different dimensions, which has a tendency to break the continuity of a stack and cause considerable loss of heat through the interstices in the brickwork. It is not advisable to exceed the dimensions of the oven shown in fig. 37, which will hold about 10 tons of work, the internal measurements being 10 feet by 10 feet by 6 feet 6 inches, on account of the difficulty in maintaining a large chamber intact, as well as of loss of heat by radiation, the consumption of coal necessary to

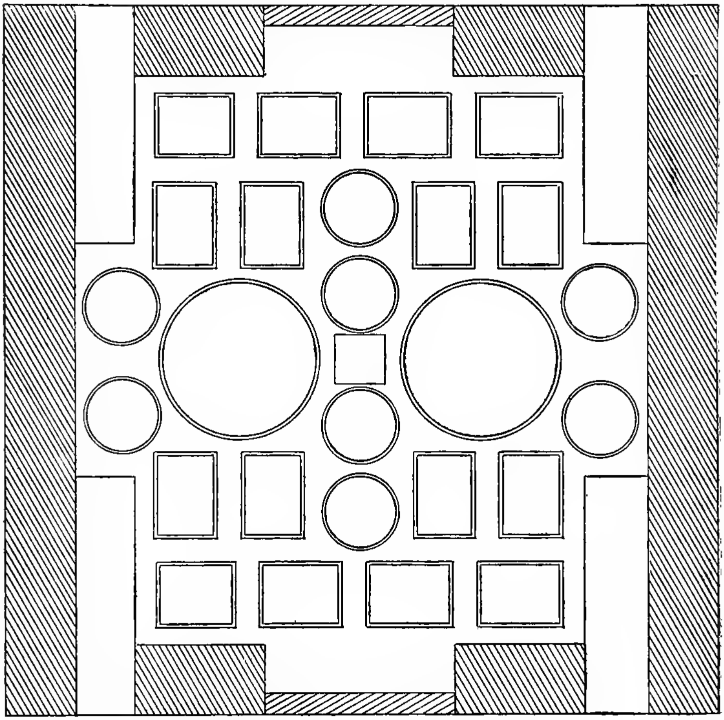


FIG. 37.—Annealing oven—10 tons.

maintain a continuous heat becomes excessive and out of economical proportion to the amount of work to be annealed.

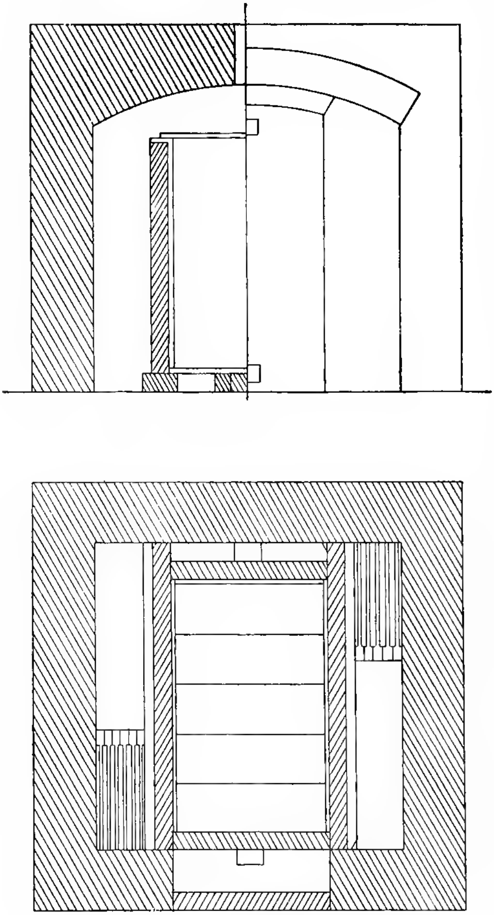


FIG. 38.—Case oven.

There are many castings which cannot be annealed in pans in the ordinary way, because of their length or unusual shape, and for dealing with these it is necessary to build what is termed a case oven (fig. 38). These hold large quantities of work, and would, no doubt, be used for general purposes but for the fact that they take considerable time to pack and unload. They are also very extravagant in fuel, on account of the thickness of the retaining walls restraining the passage of heat into the annealing material, firebrick being a notoriously bad conductor of heat; for this reason they may be regarded as a necessary evil. A case oven should always be fired from both ends, or the result will be unequal annealing, and long castings, for the accommodation of which these ovens are built, will be turned out soft at one end and hard at the other, owing to the difference in the temperature between the firing and flue ends of the oven. If the oven is too small for four fires, the difficulty may be overcome by having two diagonally opposite.

It is upon the judicious manipulation of the dampers that the successful working of an oven chiefly depends, and for this reason they should be designed to work in a grooved frame of cast iron (fig. 39), and built into the flue in such a position that they are not likely to become distorted with the intense heat of the oven; this might cause them to become jammed, and seriously interfere with the proper working at a critical moment. Cast iron plates are to be preferred to wrought iron, as they do not buckle so badly.

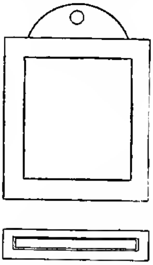


FIG. 39.—Damper and frame.

The fire-doors are set at an angle, so that they keep shut by their own weight, no latch being necessary; at the same time the joint with the frame should be a good one, and a grid in the middle of the door will be an advantage, as by admitting air over the freshly-laid fuel for a short time after firing, a more complete combustion is assured.

Rectangular cast iron water troughs are fitted to each ashpit; they are not bedded in, but fit loosely, so that they can be easily replaced in case of breakage. They are to be kept full of water during the whole period of annealing, as the steam rising from the surface assists combustion, and at the same time prevents burning of the fire-bars. A round crossbar is built across the front of the ashpit about 6 inches below the bottom of the fire-bars; this acts as a fulcrum on which to rest the cleaner, a firing tool used for clearing the spaces between the fire-bars. The fire-bars are cast from hard grey scrap, and the air space between each bar should not exceed half an inch in width.

The buckstaves are sometimes made of cast iron of T section, but, owing to the enormous strain due to expansion and bulging of the brickwork, they are liable to fracture, unless the section is unusually heavy. Light wrought iron or steel girders or channels are much more suitable; they should penetrate at least 2 feet into the ground and be packed close up against the brickwork in such a way that they will retain their position when the top is pulled in by the tie rods. These rods are of 1⅛ inch round iron, screwed at each end for a distance of at least 6 inches to allow for taking up when the rods are fully expanded under the heat radiated from the oven. When first put up the nuts are tightened up every day until the limit is reached; after this they may be tried at intervals, and any slackness due to stretching of the rod taken up.

In building the inside course, or lining, of an oven it is of the greatest importance that the joints between the bricks should be as thin as possible, and the best way to do this is to dip each brick into a wash of fireclay instead of using a trowel in the orthodox way. A lining built in this manner will, after the first heat, present an apparently jointless surface, the whole of the interior of the oven lining being covered with a thick glazed coating of fused silicates. Fireclay is by no means a good binding material, and if laid on too thickly, so that the joints are unduly wide, the walls will rapidly burn away, and cracks develop sooner or later, causing considerable loss of heat.

Special attention should be paid to the parts adjoining the firegrate, where the cutting action of the flame is so severe that, however well built the walls may be, they will rapidly burn away. The application of gannister to the affected part will postpone repairs to a certain extent, but that part of the lining should be renewed before erosion has gone further than 4½ inches, the width of bricks in the lining.

In building the draught holes a "well" or "sump" is made, the bottom of which is not less than 6 inches below the lower edge of the outlet leading to the flue (fig. 40). The object of this is to catch and retain the sand, scale, and ore which would otherwise be carried into the flue and ultimately impede the draught. Even with this precaution the finer particles will always be carried through into the flue, and in time their effect on the draught is quite noticeable; for this reason it is always advisable, where the work is continuous, to build twin flues, so that they may be cleaned alternately. The first cost of this method is considerable, but the corresponding advantages are apparent when it is considered that any variation in the velocity of the draught in the flue reacts upon the oven, and is therefore detrimental to the uniformity of temperature so necessary. In order to reduce the risks of stoppage, the flue should, if possible, lead direct to the chimney, or at least without any sharp turns, where the dust is usually precipitated; but if such a course is not convenient, then an inspection cover should be placed at the points where the run of the flue is diverted from a straight line, as well as at the base of the chimney. The roof of the flue is to be well arched, in two courses, to prevent collapse, and under no circumstances should it pass under a cartway or where it will be submitted to constant shocks from falling castings, breaking pig iron, etc., which may have an injurious effect on the joints already deteriorated by the heat.

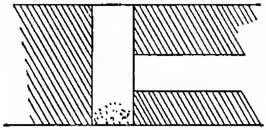


FIG. 40.—Section of flue.

The annealing of malleable castings is a subject which has given rise to much controversy in all countries concerned, the disputed point being whether the change that takes place in the character of the iron is due to a change in the nature of the carbon content, or whether it is caused by the extraction of a certain percentage of carbon.

The advocates of the first theory state that when the castings are heated up to a certain temperature they become sufficiently porous to allow the oxygen contained in the annealing medium to penetrate into the iron, and, combining with the carbon, to precipitate it in such a manner that it becomes what the German chemist Ledebur called "temper carbon." This is an amorphous graphitic free carbon, and is so finely distributed amongst the crystals of iron that there are no cleavage planes; hence its malleability. The characteristic fracture of this kind of malleable cast iron has given it the name of "black heart malleable," as it presents a velvety black surface surrounded by a narrow rim of lighter material, merging into silvery white at the extreme edge.

With regard to the second theory—that of elimination or extraction of carbon—this is undoubtedly the reason ascribed by Reaumur to his discovery, viz., that at a certain temperature the oxygen in the packing material extracts some of the carbon in the iron, and, as carbon dioxide, passes off with the products of combustion. The result is a steel casting, or rather, a casting having an outer skin of mild steel surrounding a core of cast iron annealed and rendered slightly ductile by the action of heat only. The characteristic fracture of this class of work is distinctly "steely" in appearance, the structure ranging from granular to finely crystalline, according to the quality of the pig iron from which it was made. To this class of iron the somewhat unwieldy name of "Reaumur process malleable" has been given to distinguish it from "black heart." The entire process is a reversal of the cementation method of steel manufacture, in which bars of wrought iron are packed in iron boxes containing powdered charcoal, salt, and wood ashes. These are heated in a furnace until a temperature is reached at which the iron absorbs sufficient carbon to convert it into steel.

From the foregoing it will be gathered that there are two distinct classes of malleable cast iron, and therefore the reason for controversy is not apparent, but it will be better understood when it is stated that both theories—conversion and elimination—are applied to each class, while a third suggestion is that part of the carbon is eliminated and the remainder is converted or precipitated. As a matter of fact, the chemical reaction which takes place during the annealing process has not yet been definitely ascertained, and consequently much has to be assumed; but investigation and experiments recently carried out by leading authorities point to the conclusion that with iron low in sulphur, such as that produced in America, and annealed in iron scale, the result is "black heart malleable," due to conversion or precipitation, while with European irons, which are comparatively high in sulphur, annealed in hematite ore, the product is a peculiar grade of steel produced by elimination of carbon. Only by these means is it possible to ensure uniformity and commercial success. Any variations on these methods, such as annealing a low sulphur iron in hematite ore, or a high sulphur iron in rolling mill scale—although both are practicable—are not commercially practical on account of the unevenness which will be found to exist amongst the castings.

The annealing material in which the castings are packed is red hematite ore ($Fe_2 O_3$). This is granular in form, and the most convenient size to use is that which is commercially known as "50 mesh"; this will pass through a $\frac{3}{8}$ inch riddle. New ore, *i.e.*, the raw material as it comes from the mines, is too strong to use alone, as castings packed in this would be badly pitted owing to the action of the oxygen on the iron; it is therefore mixed with old ore which has already been used for annealing purposes in various proportions according to the class of work, but always with a predominating proportion of old ore. Each time the oven is emptied the ore is spread out thinly over a floor reserved for the purpose, where it is watered daily with soft water (rainwater) or a weak solution of sal ammoniac; this enriches the ore by the formation of oxide of iron, and the process is hastened by turning it over on alternate days in order to expose it all to the action of the atmosphere. It is possible to anneal castings in ore which has not been treated in this way, but simply thrown into a heap and used again immediately. The action is, however, weak, and unless enriched with an undue proportion of new ore, the time necessary to effect the anneal is prolonged, and there is a tendency to burn the work, owing to excessive scaling of the pans and consequent weakening, causing subsidence of the tiers and opening of the joints.

Before the castings are annealed they are cleaned with a wire brush, and have all cores removed. If they are of such a shape that is not likely to be broken in the process, they may be rather closely packed into a tumbling barrel with a few shovels of small, hard scrap—half an hour in the barrel is quite sufficient—this will knock out all the cores and remove every particle of adhering sand. In some foundries it is customary to use small star-shaped castings of hard white iron in the tumbling barrel, and these are very effective, as the points get into the corners of the castings and remove sand that would otherwise be difficult of access. The wire brushes are made in several different shapes in order to clean out castings of complicated design. For plain castings, which would probably get broken in a tumbling barrel, and which have no interstices where the sand can lodge, the work can be done much quicker by means of circular brushes mounted on a buffing spindle; these are generally arranged for external and internal brushing, the brushes being of different diameters. Special care is taken to remove every particle of sand from surfaces that will ultimately be machined, and unless this is done there is always the possibility of the sand fusing in the annealing oven, after which it can only be removed with difficulty. Sand adheres much more tenaciously to castings that have been muffled.

The teeth of gear wheels are first thoroughly brushed and then painted with lime; this is mixed with water in the same way as for whitewashing, and prevents the teeth from being burnt through overheating. Letters and figures treated in this way are not likely to become obliterated through the same cause, but it must be understood that this is merely a precaution against accidental overheating of the oven.

Castings of any design that suggest unequal cooling strains should not be struck or hammered in any way in order to rid them of superfluous sand, the molecules being in such a high state of tension that even a sharp tap will sometimes cause breakage, and in most cases will start a small crack, which, although imperceptible in the hard casting, will extend under the influence of heat to such an extent as to render the casting absolutely worthless.

It will be seen that from the time they leave the moulding shop until they are in the ovens the unannealed castings require the most careful handling, and unless this precaution is taken the result will be an unnecessarily high percentage of softened wasters.

After being thoroughly cleaned, the castings are sorted into separate heaps—heavy, medium and light; this is for the convenience of the annealer, who arranges their position in the oven according to treatment required.

The packing of the castings in the annealing pans is carried out as follows:—A layer of ore 2 inches thick is spread out over the bottom of the first pan, and on this a layer of castings is laid as closely as possible without actually touching each other (fig. 41); over these sufficient ore is laid to cover them and levelled down, and on this another layer of castings is laid; this is repeated until the pan is full. The second pan or ring is then placed over the first, and the joint between the two is luted or "pointed" inside and out with a mixture of one part fireclay to ten parts black sand from the foundry floor, mixed with water to the consistency of mortar and applied with a trowel, and the packing carried on as before, the ore being well worked down at intervals with a pointed iron rod not more than $\frac{3}{8}$ inch diameter; the latter is necessary to ensure close packing of the ore, and unless it is done the mass will sink under the influence of heat until the topmost pan is empty, and the castings beneath will have become correspondingly distorted. As much as 15 per cent. more work can be packed into an oven when the ore is well "rammed" than would be possible otherwise. Owing to its character, the ore cannot be rammed with a flat rammer; only an iron rod that will penetrate between the castings is suitable for the purpose.

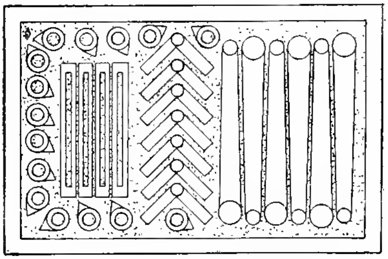


FIG. 41.—Method of packing.

The number of boxes or pans that go to form a vertical tier depends on the height of the oven inside, but the topmost pan in each should be finished off with a layer of ore 3 inches thick, strickled off flush with the top edge. The lid, which is a flat plate of the same dimensions as the outside of the pan and 1 inch thick, is then put on, and the joint luted, as explained before. The practice of having lids to fit inside the pan is not recommended, as when the mass of ore and castings subsides, as it always will do to a certain extent, the lid also sinks and breaks the joint, and the upper layers of castings get burnt.

The operation of packing in small pans is carried out in two ways, according to circumstances. When the supply of castings is occasional and the oven has to wait for several days until a sufficient quantity has accumulated to fill it, the pans are laid and packed inside the oven, which has had time to cool down sufficiently to admit of the work being carried on there. As may be inferred, this method is not an economical one owing to the extra consumption of coal required to raise the temperature to the annealing point from a comparatively cool state. In addition to this there is the loss of time, which is important when the works are being pressed to their full capacity. To obviate this the castings are packed and the tiers built up outside the oven before it is ready to receive them; the lowest pan rests on a stool (fig. 42); this must of necessity be a substantial casting, otherwise it would collapse under the weight of the tier when heated up. As soon as the oven is emptied the tiers of boxes are picked up by a charging trolley (fig. 43) and deposited in position. The shaft of the trolley is of sufficient length to enable this to be done without the necessity for entering the oven.

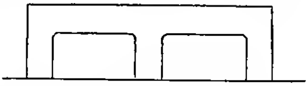


FIG. 42.—Stool.

The trolley is of substantial construction, as it is required to carry a weight of from 12 to 15 cwts. Owing to the length of shaft necessary to deposit and withdraw the pans furthest away from the door, ample leverage is obtained, and by arranging the wheels so that they revolve independently on a shaft, which is also free to revolve in its bearings, the trolley is easily manipulated by two men. The flooring on which the work is done must be kept level—cast iron plates are best for the purpose—as any unevenness will not only impede the working of the trolley, but is dangerous on account of the high centre of gravity of the load, and consequent liability to capsize if suddenly thrown out of the vertical.

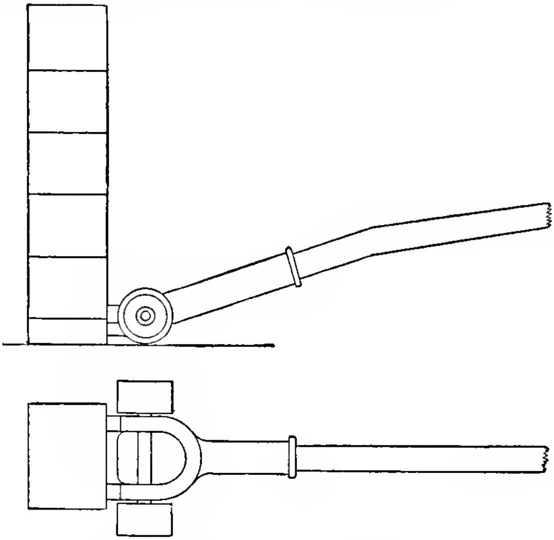


FIG. 43.—Trolley for small pans.

To further expedite matters, instead of sealing up the oven by building a wicket in the doorway, it may be closed by means of a firebrick door, the construction of which is shown in fig. 44; this can be slung to a "monkey," which travels on a runway secured to the buckstaves along the front of the stack, by means of a small pair of chain blocks or a lifting screw; the door can be slightly raised and moved across or away from the doorway as required, and after lowering into position, the "monkey" is available for other ovens. The sealing in this case is accomplished by applying the mortar (sand and fire-clay) to the inner edge of the wicket, which is then lowered into its place and secured by means of two crossbars fitted with tightening screws, or by iron wedges. In any case, the pressure required is only slight, and after pointing the edge of the door the fires are lit. So expeditious is this method that four men can withdraw and refill a 4-ton oven in two hours, including cleaning and relighting. The system, however, is limited to the use of small pans, as it would not be practicable to handle the larger ones in the same way.

In the packing of a case oven it is treated as a large pan, except that, as the front end is open, a retaining wall of firebrick is built across it as the work proceeds; when full it is covered with a row of plates similar to those laid along the bottom, and well luted.

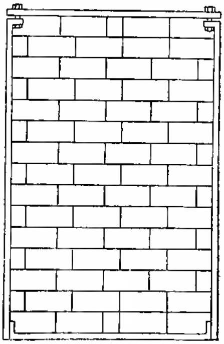


Fig. 44.—Firebrick door.

Where no case oven is available and only a few are required at a time, long castings are annealed in a vault built up in an ordinary can oven. In this case the side tiers are first built up in the usual way, and down the centre of the oven a low vault or case is built of firebrick resting on supported iron plates (fig. 45); on the top of this tiers of two or three pans may be placed to economise space and fill up the oven, so that the consumption of coal will not be out of proportion to the weight of castings annealed; this proportion varies considerably with the weight of the work in it. Starting with a cold oven of medium size, holding 4 tons of mixed castings, it works out at an average of 18 cwts. of coal per ton of castings. This may be reduced by as much as 15 per cent. by a skilful firing, well-sealed ovens, and close-fitting dampers, while neglect of these details will lead to a corresponding increase.

The fires are started immediately after the oven is sealed up. Best steam coal, in lumps only, should be used throughout—any good long-flaming coal is suitable, and if the castings are small or of such a character that they are not likely to fracture owing to rapid expansion, the fires may be forced with dampers wide open, until the heat is attained as shown by the pyrometer or cones; in an oven that has not been allowed to get cold this takes about ten hours; a cold oven will require twenty-four hours under similar conditions of firing. There are some castings, however, that, owing to their shape, are in a state of highly conflicting strains, and these will almost always fracture if the fire is forced at the beginning. In this case it is necessary to proceed slowly until a dull red is reached—about 1,200° F. The time taken for this should not be less than that required to attain full heat in the previous case. The firing may then be forced, and the full heat attained in about thirty-six hours. All wheels over 12 inches diameter, and castings made up of very unequal sections, should be treated in this manner. When the requisite temperature is reached (1,800° F.) the dampers are partly closed, leaving only sufficient draught to maintain the heat,

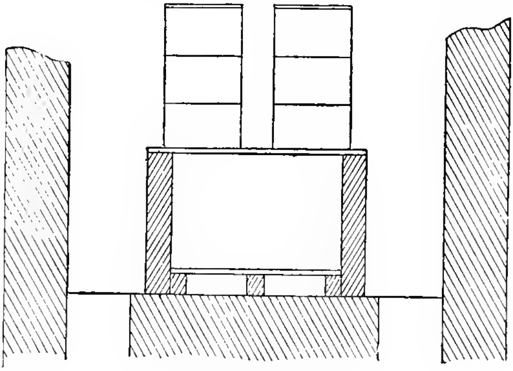


FIG. 45.—A vault.

which at first will fall off rapidly by absorption unless regulated properly. A drop of 80° to 100° F. is permissible, but should not be exceeded, and if kept well within this it will be an advantage.

Each time the fires are made up again the dampers are left full open until the heavy smoke has cleared away, which would otherwise leave a non-conducting deposit of soot on the pans, after which the damper is again partly closed.

It will be necessary to clean the fires every six hours, and as this operation admits considerable quantities of cold air into the oven, the fires should only be allowed to burn down one at a time, the others being kept burning briskly to maintain the temperature. The cleaning must be done quickly and thoroughly, all clinker being removed from the fire-bars with a slice and raked out together with the dead ashes. Fresh coal is then put on, and no other fire in the same oven must be burnt down or cleaned until this has burnt through.

The condition of the oven should be frequently examined through the observation holes in the wicket, which should be luted up again each time, and if the temperature is regularly maintained, the pans will commence to blister or "scale" in about twenty hours after the first closing of the dampers. The scaling increases until it leaves the pans and falls to the floor, another layer of scale forming almost immediately. From forty-eight to sixty hours will have elapsed from the commencement (observed) of scaling until this point is reached, and from this time the interior state of the oven is observed more often. When the second layer of scale has formed, but just before it commences to fall away, firing is stopped and dampers completely closed, and the oven is left to "soak" and cool down gradually; no less than twelve hours should elapse before the wicket is removed and the pans allowed to cool down more quickly.

By far the most satisfactory castings are those which are allowed to cool down in the pans until they can be handled, but as this has many disadvantages from a commercial point of view, they are generally taken out as soon as they have reached the state known as "black-hot." Malleable castings should never be exposed to the air at a temperature above dark "blood-red" (900° to 1,000° F.), or the result will be to chill them; this changes the nature of the carbon content and stultifies the entire operation of annealing through which they have passed.

It is only within recent times that this change in the structure of malleable cast iron was found to be due to air chilling. Previous to this it was generally supposed that when the castings had been annealed for the prescribed period the final condition was fixed, and was no more susceptible to change than a red-hot iron forging would be. The result of this was that, when the castings proved to be harder and not so ductile as anticipated, the condition was ascribed to other causes than the real one, being usually put down to imperfect annealing due to variations in temperature of the oven, weak ore, or an excess of sulphur in pig iron or fuel. As a matter of fact, the appearance presented by a fracture of a hard casting due to "chill" and that due to imperfect annealing are entirely different. In the first case the structure is changed from a granular to a fine crystalline one, very similar to that which is found in grey iron cast against a cold chill, except that instead of being superficially changed to a depth of $\frac{1}{8}$ inch, more or less, the malleable casting is changed right through. In the second case the fracture shows all the characteristics of the unannealed casting, only differing in colour, and being surrounded by a narrow band of blue-grey iron, showing that annealing has just commenced.

When the pans are withdrawn in tiers by means of the trolley previously referred to, they can be taken out red-hot and left standing until the castings are cool enough to take out, but where no such facilities exist the lid is removed from the top of each tier by means of a long crowbar; this will allow the heat to escape more rapidly, and when there is no fear of chilling, the tiers can be pulled over and the castings emptied on to the floor.

A well-annealed casting will have a fine blue-grey skin, with blue predominating, and except for a flimsy iridescent skin, or scale, which comes away easily, the castings should be perfectly clean and the sharp edges intact. If insufficiently annealed they will be of a greyer colour, and there will be no signs of the iridescent skin. On the other hand, if the annealing has been unduly prolonged, or if the temperature at any time has been too high, various fused or semi-fused substances will be found adhering to the work, the sharp edges are rounded off, and the excessive tumbling necessary to clean them still further destroys the symmetry of the castings.

On examination an over-annealed casting will be found to have a distinct skin of very soft iron about $\frac{1}{16}$ inch in thickness; this is not homogeneous with the rest of the metal, and can be peeled off. This is caused by a secondary process of annealing, which sets in immediately the first one is completed. It does not, however, extend beyond the depth stated, and if put through another oven the layer will become detached and another one will be formed on the body of the casting.

The treatment of castings that are insufficiently annealed requires care and judgment in re-annealing, especially if, as it sometimes happens, only those furthest away from the fire are underdone, while those from the hottest parts of the oven are soft enough. The top of the oven is naturally always hotter than the bottom, and consequently the work which requires the most heat to anneal it is put in the upper pans; this is one reason why sometimes the castings at the top are soft while those at the bottom are hard. Another is that, in large pans, the sides nearest the firegrate receive more heat than those further away, or than the centre of the pans. The usual practice to counteract this is to place the lightest castings, or those which require the least amount of heat, in that part of the oven where the temperature is lowest, keeping the heavy work and the hardest iron for the upper pans and the hottest side of the lower ones. It is possible under these circumstances that, if the entire contents of the oven are re-annealed, those which were already softened will be overdone, and it requires an experienced eye to discriminate between those that require further treatment and those that are sufficiently annealed, as well as to decide approximately how much more heat the hard castings will require to complete the anneal.

If the oven is systematically packed as already described, and the first castings drawn are hard, it may generally be taken for granted that the remainder of the work is in a similar condition, and the best course then is to seal up the oven again and force the firing until the required temperature is reached, maintaining it for a further period of twelve to twenty-four hours, as the condition of the fracture of a tested casting may indicate.

When only a part of the work is hard, these castings are re-packed in pans, using black ore only, and placed in a special re-annealing oven for further treatment. This is a small oven which can quickly be brought up to the required temperature, and which may also be used for very light, thin castings that can be annealed in two or three days. The construction of this oven is shown in fig. 46. As a rule it will be found that re-annealed castings are not so satisfactory as those completed in one heat, the cooling and re-heating affecting the carbon content—a delicate element which up to the present time has defied control, and the vagaries of which are apparently inexplicable.

It is interesting to note that only the carbon is affected by the annealing process, all other contents remaining the same as in the pig iron. These have considerable influence in determining the ultimate condition of the carbon, but beyond the fact that there is a considerable difference in the nature of the carbon of high and low sulphur irons respectively after annealing, and that iron high in silicon can be annealed at a lower temperature than that in which the percentage of silicon is low, metallurgists are apparently at fault, and no reliable information is forthcoming.

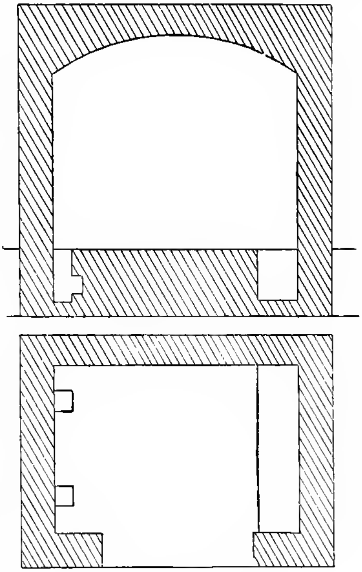


Fig. 46.—Re-annealing oven.

The scalings from the pans are sold to metal merchants, who stipulate that they must not contain an excessive proportion of sand and other impurities. The present price is about 7*s*. 6*d*. per ton. In some foundries the scalings are used by the furnaceman for cleaning out the cupola at the end of the heat. A few shovelsful thrown on the top of the last charge have the effect of bringing down considerable quantities of slag and other adherent matter when the bottom is dropped, leaving the lining cleaner and easier to repair than would otherwise be the case.

Castings that are required to be exceptionally soft are double annealed—that is to say, they are put back into the ovens for a further period of six days, and so that the annealing may not be overdone they are packed in old ore only, and placed in the coolest parts of the second oven. It is not necessary to clean them in any way before repacking them, and above all, they must not be tumbled, or, on withdrawing them at the end of the second heat, they will be covered with a thick tenacious scale that is most difficult to remove. Even if the ore has been treated with sal ammoniac it will cause the same accumulation of scale, and for this reason old ore as taken from the ovens must be used, the finishing anneal being done more by heat than by the action of the ore, which merely acts as a pabulum to hold the castings in position.

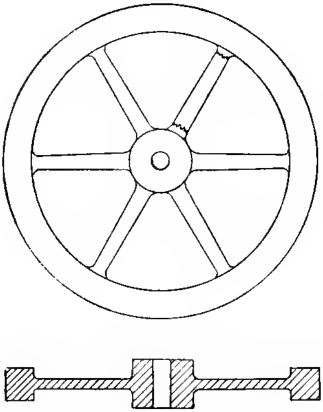
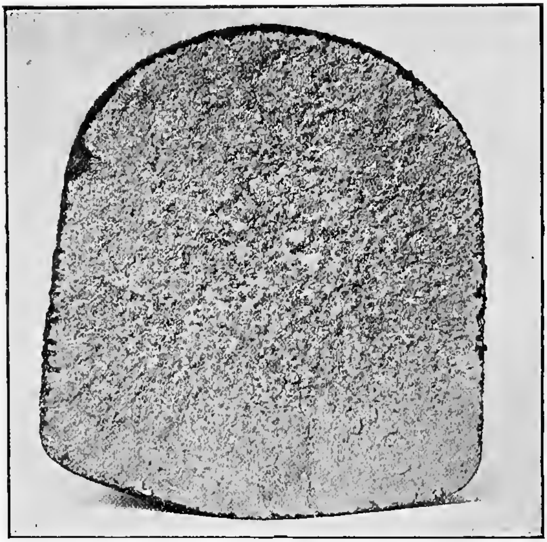


Fig. 47.—Fractured wheel.

If a piston or wheel with a heavy rim is loosely packed, the rim will sink below the level on account of its greater weight; for this reason they are always placed at or near the bottom of the oven, where the least subsidence takes place.

One of the greatest difficulties the founder has to contend with is the frequent breakage of wheel arms in the annealing oven (fig. 47), especially if the rim is heavy and the arms light in proportion. This is due to the fact that the heat passing through the sides of the pan reaches the rim first, causing it to expand while the arms are comparatively cool. The risk is considerably minimised by setting the wheels up on the edge in a case oven so that the heat reaches all parts of the wheel simultaneously. The method has the disadvantage of sometimes causing the castings to assume an oval shape



MALLEABLE PIG IRON.—MEDIUM MOTTLED.

Approximate Analysis.

Graphitic carbon, 1·90 per cent.; combined carbon, 1·75 per cent.; silicon, ·84 per cent.; sulphur, ·152 per cent.; phosphorus, ·05 per cent.; manganese, ·36 per cent.

under the combined influence of pressure and heat, unless the ore is very closely packed round them, but as a rule it is not very difficult to bring them back into shape afterwards, and whilst a bent casting is an every-day detail, a broken one is a dead loss.

In most small foundries the temperature is determined by observation only, and is not measured in any way. A skilled annealer can note with commendable accuracy variations in temperature that would not be apparent to anyone less experienced, and there are still some founders who claim that the trained eye is more reliable than a pyrometer, and not as likely to get out of order. This claim is evidently based on unfortunate experience in the use of cheap and inferior pyrometers, as the improved instruments are now considered indispensable in large establishments. They certainly require careful handling and adjustment, and add to the cost of production in small quantities, but expert annealers constitute a class of skilled men for which the demand is greater than the supply, and under these circumstances it becomes necessary to ascertain the temperature by some other means when the services of an expert are not obtainable. Probably the simplest and most inexpensive way of doing this is by means of what are known as "Seger cones." These are small triangular pyramids of refractory earth mixed with substances having different melting points, which collapse when the prescribed temperature is reached. They may be obtained with melting points ranging from 1,094° F. to 3,470° F., and are so simple to use that an unskilled labourer can readily understand their working and accurately gauge the temperature of the oven. For this purpose three of the cones are placed in the hottest part of the oven near the top, shielded from the direct action of the flame, and in such a position that they can be observed through the holes in the wicket or door. The cones most suitable for the purpose are those numbered 010, 09 and 08, having melting points of 1,742°, 1,778°, and 1,814° F., respectively. The collapse of the first of these indicates that the required temperature is being approached, and that the firing may be slightly checked. When the second cone begins to bend over the necessary temperature has been reached, and dampers are to be closed. The third cone acts as a danger signal, and under good management should remain erect throughout the duration of the anneal.

Fresh cones may be introduced into the oven through the observation holes during the process, and as they are sold cheaply, their continuous use is a good investment. Nothing is so conducive to good annealing as a full temperature maintained with as little variation as possible.

The American process of annealing in the production of blackheart malleable castings differs from the European method in that the heat is brought up to the desired point as quickly as possible and maintained there for only a short period—about forty-eight hours—after which it is allowed to cool down very slowly, in consequence of which there is less distortion. The high sulphur iron used in this country will not stand this treatment, as a large percentage of the castings would inevitably fracture under rapid expansion. Rolling mill scale, which is the American medium in which the castings are packed, will also anneal the irons of this country, but the result throughout the oven is not so even as when ore is used; in addition to this a very tenacious scale is formed on the castings, and this is difficult to remove. On one point, however, both systems are in complete agreement, viz., that castings which are allowed to cool down slowly in the pans in which they have been annealed are in every way superior to those which have been exposed to the air while at red heat.

Pipes and other hollow castings having comparatively thin walls of metal are liable to be crushed in the annealing process, and as it is always difficult, and sometimes impossible, to restore them to the proper shape, some precaution is necessary to prevent it. Filling with ore is insufficient, as it cannot be tightly rammed and will yield to the pressure. Black sand, rammed tightly, is better, but as the sand must be damped for the purpose it will give way a little when dried up with the heat. The best way is not to remove the core until the casting has been annealed. This method has one disadvantage —it does not allow of inspection of the interior previous to annealing. If, however, due care has been exercised in making the core and preparing the mould, the chances of annealing a defective casting are reduced to a minimum, and the assurance of a well-shaped casting is worth the risk, as in some cases a casting of this description will become so badly distorted as to be utterly useless.

It is contended by some that the sand will prevent annealing of the surface with which it is in contact, leaving it hard and unfit for machining, if such is necessary. It is difficult to see upon what grounds this assumption is based, as if the action of the annealing medium will penetrate a casting 2 feet thick, it must be obvious that it will anneal a comparatively thin wall of metal from one side, regardless of whatever substance may be on the other. Probably the idea originated in the early days of manufacture, when the process of annealing was imperfect and hard castings were attributed to causes other than real ones.

In order to economise space and ore it is easy to pack small castings in the open spaces amongst larger ones. An illustration of this is shown in fig. 48, taken from actual practice. In the spaces between the arms of the wheel are placed elevator buckets, and they in turn are filled with layers of small, light castings packed in black ore only; the remaining space is occupied by other castings of appropriate shape.

The following table gives approximately the temperature of the annealing oven as it appears to the eye of the observer:—

	Deg. Fahr.
Dull red heat ...	1,000
Red heat... ...	1,400
Bright red heat ...	1,600
Yellow heat ...	1,800 (annealing temperature)
Melting point ...	2,000

The boxes, or "pans," as they are generally termed, are made from scrap iron of every description melted down in the cupola and run into open moulds; plenty of malleable scrap is used, as this prevents porosity, which is fatal to successful annealing, while the pans are much more durable and do not scale so heavily as would be the case if ordinary cast iron pans were used. Where there is no separate cupola available it is customary to make up the last charge of "pan iron" when all the malleable work has been cast up, so that no iron of a doubtful character may get into the moulds, and as the cupola is thoroughly cleaned out before the next melt no contamination is likely to occur afterwards.

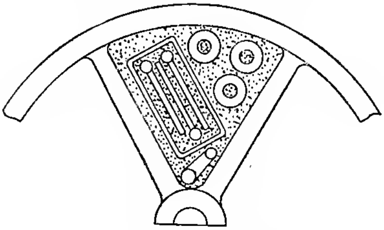


Fig. 48.—Method of packing.

The shape of the pans may be either cylindrical or rectangular, the capacity varying according to the class of work they are intended to contain. Only one in five is cast with a bottom to it, and this forms the lowest pan in each tier, the remainder being rings which are laid one above the other as the packing proceeds. The thickness of the metal ranges from 1 inch in the smaller pans to 1¼ inch in the larger; this is reduced by scaling each time the pans are used. Good pans will stand from eight to ten heats before they become too thin and weak to withstand the pressure within, and they are then melted down with other scrap and re-cast into new pans. If made from cheap cast iron only—such as cinder pig—the "life" of a pan will seldom extend over three heats, and they are not infrequently worthless after one heat only.

The following dimensions, measured inside the pans, will be found suitable for all practical purposes:—

Rectangular.	Round.
12″ × 12″	12″ diameter
1′ 6″ × 1′ 4″	2′ 0″ diameter
1′ 10″ × 1′ 6″	3′ 6″ diameter

A uniform depth of 12 inches is the most suitable, as, if made any deeper, they are not so convenient for packing, while the adoption of shallower pans, although useful for some special purposes, only adds to the number of joints. This is undesirable in view of the ever present risk of burning the work owing to defective joints.

The use of pans designed on the "spigot and socket" system (fig. 49) is favoured by some annealers. This ensures good joints and makes a rigid tier, but it has disadvantages that do not recommend it for general use. The pans are not so easily moulded, and consequently cost more than those with plain edges, and owing to the distortion that invariably takes place, much time is lost in fitting them together after the first heat, unless the same pans occupy the same relative positions, which is not always practicable. There is also the difficulty of fitting new pans to old ones, and if the sockets are made of ample size to allow for this there is the risk of telescoping under the influence of heat and vertical pressure.

Round pans are much stronger than rectangular ones, being "self-stayed"; they offer a greater resistance to internal pressure than the flat sides of the latter, which bulge out under each successive heat until unfit for further use; for this reason the sides should never exceed 2 feet in length. On the other hand, much more work can be packed into an oven in square pans than in round ones; roughly speaking, this amounts to about one-fourth more, or as the area of a square to that of a circle having a diameter equal to one side of the square. The economical advantage of close packing more than counterbalances the loss in pans through distortion, and square pans are therefore much more generally used.

All pans must be fairly true on the edges so as to ensure as good a joint as possible, and uniformity in depth all round is essential in order that the tier may retain its vertical position throughout the heat, and the strongest and newest pans are always used at the bottom of a tier in order to withstand the combined weight, while for the topmost pans in each tier those which have been burnt down to $\frac{1}{2}$ inch or $\frac{3}{8}$ inch in thickness may be used. The largest rings or pans, 3 feet 6 inches diameter, always become very badly distorted along the edges in spite of all precautions, so that in building up the tier there will sometimes be an opening in portions of the joint of from $1\frac{1}{2}$ inches to 2 inches which cannot be effectively sealed with mortar only, and in this case the joint is made good by covering the openings on the inside with iron plates—pieces of old broken pans being generally used for the purpose—before luting the joint all round. A lid or cover for large pans

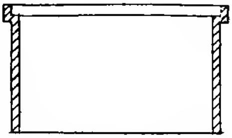


FIG. 49.—Socket pan.

of this size would be too unwieldy to be practicable, so that the tier is covered by means of plates, as shown in fig. 50. Similar plates are used for the bottom on which the tier is built up, as a pan with a bottom to it is seldom used for large sizes, rings only being used, although they are all known as "pans" in some districts, and as "cans" in others. A covering of plates of this description is necessarily weak, and owing to the number of longitudinal joints there is always a certain amount of risk of burning the castings in the topmost ring, so that, in addition to well luting the joints, it is advisable to cover the whole with a layer of black sand about 3 inches thick; this must be well beaten down with the palms of the hands and will effectually prevent ingress of the flames if the luted joint should be broken.

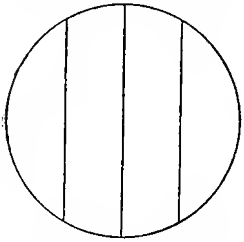


FIG. 50.—Top and bottom plates.

CLEANING AND STRAIGHTENING

Properly annealed castings require very little cleaning. In the case of large castings a good hammering will usually dislodge all the adhering matter, and this may be accomplished by cutting down all the feeders and gates before grinding them off. Smaller castings, from 50 lbs. downwards, are put into a tumbler with a quantity of small hard scrap; this scratches the surfaces and leaves it clean and bright, while the addition of a quantity of leather scrap will give a polished surface that is often called for. Instead of utilising hard scrap, some firms use what are called "stars" (fig. 51); these are very effective, but as they have to be specially made, the advantage over hard scrap is doubtful. By hard scrap is meant small waster castings, small feeders and runners broken up into convenient lengths, together with the flash knocked off from castings before annealing. As the sharp edges of the scrap become rounded by constant friction it should be discarded and fresh scrap substituted, or the time required for cleaning will become unduly prolonged. Old emery wheels that are useless for other purposes may be broken up and thrown in. With the ordinary horizontal tumbling barrel (fig. 52) about two hours are necessary to complete the cleaning and polishing, and the consequent friction for this prolonged period rounds off all sharp edges and spoils the appearance of the work. In many cases this is immaterial, but in others it is important, and the difficulty may be overcome by using a tumbler that is hung obliquely (fig. 53). This gives an endways motion to the castings in addition to the rolling

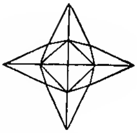


Fig. 51.—Cleaning stars.

motion, and is so much more effective that the work can be done in from thirty to forty-five minutes. In either case the tumbler should be run at a speed of not more than fifty revolutions per minute. If this is exceeded the centrifugal force gradually overcomes the force of gravity in proportion to the increase in speed until the castings are carried round without any independent motion, and the process becomes inoperative.

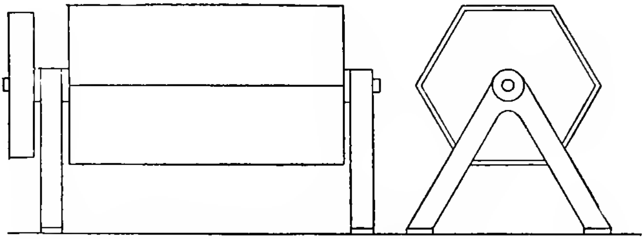


Fig. 52.—Horizontal tumbling barrel.

The final dressing of the castings consists in removing all superfluous metal, such as flash, gates, feeders, etc. Very small castings are moulded so that the runners break off close up, and these are finished when they are taken out of the tumbler, but larger ones have the gates and feeders broken off about ½ inch from the casting so as to prevent possible damage to the surface, and these protuberances have to be chipped or ground off level.

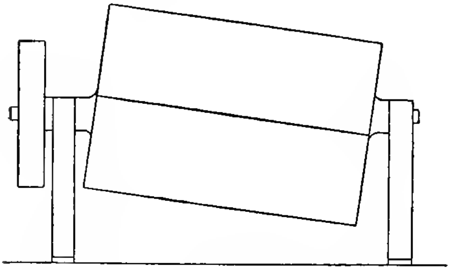


Fig. 53.—Improved tumbling barrel.

The grinding is done by means of coarse emery wheels of different sizes to suit the class of work done. They range from

24 inches by 3 inches for heavy castings down to 6 inches by $\frac{1}{2}$ inch for light and intricate work. All machines should be provided with a rest on which the work can be held while grinding, and castings which are too heavy to handle in this way may be suspended by means of chain blocks in such a way that they hang by their own weight against the face of the wheel. This is a better way than standing the work on end and allowing it to lean against the wheel, as, being suspended, a casting can be manipulated with ease by one man which would otherwise require two men to handle it.

Makers of emery wheels will supply wheels specially adapted for malleable castings, which have a tendency to clog the ordinary wheels, the soft metal filling the interstices so quickly that the action becomes a rubbing and not an abrasive one. This always happens if the wheel is too hard or too fine grained, while if too soft the particles of abrasive are torn out without doing effective work; a grade of 14 to 16 will be found most suitable for all-round purposes. The numbers indicate the size of mesh through which the grains will pass; thus, a 16-grade wheel is made of grains that will pass through a sieve having a mesh of $\frac{1}{16}$ inch, but will not pass through the next size smaller. Even the most suitable wheels will glaze and clog if too much pressure is applied, so that to remove a maximum of material in a minimum of time only a moderate pressure should be used. The peripheral speed should be kept as near as possible to that recommended by the makers. This is done by changing the wheels as they wear down and putting them on a suitable spindle running at a higher speed. If they are run at too high a speed the wheels will glaze, and if too slow the emery is dislodged as in a soft wheel.

Wheels that are glazed or worn out of truth can be corrected by means of a dressing tool, of which there are several kinds on the market, and if this is done frequently more work can be done, and at a cheaper rate than if the wheels are allowed to become eccentric, in which the case of trueing up involves cutting to waste a considerable quantity of valuable abrasive material. Eccentricity is also due to unsteady foundation. The bearings of grinding machines may be either babbited or of hard cast iron, the latter for preference, and should always be enclosed to protect them from the cutting action of the dust, using a solid lubricant and screw-down lubricator in preference to sight-feed appliances or simple oil holes. They must be kept a good fit on the spindle; any looseness or play will soon cause the wheels to run out of truth. The workmen employed on grinding machines should wear goggles to protect their eyes from the flying particles of emery and iron.

An intelligent grinder can not only distinguish between hard and soft castings by the rate at which the metal is removed, but by observing the character and appearance of the sparks it is possible to grade the castings into several qualities with a fair amount of accuracy.

The use of pneumatic appliances in the fettling or dressing shops is of modern growth and is rapidly coming into favour, especially pneumatic hammers for chipping down where grinding cannot be done, but the cost of installing the necessary air-compressing plant, together with maintenance, distribution, and cost of appliances, make the system prohibitive unless a large and continuous output is assured. The use of the sand blast for cleaning castings does not compare very favourably with the old-fashioned methods, but if the output justifies the cost of installation there is no better method of cleaning castings than by tumbling them in a barrel hung on trunnions through which a sand blast is introduced.

A final polish is given to some classes of work, and this is done by putting them loosely in a tumbler without any hard scrap or gritty material, using only leather waste. The addition of a small quantity of graphite at first with new leather causes the latter to become impregnated with it and gives a particularly good finish. Old and discarded plumbago crucibles, broken up small and used in conjunction with the leather, also help to improve the appearance of the castings.

All malleable castings are liable to become distorted in the annealing process. This is principally owing to the fact that it is not possible to ram the annealing medium sufficiently tight to prevent the subsidence of the mass, which, owing to the superimposed weight, takes place when the heat is up, and continues during the whole period, and if the proper temperature has been maintained the subsidence, measured from the top, will amount to from 4 inches to 6 inches in a tier of boxes 5 feet high. As some castings, owing to their shape, are more liable to distortion than others, it is usual to place any that would be difficult to restore to shape as low down as possible in the bottom pan, where the subsidence is least.

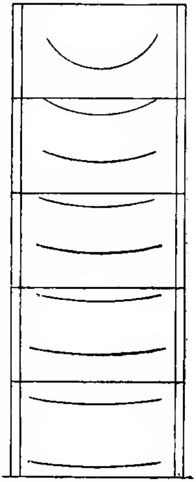


FIG. 54.—Distortion by subsidence.

The distortion of castings from this cause is seldom difficult to correct because the intervening layers of ore form a cushion which causes the deflection to take the form of an easy curve. Fig. 54 shows the effect of this in different parts of the tier. The worst form of distortion, and one that it is frequently impossible to correct entirely, is that which happens when the ore is not well worked down, or when there is only a thin layer between two layers of castings. In both cases the upper castings will sink until they are almost, if not quite, in contact with those beneath, and gradually sinking further, they cause an abrupt bend (fig. 55) which is almost sure to fracture on any attempt to straighten it, except at such a high temperature that it would seriously affect the nature of the casting in its finished state.

Fig. 55.—Abrupt bend.

Castings such as lever handles, pipes etc., which are packed on end and occupy two or more pans, are also liable to distortion owing to side pressure of adjacent and imposed castings (fig. 56) and also to the tilting of the tier, which is sometimes unavoidable. When the fires are first lit the sides of the tiers nearest to them expand quickly and cause the tier to lean slightly away from the fire until the temperature throughout the oven is fairly equalised, when it again becomes perpendicular, but subsequently the side nearest to the fire becomes softer than the other and, collapsing under the weight, causes the tier to lean over to that side (fig. 57). The effect of this on the work is very slight, but if aggravated by the other causes already described the difficulty of straightening is increased.

Fig. 56.—Distorted lever.

Thin, light castings are easily straightened cold with a hand hammer on an anvil or block which is slightly hollowed on the face, and if the bent portion is not more than ½ inch thick and about the same amount per foot out of truth it may safely be heated to a dull red blood heat, and swaged down with a flat set and a light sledge hammer, but for dealing with heavy castings and large flat surfaces it becomes necessary to use a powerful screw-press similar to that shown in fig. 58.

The bed or block of this is of cast iron, 6 inches thick, and solid, except for the hole in the middle; it is 4 feet 6 inches square, is planed level on the top and rests on four stout cast iron supports, which in turn are bedded in concrete on a solid foundation. The solidity of the bedplate is essential, as it is partly an anvil block intended to resist the heavy blows of a sledge hammer on castings held down by the screw, for which purpose a lighter plate, even when stiffened with ribs on the under side, would be too springy and unsuitable.

The uprights are of 3½-inch steel shafting, turned down to 3 inches at each end to fit the holes in the plate and crossbar, and secured with nuts. The crossbar is a malleable casting, 6 inches deep at the centre and 4 inches at the ends, the thickness between the bosses being 2 inches.

The screw is 2½ inches diameter with a square thread of ½-inch pitch working in a gunmetal nut, which fits accurately into the crossbar and is flanged and shouldered to take up the thrust.

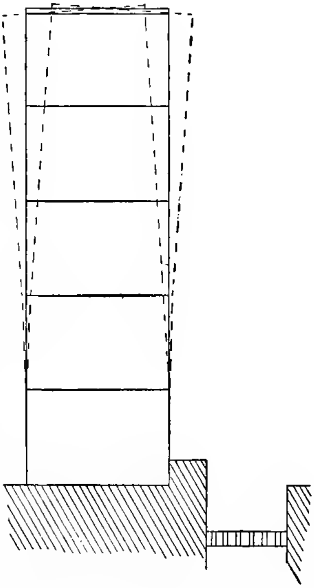


FIG. 57.—Oscillation of tiers.

The end of the screw is hardened, and to ensure steadiness when the pressure is applied, as well as to prevent marking the work by the boring action of the point, it works in a malleable nose-piece fitted with guide rods working in holes drilled in the crossbar. The wear and tear on both screw and nut are necessarily very heavy, and however accurately fitted they soon work loose, so that without some provision such as that shown there will be risk of side-slip, especially when working on a die built up of separate loose pieces.

The wheel is of cast iron, with a heavy rim to give momentum to the screw, and it is pierced round the rim with holes 1¼ inch diameter into which a steel bar can be introduced in order to give greater leverage if necessary.

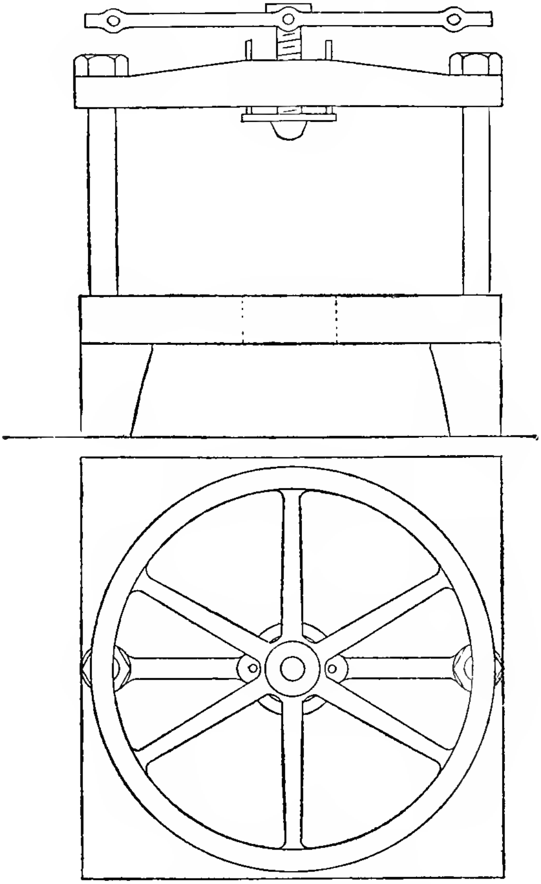


FIG. 58.—Straightening press.

The furnace for heating the work is very similar to that already described for muffling, except that the floor is level with, or slightly higher than, the bed of the press, and it should be erected in close proximity to the press so that no time may be lost in transferring the work. This is particularly important, as it is sometimes necessary to rig up the press in such a manner that the pressure is only applied to certain portions of the casting; this takes up some little time, and as it can only be done with the casting in position it must be done as quickly and with as little loss of heat as possible. Perhaps the best, and certainly the most expeditious way is to have a davit or wall jib located midway between the press and the furnace, so that the arc traversed by the outer end passes through the centre of each. Attached to this is a pair of handy chain blocks which should be non-slipping to prevent accidents, and these in turn carry a pair of grab hooks or biters for picking up the hot castings; of these there are many kinds in use, but those illustrated in fig. 59 will be found suitable for castings of any shape, and the same may be said of the tongs which are used for handling the work. Two of each of these should be kept handy, so that men on opposite sides of the work can assist one another in manipulating it. The following examples are typical of the methods employed in straightening various classes of work.

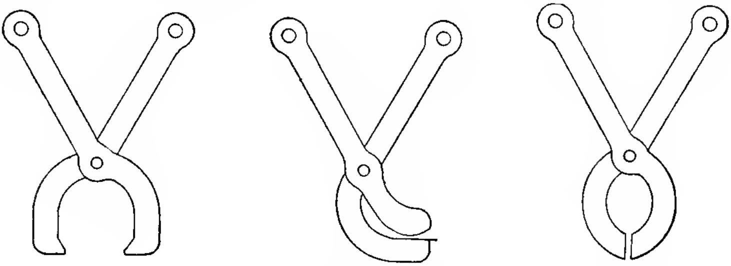


FIG. 59.—Biters.

Wheels. These belong to a class of work where the form of the casting in every dimension must be fairly good, and as they are sometimes distorted in several directions, the work of straightening is one which calls for some skill on the part of the straightener in order to carry it out in a few operations and with as little loss of time as possible. Fig. 60 shows, slightly exaggerated for clearness, a spur wheel blank distorted in three directions. The rim is not straight, the boss is out of line with the rim, and the rim is also oval. The casting is brought to a suitable heat—dull red, or about 1,000° F. is best—and laid on the centre of the press. A short length of steel girder, which must be longer than the diameter of the wheel, is placed so as to rest on the boss with the ends lying over the highest parts of the rim, on which immediately under the girder are laid two distance pieces corresponding to the height of the boss above the rim in the pattern; pressure is then applied to the girder, which first presses the boss down until the distance pieces are reached, and the rim is then squeezed down flat on the bed. The pressure is maintained for a few moments while the rim is hammered down with a sledge hammer to prevent springing back when the pressure is removed, and when this has been done the wheel is turned on its edge with its longer diameter in the direction of the thrust of the screw, and pressure is again applied until it resumes a circular shape, as shown by callipers or trammels.

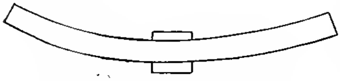


Fig. 60.—Distorted wheel.

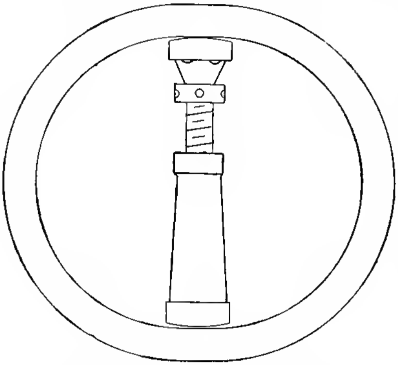


Fig. 61.—Use of screw jack.

Rims only, commutator rings, large flanges, and all castings of a similar class are treated in the same way, except that there is no boss to bring into line.

It is seldom that such castings are made in malleable iron larger in diameter than the press described can accommodate, but in such a case the best way to overcome the difficulty is to adopt another plan for flattening down, bringing the opposite sides alternately under the screw, and to correct any ovality by means of screw jacks (fig. 61).

Cylindrical castings, such as short lengths of piping which have become flattened, may be restored to their circular shape by squeezing between a pair of saddle-blocks (fig. 62), of which several pairs to suit approximately different diameters should be kept in stock, or a plug with rounded ends may be forced through. The barrels of hubs of the artillery type become flattened at one end only, the other being stiffened by a flange, and in this case they are corrected by driving in a conical plug. If the flanges are bent they are flattened down on to a plate larger than the flange, in which a hole is cast large enough to miss the fillet at the junction of the barrel and flange. In the case of a pipe with a flange at each end, the ring is made in halves to slip under it.

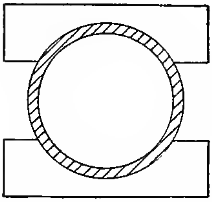


FIG. 62.—Saddle blocks.

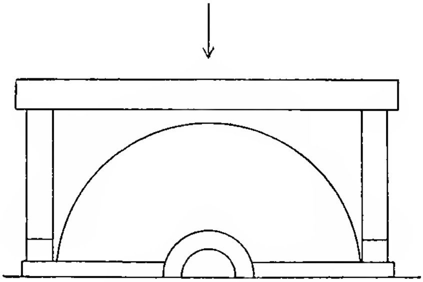


FIG. 63.—Bridging.

Fig. 63 shows how to straighten the flanges of a crank-case which have been bent downwards; and although it is possible to accomplish this by pressing the centre of the casting and hammering down the flanges, there is always a risk of fracture at the angle that is avoided by packing and bridging as shown.

For castings of irregular shape, and for those which do not allow of their being pressed down on the flat surface of the bed, recourse must be had to die-blocks; these are of cast iron, and are made to follow the outlines of the casting in one or both planes, as may be required. A block for a bevel wheel, for instance, would have a tapered hole representing the face of the teeth, into which the wheel could be pressed, while the crank-shaft shown in fig. 64 would require two blocks; the lower one is moulded from a plaster cast, taken from the pattern in such a way that when pressed down on it the shaft is in line and the cranks are at the correct angle. The upper block is of inverted V section, with projections cast inside to bear on cranks and shaft in such a way that they are forced into their proper place on the die.

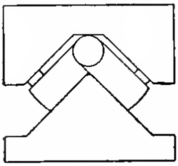


Fig. 64.—Die-block.

When one only, or a few castings are required, the cost of making a die-block is not admissible, and the work must be done on a temporary die built up of any suitable packing-pieces by placing the pattern under the press in the position to be occupied by the casting, and so using it as a templet. There should be no difficulty in doing this; but, of course, the work cannot be as accurately or as quickly done as on a specially prepared block, which is similar in effect to drop-forging, the difference being that the shape (in section) is already formed, so that it is only necessary to get the various parts of the casting into correct relation with one another.

A good stock of wedges is indispensable, and they may be of malleable iron made in different thicknesses and widths, the taper being at the rate of 1 in 12. They are mostly used for forcing out portions that have been crushed in, and may be either forced in under the press or driven in with a sledge hammer, as may be most convenient. Fig. 65 is an example of how they are used on a casting not amenable to other methods. The wedges are also used for packing and for built-up dies, and used in pairs, head to point, they are more easily adjustable than parallel blocks for the purpose. A few should be curved one side, so that they can be used for circular openings.

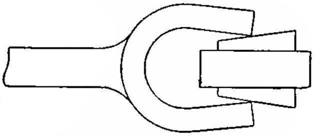


FIG. 65.—Use of wedges.

Long castings, and especially those of circular section, should be supported on V blocks under the press, otherwise there is always the risk of side-slip; an inverted V block under the screw will also ensure steadiness and pressure applied in the proper direction. In nearly every case it will be found that the casting will spring back slightly when the pressure is removed, so that it is necessary to force the corrected portion a little beyond the amount required, to allow for this; the amount varies with the size and shape of the casting, and also the temperature at which it is pressed, so that it is not possible to state exactly what the allowance should be; it is approximately $\frac{1}{16}$ inch per foot in length or diameter; but some experience is necessary to be able to judge it to a nicety.

Thin flat surfaces and discs should never be hammered at the edges, or they will become buckled, and when this happens they are usually most difficult to restore; if hammering is really necessary it must be done at least 1 inch away from the edge.

It will be found that castings that have been annealed in a case oven are less liable to distortion than those out of ordinary ovens, in which the annealing pans also become distorted with the heat.

A desirable, though not indispensable, adjunct to the straightening press is a setting plate. This is a large cast iron plate, 5 feet square and 4 inches thick, pierced with holes 1½ inch diameter and 6 inches apart. It should be bedded down on the floor so that the straightener can get quickly round and over his work, and is chiefly of value because it allows a badly distorted casting to be straightened at several points with only one setting by means of wedges driven in between the affected part and steel pins dropped into the nearest hole in the plate. Fig. 66 shows how a large gear ring blank, that is not merely oval, but also irregular in shape, may be corrected on a setting plate, and it will be seen that neither press nor screw-jacks could be so effectively utilised for the purpose.

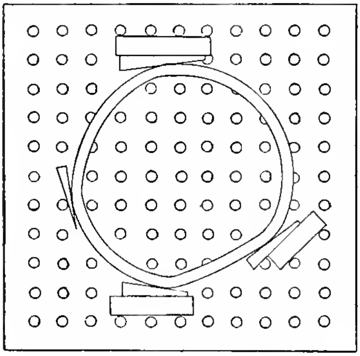


Fig. 66.—Setting plate.

Plain flat castings of any description can be laid one on another in a pile under the press, with a flat slab on top, and the whole lot flattened down together. This will save time, although the pressure, being transmitted from one to the other, had better be maintained for a minute or two to allow the castings to cool down slightly, and so prevent springing or recovery when released. Close-grained castings will sometimes spring considerably; but a few smart blows with a hammer on the surface while under pressure will give the crystals a set and prevent this.

Castings in which there are abrupt and widely different changes of section are apt to warp more or less after being straightened hot; but as this only happens when they are allowed to cool down quickly in the open air, it may be avoided by burying in ashes immediately after straightening; this should also be done in every case where a casting has accidentally become overheated in the furnace, otherwise a chilled surface will result.

It must not be supposed for a moment that any blacksmith can straighten a malleable casting; on the contrary, they are inclined to be over-cautious, and to work with a constant fear of breakage. Local straightening with the aid of a forge is advisable in some cases, when only a part of an otherwise correct casting has been bent or distorted, such as a projecting arm or bracket, and this is straightened after heating that part only, doing away with any chance of subsequent warping or chilling which might occur if the entire casting was brought up to the required heat.

Long castings that are bent along their whole length cannot be straightened by pressure applied to the centre only, but must be done in sections in a similar way to that adopted for working on cold rails with a rail-bender, which can be used for the purpose instead of a press, and unless the section of the casting is very heavy and very badly bent they can also be worked cold, as the amount of deflection required at each point will be very small.

Castings should always be warmed in very cold weather, as there is then greater risk of fracture, and, as a substitute for ashes in which to cool them down, old ore is frequently used.

To break a substantial malleable casting that has been properly annealed is an exceedingly difficult proposition owing to its excellent resilient properties, and if it is necessary to break up a large waster annealed casting into suitable pieces for re-melting, it can only be done by bringing it to a bright red heat and immediately plunging it into cold water; the sudden contraction will cause it to fracture in several places, and will so harden the iron that it can be broken up under a heavy drop-weight.

The cooling bosh is an accessory to be found in all malleable foundries, and is usually a tank of wrought iron, not less than 2 feet deep, sunk in the ground to the level of the edge, and fitted with supply and discharge pipes, so that when necessary a stream of water can be kept flowing through. The discharge should be as near the top as possible in order to carry off the heated water. In addition to the purpose already referred to, it is used for breaking up large feeders, which sometimes weigh over 1 cwt., and which, on account of their bulk, cannot be broken up otherwise.

DESIGN

The principles governing the design of malleable castings are similar to those adopted for common iron, with the exception that, owing to the higher contraction of the iron employed, the initial strains are proportionately greater, and, although these strains are relieved in the subsequent process of annealing, the fact must not be regarded as having any influence on proposed designs, as it is in the hard unannealed casting that faults due to unskilful design are originated, and no amount of annealing will convert a structurally weak casting into a strong one.

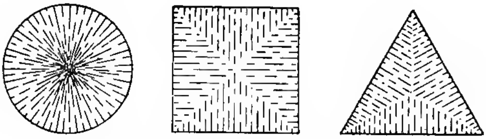


Fig. 67.—Disposition of crystals.

The first, and perhaps the most important, point to take into consideration is the disposition of the crystals as the iron passes from fluid to a solid state; this is governed by natural laws, in obedience to which the crystals always arrange themselves in certain definite directions during the cooling of a casting in the mould, and retain their position after it has set, the line of direction being that in which the heat passes from the centre of the mass or section to the outside (fig. 67). From this it will be seen that the "set" of the crystals is determined entirely by the form of the casting; regular crystallisation means a maximum of strength, but the point at which the continuity is broken or interrupted is a potential source of weakness; this is not so apparent in common iron, but in a malleable casting the high rate of contraction is sufficient to cause the crystals to pull apart at what may be important points, and so destroy the homogeneity of the mass entirely. This is especially noticeable in castings having a sharp angular section (fig. 68); here the crystals, acting independently, show a well-defined line of separation running from the inner to the outer angle. This can be plainly seen by breaking up a casting of the section shown, and is a palpable weakness. It may be avoided by rounding the inner and outer angles, as in fig. 69; the radiating form then assumed by the crystals gives a maximum of strength and reduces the structural strains to the lowest possible limit.

In the girder, or H section, it is not possible to apply this remedy, and for this reason it should be avoided, not merely because of the divergence of the crystals at the angles, but also because of a tendency to rupture while cooling, owing to the sand preventing the sides from coming in. Channel sections are also subject to this weakness, but otherwise they may be treated as for angles.

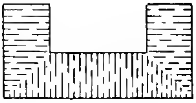


FIG. 68.—Bad section.

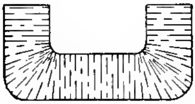
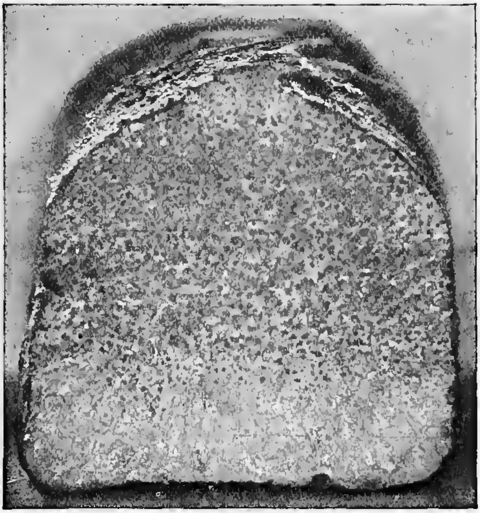


FIG. 69.—Good section.

By means of chills, crush cores, and the proper disposition of the feeders and gates an expert moulder can counteract most of the defects to which a casting may be liable, but it is better policy to do so in the design than to trust to mechanical aids which, after all, only set up an artificial structure of the crystals and induce strains that cannot be rectified by annealing, but are only relieved to a certain extent.



Malleable Pig Iron.—Hard Mottled.

Approximate Analysis.

Graphitic carbon, 1·00 per cent.; combined carbon, 2·62 per cent.; silicon, ·72 per cent.; sulphur, ·162 per cent.; phosphorus, 0·5 per cent.; manganese, ·33 per cent.

To put it in another way, the object of the designer should be to aim at getting a casting in which the disposition of the crystals throughout is a perfectly natural one. Of course this is not possible in all cases, but by keeping the idea in view it is always possible to get the best of a difficult detail.

There are so many different grades and qualities of malleable iron that it will be necessary to decide upon one of them before the factors for necessary calculations can be ascertained, and the following table, based on averages, will be useful:—

Class of work.	Iron.	Max. T. S.	Elong. %.	Reduction %.
Cast gears, brake drums, sprockets, elevator buckets, etc.	Close grained	27	1·5	2·0
Wheel blanks, engine details, brake bands	Medium	22	3·0	4·0
Gear cases, machine parts and all thin sections	Open	18	4·5	5·0
Admiralty specifications . . .	—	18	4·5	5·0

Crushing stress 50 to 80 tons per square inch.

It is noticeable that the increase in tensile strength is only secured at a sacrifice of ductility, and in the course of extended experiments by the author on specially cast test bars, 12 inches long and 1 inch square, the results varied from 17 tons T.S., with an elongation of 6 per cent. and reduction of 8 per cent., up to a T.S. of 34·3 tons, in which case the elongation and reduction in area were practically nil. With such a wide variation in the physical properties of the metal the designer must decide for himself the grade that is most suitable for the particular detail upon which he is engaged, and the specification must be lucid enough to enforce the fulfilment of his requirements, otherwise he will only be courting disappointment and failure, of which the following is taken to illustrate only one of hundreds of similar mistakes.

Fig. 70 shows a rubbing (reduced) taken from a pinion, cut from blank, after one week's wear. The specification for this merely called for "malleable cast iron of good quality and having a tensile strength of not less than 18 tons."

In order to illustrate plainly the principles referred to, the following examples are given from actual castings, and although it must be admitted that more defects are produced by bad moulding than by bad design, there are some cases in which a proficient moulder cannot make a mould from a given pattern except by adopting methods that are conducive to shrinkage and other flaws. The designer should always bear in mind the fact that sharp corners and thin partitions or pockets of sand can only be made sufficiently coherent to withstand the flow of molten iron by hard ramming and wetting the sand to an extent that will generate an excessive volume of steam where the iron comes in contact with it, and as it is not generally possible to vent these parts of a mould sufficiently to allow the escape of a sudden accumulation of pressure, it is inevitable that a certain amount of gas or air will be imprisoned in the metal, the result being a sponginess for which the designer and not the moulder is directly responsible. In many instances this may be prevented by the introduction of a dried core at the point likely to cause trouble, and the patternmaker may be instructed accordingly; but as this course is not always possible it may be necessary to make alterations in the design so that the difficulties are removed without affecting the purpose of the casting.

FIG. 70.—Wear on soft pinion.

Probably more unsound castings are due to being designed on grey iron principles than to any other cause, and owing to lack of reliable information on the subject, this is to a great extent excusable.

To exemplify this it may be instanced that in order to secure the necessary combination of lightness and strength in some forms of grey iron castings it is necessary to make use of ribs and gussets, which always cause trouble in the foundry.

Assuming that it is decided to have the same detail in malleable, it is common practice to retain the original design, but to make the scantling lighter throughout, that is to say, to reduce the thickness all over including the ribs and gussets already mentioned, the results under the altered conditions of foundry practice being usually disastrous.

In nearly every case it will be found that by retaining the original thickness of metal in the body of the casting all these stiffening devices will be superfluous, owing to increased strength of material, and by dispensing with them altogether the weight can be kept down to the desired point with the additional advantage of ensuring a sounder casting than would otherwise be possible.

Although it is generally considered advisable to introduce a fillet into the angle formed at the junction of two walls of metal, no importance seems to be attached to the size or radius of such fillet, and there is an erroneous idea prevalent amongst designers that it should be as large as possible, restricted only by the weight and symmetrical requirements of the casting. As a matter of fact, while the fillet is a necessity in such cases, the radius must be limited, or it will render the casting liable to the very defect it is intended to prevent, *i.e.*, rupture at the point of intersection. It has already been explained how this may occur in the absence of any filleting at all, but in the present case it is caused by the body of metal formed by large fillets remaining in a plastic condition after the adjoining walls have set.

The real object of introducing a fillet is twofold—it does away with sharp corners in sand which are necessarily weak and liable to break away, and it also ensures a regularity in the crystallization of the iron which is broken, and therefore conducive to rupture, if the angle is a sharp one. In either case the radius need never be more than ¼ inch, but should not be omitted even if it will be necessary to machine or chip it out afterwards.

The matter is not so important in plain castings of simple design, in which the art of the moulder can assist in meeting the requirements of the designer by the use of skilfully placed chills and feeders, but in more complicated work it is often impossible to place these accessories where they will be of any benefit, and the designer will be compelled to take a certain amount of risk unless the design can be changed to one of more accommodating form.

As an alternative, these complicated details, however satisfactory they may have proved in common iron, will invariably give better results in malleable if it can be arranged to build them up of two or more separate castings bolted together. This can be done in most cases, and the increased cost of fitting up and machining is more than counterbalanced by the greater reliability of the structure.

The design of malleable cast wheels of every description is one that frequently calls for modification to suit the requirements of the founder. The principal difficulty lies in designing the arms so that they will act synchronously, or as near as possible, with the rim and boss in cooling contraction and subsequent expansion in the annealing oven. In most wheels the sections of the rims or boss are heavier than that of one of the arms, and in the case of flywheels and wheel blanks for cutting the difference is considerable, and it is with this class of work more than any other that the moulder is heavily handicapped. Fig. 47, page 84, is an example of a wheel that will give trouble in this respect, and will be particularly liable to the defects referred to.

Reasons for this had better be explained. During the cooling process in the mould, the arms, being the lightest, will be the first to set, and in doing so they will contract and pull the crystals at the junction with the rim and boss—which will be in a semi-fluid state owing to its greater mass—making the structure at the end of each arm spongy, or "rotten" as it is termed, and as the crystals set hard in this state the subsequent contraction of the rim does not close the bad places up again. In the meantime the rim, contracting slowly, is resisted by the arms, and not being cooled sufficiently to stand the strain, it will probably pull apart at that part which happens to be the hottest, and consequently the weakest, owing to the proximity of a runner or feeder, and when finally the entire wheel has cooled down the arms are in such an abnormal state of compression that when heated up again in the annealing oven they are almost sure to fracture. Here again the moulder can do much to minimise the risks, but it may be, and generally is, possible for the designer and the founder working in harmony not only to minimise but to entirely eliminate them.

The design of the arms is the first and most important consideration. If the rim is comparatively light, these may be either elliptical or + section, the latter for preference, as it offers a greater surface to the action of the annealing medium, thus ensuring ductility and freedom from strain that is highly desirable, while maintaining an appropriate rigidity due to the shape of the section. Rectangular sections should be avoided as being liable to start cracks from sharp corners. The old-fashioned girder section is bad, contraction flaws being caused chiefly on the inside where they cannot be properly inspected.

Flywheels and wheel blanks, with heavy rims over 15 inches diameter, should always be of the disc type, lateral rigidity being secured by the introduction of radial ribs or webs, and, if necessary, the disc may be lightened by circular holes, the edges of which are rounded as a precaution against fracture. The holes must not be too large in diameter, or the section of the intervening metal will not be strong enough to resist the pull of the rim in the early stages of the annealing process. Most wheels can be made with curved arms, but the curve should be a decided one, as there is not sufficient elasticity in white iron to withstand a bending strain unless evenly distributed.

Many failures have occurred owing to the designer having misunderstood the real structure of the material. A malleable casting has been defined as "a wrought iron casting," and although there is some truth in this definition, the fact is sometimes overlooked that, although the two kinds of iron may give an approximately similar analysis, there is a considerable difference in the structure. Malleable wrought iron is fibrous or laminated, while malleable cast iron is distinctly crystalline, or granular, and can only be used in the place of wrought iron when it is physically better adapted for the purpose. It must not be regarded as a substitute for either wrought iron or steel, but rather as a distinct material, possessing certain properties common to both, and, consequently, better adapted than either for specific purposes.

It is by no means unusual for details to be designed in which a part of the casting has to be screwed to form a stud or other connection, and though there is apparently something economical in this, there is really no surer way of weakening a malleable casting than by screwing it externally. The sharp angle at the bottom of the thread and the crushing action of the dies or screw-cutting tool both contribute to cause a weakness at this point which it is well to avoid. In fig. 71 is shown what is known as a fork end, a detail familiar to all malleable ironfounders. By having it cast with a stalk, as shown, the cost of drilling, screwing and fitting with a stud is avoided, but the latter would be stronger and more reliable, especially under bending or reversed stresses, or in tension when carrying the ends of tie rods or braces. If circumstances call for this type of casting, the stalk or stud should be about 25 per cent. larger in diameter than a steel stud of the required diameter, and the thread should be cut in a lathe with a sharp screw-cutting tool, which is much superior to dies for the purpose, as it does not break up the structure of the material. There is one important point which must not be overlooked—it is easier and cheaper to replace a broken stud or bolt than to replace a damaged casting.

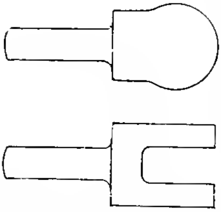


FIG. 71.—Fork end.

It is essential that the designer should at least know how every detail originated by him will be moulded, so as to ensure that the more important parts will be situated in that part of the mould which is most conducive to homogeneity. As a rule it will be necessary to have important machining parts at the bottom of the mould, or at least as low down as possible, so that the superincumbent weight of metal will make for density at that part, while freedom from impurities is ensured by all dirt, slag, etc., rising to the surface or highest attainable point. At the same time, if there is a core immediately over that part of the casting that is required to be sound, the designer can arrange for it to be properly supported without having recourse to chaplets, which are not only a cause of blowholes, but also, owing to the fact that fusion with the surrounding metal is not complete, even with tinned chaplets, a uniform surface cannot be obtained. Unless specially instructed, the moulder will always support the core in this manner, irrespective of the purpose to which the casting will be put or of any machining that may eventually be done to it.

PATTERNS

A great deal of confusion exists among patternmakers in general as to the allowance to be made for contraction on patterns for malleable castings, with the result that considerable inconvenience is sometimes caused owing to the castings being larger or smaller than anticipated, especially if they are of considerable dimensions, and to elucidate the matter it will be necessary to explain the various factors which influence the ultimate proportions of the casting.

The contraction of malleable pig iron is, approximately, $\frac{1}{4}$ inch per foot. If there is an excess of white iron and hard scrap in the mixture it will be slightly more, and conversely it will be less if grey iron and soft scrap predominate, and even with properly proportioned mixtures the difference is not so slight that it may be regarded as a negligible quantity. In a casting 4 or 5 feet long the amount would be quite appreciable, in many cases it would be equal to the amount allowed for machining.

The rate of melting and pouring has also a certain definite influence on the amount of contraction. In a mould filled with very hot iron the contraction will be greater than if the iron is allowed to cool and thicken before pouring, and iron melted slowly and uniformly will contract less than if melted rapidly. But it is in the annealing oven that the greatest change takes place, for during the process the castings expand considerably, the amount being at least $\frac{1}{8}$ inch per foot, in some cases it may even equal the original contraction, and the casting will then be of the same dimensions as the pattern; this is especially noticeable in large, heavy castings, and if we add to this the rapping which a pattern of this description generally receives in the moulding shop, it is probable that the dimensions of the casting will even exceed those of the pattern.

Castings of circular form, such as commutator rings and the rims of wheels, are liable to resist contraction to a certain extent, but the subsequent expansion is in nearly all cases equal to pattern size, while for diameters above 2 feet 6 inches it may be a trifle more. It has been conclusively proved by experiment that the expansion of cast iron under heat is continuous, so that if from any cause the duration of the anneal is prolonged, the expansion is carried still further than the instances given above.

With so many factors having a direct influence upon the ultimate size of the casting, it is only natural that so much doubt and uncertainty exists amongst patternmakers, for it is obvious that no fixed rule can be laid down for their guidance, and the best that can be done is to give an approximation suited to various classes of work.

The following contraction table will be found to include all the classes referred to :—

Light castings	$\frac{3}{16}$ inch per foot.
Medium ,, ...	$\frac{1}{4}$,, ,, ,,
Heavy ,, ...	$\frac{1}{8}$,, ,, ,,
Rings above 1 foot 6 inches diameter	$\frac{1}{12}$,, ,, ,,

The allowance to be given for machining is also an uncertain quantity, and much depends on whether the machined surface is intended for fitting purposes or to act as a bearing or other wearing surface, possibly hardened; and in addition to these there are machined surfaces which are only intended to give a finished appearance to the work, and are probably polished for effect. In any case it should be borne in mind that excessive machining weakens a malleable casting, owing to the fact that the outer skin or layer of the iron is the strongest and most ductile part. This layer gives the patternmaker a latitude of approximately $\frac{1}{2}$ inch over all, so that in small castings $\frac{1}{16}$ inch is sufficient for any purpose, but for castings exceeding 12 inches in any dimension there are two factors to be reckoned with, the influence of which increases with the dimensions—they are expansion and distortion. The first has already been referred to, and the second is dependent to a great extent on the form of the castings. If they are solid and massive in design they are not likely to lose their proper shape in the annealing oven, but should they do so, and this must always be regarded as a possible contingency, it may not be possible to get it back true to pattern. Such castings as wheel blanks and sprockets may be slightly oval or otherwise out of truth, and it would be unreasonable to expect dead accuracy in the rough casting; but, taking everything into consideration, the necessary allowance may be assumed as $\frac{3}{16}$ inch. This is not an excessive amount of metal to remove by machining, while at the same time it is ample to compensate for distortion.

The dimensions of coreboxes come under the same influences, and they are consequently subject to mistakes on the part of the patternmaker; for instance, a round core intended for a hole to machine out to 12 inches, with an allowance of $\frac{1}{8}$ inch, would in a malleable casting perhaps be too large to clean up, owing to expansion during annealing; the allowance, therefore, should be in consonance with the outer dimensions.

The relative cost of malleable castings makes it imperative that weight is to be kept down as much as possible, particularly when a certain amount of iron has to be cut away afterwards, and the coring of machined holes should therefore be studied with this in view. This also applies to the manner in which the cores are fixed in the sand, as it frequently happens that the cored holes are so much out of place that they will not clean up, and in most cases this is due not so much to the placing and fixing of the core by the moulder as to the meagre print allowance given by the patternmaker; this especially applies to overhanging and depth cores secured at one end.

It must be remembered that a well-dried core is as buoyant in the molten metal as a cork is in water, and the lifting force exerted at the free end of a depth core is very considerable, increasing, of course, with the length of unsupported core, so that to counteract this either a chaplet or stop must be placed over the core by the moulder, which is not always desirable, or else the patternmaker must make the corebox long enough, with long prints on the pattern to correspond, so that the core may be held firmly enough in the sand to resist the tendency to float, and for this purpose that part of the core which goes into the print should not be less than one-third of the entire length; thus a core for a hole 8 inches deep would be 12 inches long, allowing 4 inches for print.

As 99 per cent. of malleable castings are made in green sand, there is occasionally some difficulty in deciding whether certain parts of a casting should be moulded or formed with a core, and although the cost of patternmaking and moulding is considerably reduced by dispensing with cores as much as possible, the question of sound castings must be the first consideration, and to secure this result in castings of any size and importance the pattern must be so constructed that there are no projections, hanging pockets, or thin walls of green sand, as these are prolific sources of blowholes and other defects, owing to the difficulty of making them strong enough to withstand the wash and pressure of metal, and at the same time porous enough to permit the escape of gases and steam.

As a matter of course, the only alternative is to use cores, and in all cases provision must be made for securing them in position, so that there will be no unevenness of metal owing to cores fitting loosely into prints, while at the same time it may be noted that if the allowance is too fine there is the possibility of the core being crushed when the mould is closed; this will cause scabbing and dirty castings.

In the case of important and intricate patterns the foreman moulder should always be consulted, and the pattern made to suit his requirements, which are based on a technical experience which a patternmaker cannot be expected to possess, although an elementary knowledge of moulding is essential.

The shape of some castings renders it necessary to mould them in three- or four-part boxes, but this troublesome process can generally be simplified by the adoption of external cores. By this means the work can be done in an ordinary two-part box, and as the cores present a dry surface to the molten iron, there is greater probability of the casting being sound than would otherwise be the case. This is an important point, and one that should be especially considered in the production of malleable castings, owing to the rapidity with which the surface metal congeals after pouring. The above may or may not mean an increase in cost of patternmaking, so much depends on the design of the pattern, but even if it does increase the first cost, the corresponding saving in the cost of moulding and reduction in percentage of wasters will usually be found to offset this.

In most malleable foundries it is usual to have what is called a "button" nailed to the pattern at the points where a feeder will be cut. These are cut out of $\frac{1}{4}$ inch wood, and the shape and also the location of these is determined by the foundry foreman; they save time by indicating the exact spot at which the moulder is to cut the feeder without having to appeal to his foreman.

In repetition work a pattern is also made for the feeder. The bottom of this is identical with the button, and is fitted with two dowels which go into corresponding sockets in the button (fig. 15, page 39), so that the worker moulds pattern and feeder simultaneously, instead of having to carve out the feeder as for odd jobs. The shape and dimensions of feeder patterns are also decided by the foundry foreman.

For plate moulding the spinning gate, runners, and feeders are all built up and connected to the patterns, so that all the moulder has to do is to cut the sprue or down-gate. When the shape of the patterns is convenient, it is usual to arrange them so that the feeder is in the centre as shown in fig. 13, page 38, and by spinning the metal into this a supply of clean iron flows into every part of the mould at the same time, and as each pattern is alike and equally distant from the feeder, there is no possibility of one being fed at the expense of another. There are, however, many instances where it is not only more convenient, but also better practice, to gate in one part of the casting and feed in another.

Metal patterns are made of cast iron, brass, white metal, alloy, or aluminium. For plain patterns and also for those in which there are no thin sections liable to get broken by rough usage incidental to foundry practice, cast iron is the best material for standard patterns that are continuously in use, the principal objection being that they are rather difficult to clean up properly—where not machined—owing to the hardness of the outer skin, and for this reason they are best made of very soft iron, and cast in a dried mould to prevent chilling. Constant contact with damp sand renders them liable to rust and consequent pitting, and to prevent this the finished pattern is dipped in a weak pickling solution of sulphuric acid to remove every vestige of grease and coated with good stove varnish. This is not so liable to chip off as ordinary shellac varnish, but the latter is often used, preferably without the addition of red lead or other thickening matter.

Malleable patterns are not suitable for large castings. Although they cannot get broken, the surface is soft and easily dented, especially on sharp corners.

For all-round purposes brass is by far the best material, and although the cost is in some cases necessarily high, the bulk of this can be recovered by melting down when the pattern is no longer required. Soft brass is open to the same objections as malleable iron, and is, therefore, unsuitable for prolonged use, but a hard mixture is serviceable. The outstanding advantages of brass patterns are that they are easy to finish, and give a smooth non-corrodible surface, and, owing to the simplicity of soldering or sweating, complicated patterns can easily be built up of different parts, and additional details added to existing patterns or feeders moved to more suitable places without risk of their eventually working loose.

In order to reduce the weight as much as possible, and also to economise in the amount of metal required, it is usual to make what are called "shell patterns." This is done by coring or by cutting away from the wooden pattern all the superfluous metal from the interior of the pattern, leaving only a shell of $\frac{1}{4}$ inch or less in thickness, according to size of pattern. This method is especially suitable for split patterns and half-patterns for plate and machine moulding.

For large standard patterns from which only a limited number of castings are required at a time, and particularly for those which, owing to their shape, would warp or be easily broken if made of wood, the use of aluminium alloyed with a small proportion of zinc is recommended. About eight parts aluminium to one part zinc is a good mixture. Aluminium alone is too soft, and although not affected at ordinary temperatures, it oxidises so rapidly at that required for soldering that a good joint is impossible. The addition of zinc hardens it and also makes soldering possible, and, the proportion being small, does not appreciably affect the lightness which makes aluminium so desirable for the purpose.

Temporary metal patterns, and those required in a hurry or for experimental purposes, are made of soft white metal. Equal parts tin and lead is a good mixture, but the proportion of tin may be reduced or even lead alone used to suit requirements. These patterns are easily finished, but are too soft for continuous service.

When it is required to make a metal pattern from a plaster sample in which there is no allowance for double contraction, it is necessary to make use of an alloy that will not shrink in cooling, and for this purpose type metal is used; on the other hand, an emergency pattern may be required from a sample casting which is wanted and cannot be retained as a pattern. In this case it is usually left to the moulder to make sufficient allowance by rapping the pattern to enlarge the mould, but as this is often so clumsily done as to destroy the symmetry of the casting, many prefer to make use of an alloy that expands on cooling. This is cast in a mould, made from the sample, and with only a moderate rapping gives an approximate allowance that is near enough for all practical purposes, while preserving the outline of the casting. This is only suitable for small castings, and the sand must not be rammed too hard.

In the preparation of wooden patterns from which metal patterns are to be made the contraction and machining allowance is doubled. This is a point frequently missed by young pattern-makers, and also by older ones who are not accustomed to this class of work. The following table will be of assistance in setting out the required dimensions:—

COMPOSITION AND CONTRACTION OF METAL PATTERNS.

Metal or Alloy.	Contraction.	Tin.	Copper.	Zinc.	Antimony.	Lead.	Bismuth.
Cast Iron .	$\frac{1}{8}''$	—	—	—	—	—	—
Brass . .	$\frac{3}{16}''$	—	3	2	—	—	—
White Metal .	$\frac{1}{4}''$	1	—	—	—	1	—
Aluminium (9).	$\frac{1}{4}''$	—	—	1	—	—	—
Type Metal .	*Nil*	3	—	—	10	112	—
Expanding .	—	—	—	—	2	9	1

The surfaces of metal patterns that are not machined are worked up with file and scraper, and finished off with emery cloth or a fine wire scratch brush, the latter being especially suitable for intricate flat designs of an ornamental character.

Blowholes or other defects in metal patterns are filled in with solder, and if the metal will not take this they may be filled up with plaster of Paris.

Complete coreboxes should be made in all cases. It is impossible to make a core even fairly accurate if it has to be made in halves and pasted together. The exigencies of modern business methods in the machine shop require the removal of the smallest possible quantity of metal from all castings, and especially if of malleable cast iron, and consequently the allowance for machining is reduced to a minimum. If half coreboxes are used it is more than likely that when the two halves of the core are pasted together the section will be oval, and the boring allowance will be reduced or even missing on the line of the longer axis.

The same thing will occur with complete coreboxes, either of wood or metal, unless the dowelling is properly done. Too often the holes into which the dowel fits are only slightly deeper than the length of the dowels. With each core made a small quantity of sand finds its way into each of the holes, and this eventually prevents the dowel from going as far as it should do, and before this is discovered a number of cores will have been made deeper than required. This is an everyday occurrence, and yet the remedy is very simple. Either drill or bore the holes right through that part of the box in which they are situated, so that the accumulating sand is pushed out each time the box is fitted together, or make the corebox with outside lugs on one half fitting into recesses in the other (fig. 72). This is the better way, especially for metal coreboxes, as it is possible that the sand cannot always be pushed out of the dowel holes if the box rests on a level iron bench such as is usually used by coremakers.

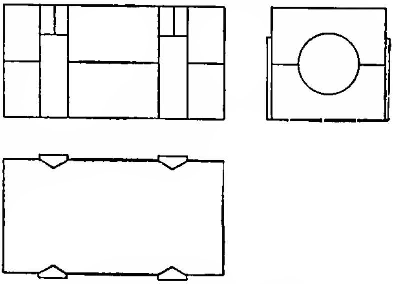


Fig. 72.—Metal corebox.

Large quantities of mining gear, such as haulage clips, are made in malleable castings, and for the gripping parts or jaws of this class of work it is necessary to have them cast with spiral grooves that will exactly fit over the strands of wire rope to secure the greatest possible grip without damaging it. To carve these grooves out accurately by hand is tedious work. The best and simplest way is to form the grooved faces by means of a core which is an exact replica of the rope itself. This is usually done by making a half-box to fit easily over the rope (fig. 73). A piece of rope, well oiled, is laid in the box and the intervening space filled with plaster of Paris mixed with sufficient water to make it flow easily, the open ends being stopped up with putty to prevent escape. This will be set in an hour, and can be removed from the rope, trimmed up, and given a coat of thick shellac varnish. This corebox, being faced with plaster, is not serviceable enough for continuous use, and therefore it will be necessary to mould one from it and have it made in cast iron or brass, if the articles are to be made in quantities. The other half of the box is shaped to fit the print on the pattern, and presents no difficulty.

It is generally waste of time to make strickle boards for cylindrical cores, as these are very seldom made in loam for malleable castings, and the foundries usually require a corebox for the purpose unless they happen to have suitable ones in stock.

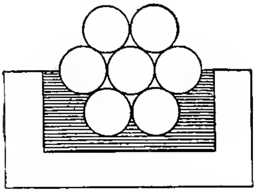


Fig. 73.—Rope corebox.

Skeleton pipe patterns do not give good results, and although not wholly unsuitable for malleable castings, the expense of making a complete pattern is more than justified by the accuracy, reliability, and appearance of the resulting casting.

The patternmaker is sometimes called upon to alter and adapt old patterns that have been used for grey iron castings so as to make them suitable for malleable, and it is in this class of work that the higher contraction of white iron is frequently overlooked in the endeavour to reduce weight by thinning down some portions and cutting or coring lightening holes in others. The principal dimensions, over all and centre to centre, should first be checked over and altered to suit the extra $\frac{1}{8}$ inch per foot contraction, and then the other details attended to. This is the safest way of working, but, unless for odd single castings, it is not often that an old pattern can be satisfactorily adapted to suit the requirements of the malleable foundry, and as a rule the cost of making a good job of it will be as high as the cost of a new pattern, while the result is not quite so good.

Figures or letters that are to appear on the casting are much more legible if raised above the surface than if sunk in, and are easier to mould, especially if, instead of having the characters on the pattern itself, they are fastened to a wooden block, by means of which the moulder can impress it upon any part of the finished mould as may be required.

Loose pieces are marked in position so that they may not get reversed or misplaced, and every corebox should be numbered or lettered, a corresponding number or letter being stamped on the print that goes with it. Core prints should be painted a distinct colour, so that they will not be mistaken for bosses or other projections, which will be of the same colour as the pattern.

In making up a spray of small patterns the best method of procedure is to take one half of a box similar to those in which the castings will eventually be moulded and fill it with black sand rammed fairly hard. The ridge is laid down the middle, and the patterns are arranged in a suitable manner on each side of it, leaving sufficient space to introduce a feeder between them. All the parts are pressed lightly into the sand, after which they are taken out singly, and tinned with a soldering bit at the parts where they will be joined together and replaced. The spray can now be soldered together without disturbing the arrangement, and after trimming the joints with file and scraper it is ready for use.

In the preparation of plates for plate moulding the method is the same whether they are of wood or metal, and consequently the following instructions will apply equally well to both.

Many patterns having one flat side can be moulded from a single plate. This forms the bottom half of the mould, and the top is simply rammed up on a flat board. The preparation of the plate is identical with that already described for making up a spray, except that, instead of being soldered together, the various parts are secured to the plate.

Patterns that are made in halves may be moulded from two separate plates or from both sides of a single plate, and in both cases great care is necessary in arranging the patterns so that the separate halves of the mould register correctly when closed for pouring. For this reason only a snap flask or a set of interchangeable boxes can be used.

A box is fitted over one of the plates, and set of half-patterns arranged as may be most convenient in the position they are to occupy; the box is removed, and the patterns secured to the plate; the box is then replaced, filled up with black sand, and rammed up as for moulding; the plate then is removed, and the surface of the mould dusted over with French chalk. The working face of the second plate is next painted over with a thin coat of shellac varnish mixed with aniline black, and while still damp and "tacky" it is fitted over and pressed on to the face of the mould, so that on removing it the sharp outline of the mould is shown in white against a black background. This is called "taking an impression," and as soon as the varnish has dried the remaining half-patterns can be secured in position, as indicated by the outlines of the impression, with a certainty of their being accurately in register.

It then remains to arrange the gating and feeding, and it will generally be found that a common feeder can be fixed in the centre of the plate to supply all the castings. This will be a loose piece dowelled to fit on a "button," marking its position if for heavy castings, while for light ones a truncated cone about 2 inches high will be sufficient.

The runners are formed by well-tapered strips ¾ inch deep and ½ inch wide; the spinner is about 2 inches diameter, and the same in height and depth. All these are fixed on one plate, which forms the top half of the mould, and are shown in position in fig. 74. In the bottom half are recesses formed below the down-gate and the feeder by buttons ½ inch thick, and also the lower half of the spinning chamber.

A single plate, with pattern halves on both sides, is prepared in the same way; but unless the position of the pins and sockets is standardised and strictly accurate, it may be safer to locate the second set by means of a "cross impression."

To do this, one half of the box is rammed up on that side of the plate to which the half-patterns are already secured, the other being rammed up on a flat board; the first box part is then dusted over with chalk, and the boxes are closed as for casting. This gives an "impression" on the black sand in the second part, and from this it is transferred to the plain side of the plate in the manner just described.

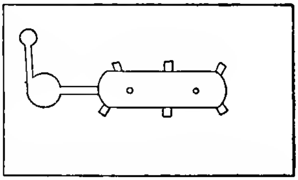


FIG. 74.—Gate and feeder on plate.

Reverse plate-moulding is an ingenious method of doubling the number of castings made in a mould from a given number of patterns. The title is erroneous, as it is the top half of the mould, and not the plate, which is reversed.

Patterns suitable for single or double plate work are also suitable for reversing, but the method is only resorted to when the number of castings required does not justify the expense of making additional patterns. On account of the gating and feeding arrangements being reversed with the mould, it is only used for occasional work on account of the extra metal required for casting. As will be seen in fig. 75, it is accomplished by laying the patterns along one side or at one end of the plate; both halves of the box are rammed up on this, and the mould closed, so that one half of the castings will be on one side of the bottom box, and the remainder on the opposite side in the top box, as shown in section (fig. 76) The system may also be worked by laying the two halves of a larger pattern, both of which are alike, in the middle of the plate; but as this requires great accuracy in the fitting of the boxes in order to ensure an even joint, it is not general practice. Reverse moulding is not adapted for continuous or standardised work, as a complete set of patterns gives a much more satisfactory and economical result.

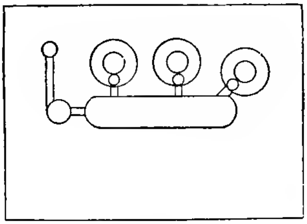


FIG. 75.

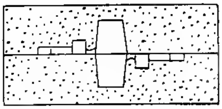


FIG. 76.

Reverse moulding.

INSPECTION AND TESTING

When castings are required in large quantities, or are of a new design not yet proved, or if they are ordered from a new firm, it is becoming a recognised custom to stipulate that a sample casting, unannealed, shall be forwarded before the order is proceeded with. This should be broken up, and the various sections carefully examined for internal flaws, which may be due to either the moulding or the design of the work. Any alterations or corrections may thus be made in the initial stage.

Defects due to moulding are, generally speaking, dirt, blowholes, and cold laps, while flaws arising from shrinkage and excessive contraction generally indicate wrong design. In the examination of unannealed castings, taking superficial defects first, the most noticeable are caused by the presence of slag and other impurities which float on the surface of the molten iron, and which sometimes find their way into the mould, where they are trapped when the metal reaches the top. They are not at all difficult to discern, and may easily be exposed by picking out with the tang of a file or other pointed tool. Unless these holes are deeper than the allowance for machining, they will have no deleterious effect on the finished article; but if no machining is to be done at that part, the reduction of area caused by their presence must be taken into consideration, and the casting accepted or rejected according to the amount of reduction and the margin allowed for in the design. Provided that the factor of safety is ample, and that the stresses incurred will be only in direct tension or compression, the presence of small quantities of dirt is not so detrimental as it would be in castings subjected to torsion or bending stress, as under these conditions they form a starting-point for rupture, and for this reason must be rejected.

A more serious defect of the same class is known as scab. It is caused by some part of the mould or core becoming detached, either by expansion of the gases generated, or by being washed away by the stream of molten metal as it runs into and around the mould. These detached portions may, as in the previous case, rise at once to the surface of the fluid metal, in which case their presence is obvious; but it frequently happens that these parts do not break away until well covered, and by this time the metal has already begun to congeal, with the result that the patch of sand is imprisoned in the metal by which it is surrounded, forming a dangerous flaw, of the presence of which there is to the unpractised eye no apparent indication. Fig. 77 shows this defect in its simplest and most easily discernible form. A patch of sand has become detached from the lower part of the mould, and has risen to the surface of the liquid metal, and is trapped against the top of the mould. If the scab corresponds in dimensions with the depression on the opposite side, the intervening metal is probably sound, and as there is no reduction of section, the defect will be merely an unsightly one. In fig. 78 the projection has been broken off by the flow of metal, and carried to another part of the mould before being trapped. In

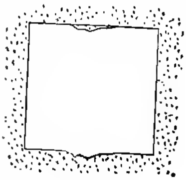


Fig. 77.

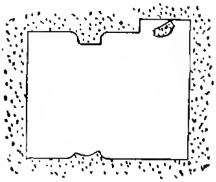


Fig. 78.

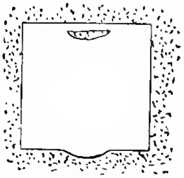


Fig. 79.

Scabbing.

this case the full extent of the flaw is not visible at the surface, but may be ascertained by comparison with the scab. Fig. 79 shows the worst form of this defect, the sand being trapped before it has reached the surface, and its presence is only indicated by the scab. The imprisoned patch of sand may be immediately over this, in which case it may be discovered by drilling a small hole at the point indicated, or it may possibly have been carried to some other part of the casting, so that it cannot be located. There is the further possibility that it may have been carried up the feeder, and that the casting is perfectly sound, which is quite probable if the scab is found immediately under, or in close proximity to it; if, however, it is some distance away, it must be assumed, especially in the case of important castings, that it is in the metal. Scab must not be confounded with swelling, which is protuberance due to weakness of the mould at the part, and usually presents a smooth, evenly-rounded surface, while the scab shows distinctly the outlines of the cavity from which the sand has broken away. It will be noted that if only the scab is visible it is possible to conceal the defect by grinding or chipping it away. Any evidence, therefore, of such treatment in places where it is not obviously necessary must naturally be regarded with a certain amount of suspicion. The best evidence of a good casting is in most cases an unbroken skin, except where necessary to remove the gate and feeder.

Cold shuts or laps are frequently mistaken for cracks, but on close observation the difference will be at once apparent. A crack presents sharp, jagged edges, due to tearing apart of the crystals, while on the other hand the edges of a cold shut are rounded and the contour distinctly curvilinear. They are due to (1) section of metal being too thin; (2) iron being allowed to cool too far before pouring. In castings of light and thin section they generally go right through, as shown in fig. 80, but in heavier sections they rarely extend more than $\frac{1}{8}$ inch or $\frac{3}{16}$ inch in depth. In either case the acceptance or rejection of castings having this fault must be left to the discrimination of the inspector, who, knowing the purpose for which they are intended, can judge accordingly. One thing must be noted, if a cold lap occurs at the edge of a casting it is a potential starting point for a crack to develop under vibration or alternating stresses. They may be closed up by caulking or hammering, but it does not require a practised eye to detect this.

The inner angles of all castings of H and ⊔ section should be carefully examined for flaws due to contraction, and the circumference of all circular castings for what is commonly called a "sear." This is generally found at or near the gate where the metal enters the mould, and is a serious defect for the reason that it will probably extend under working conditions similar to the last-named defect.

FIG. 80.—Cold shut.

What are known as blowholes are caused by insufficient venting of the mould or core, or by the mould being improperly dried. In the first case the gases generated in the mould are unable to escape, and are imprisoned in the form of globules, and in the second case they are due to the formation of the steam from the damp mould or core; this succeeds in partially forcing its way through the iron, but is arrested before it reaches the surface, and causes sponginess, distinct from gaseous blowholes, being smaller and more diffused. Both are somewhat difficult to locate, and in most cases they are not discovered until some of the metal has been removed by machining. Sometimes, however, careful observation will reveal the presence of minute holes in the skin of the casting through which some of the imprisoned

MALLEABLE PIG IRON.—SPOTTED WHITE.

Approximate Analysis.

Graphitic carbon, ·50 per cent.; combined carbon, 3·06 per cent.; silicon, ·51 per cent.; sulphur, ·184 per cent.; phosphorus, ·05 per cent.; manganese, ·28 per cent.

gases have escaped, and by probing these with a fine wire some idea of their depth and extent may be formed; but under any circumstances their presence is highly detrimental, in some cases possibly dangerous, and such castings had better be rejected without reserve.

Cracks that have been caused through injury to the casting while in a hard state must always condemn it. They are generally to be found in the immediate vicinity of a feeder or gate.

In addition to the usual tensile test by means of a testing machine there are several mechanical tests in vogue to prove the quality of the material, and of these the bending test is the most practical, as well as the most conclusive, provided the bending is done under impact; if the pressure is gradually applied as by means of a screw-press, it does not give such a reliable reading. A common grey iron bar may be deflected to a comparatively large amount by this latter means, while if supported in the same manner and struck with a hammer it would probably break at half the deflection, or even less. In other words, pressure gradually applied gives no indication of the amount of resilience possessed by the casting. A combined test for deflection and resilience is a severe one, and in most instances is the only test applied, as enough may be deduced from this to influence the inspector's judgment. Test pieces for this purpose may be (1) cast separately from the same ladle of iron as the casting; (2) cast on, but not forming a part of the casting; (3) cut from a sample casting. They should be 6 inches in length, and in order to standardise, the section should always be the same. For this purpose the author has adopted that of 1 inch by ½ inch, and the radius over which it is bent is fixed at ¾ inch.

A V block is another accessory which is available in most cases, and as the angle is usually 90 degrees it will show the extreme bending test at a glance, the distance across the top of the V to be not less than 5½ inches. When testing is frequently carried on there should be special blocks for the purpose, three in number, and forming angles of 90, 60 and 40 degrees. The test piece is laid across the V, and a 1½ inch bar or a special set having a face rounded to ¾ inch radius is held across the middle of the bar and hammered down by a succession of moderate blows until the shape of the bar coincides with that of the V.

The following table is based on tests carried out over a considerable period. It is an approximation, but nevertheless practical and fairly reliable, representing an average of several of the best known founders in the country:—

Class of Iron.	Angle of Bend (ultimate).	Tensile Strength.
Crucible—		
Open grain . . .	180 deg.	20 tons
Close grain . . .	90 deg.	30 tons
Air Furnace—		
Open grain . . .	140 deg.	18 tons
Close grain . . .	90 deg.	26 tons
Cupola—		
Open grain . . .	120 deg.	17 tons
Close grain . . .	60 deg.	23 tons

This test is seldom carried out with accuracy, even by Government inspectors, except as an experiment, but if necessary it can be done by means of a V-shaped dropweight of definite weight, falling without friction between graduated uprights, which show the height of the drop. It will be seen that with such an apparatus it is possible to make a great number of interesting and accurate comparative tests; but for the present these machines are outside the practical everyday routine of the inspector.

A favourite test for resilience only is the drop test. This is done (1) by dropping the casting from a height of about 30 feet on to an iron slab or block. It is not a very reliable test, as, when carried out in this manner, everything depends on the position of the casting at the moment of impact; it is at best only a rough-and-ready means of proving resistance to shock. A better test (2) is to drop the casting from a similar height on to a heavy block of triangular section in such a way that it will strike the apex of the block. The objection to this is that there is no means of controlling the casting as it falls, and consequently the impact may be a slanting one. The most reliable method (3) is to place the casting on a heavy slab or block, and dropping a weight upon it from a given height, after the manner of a pile driver. The size of the dropweight will depend on the scantling of the casting, but it should have a spherical face and be so designed as to drop fairly on to the casting at or near a point judged to be the most suitable for the purpose. The success of this test lies in having the slab or block resting on a solid foundation, or of sufficient mass to permit the casting to receive the full force of the blow, otherwise it is possible to nullify the test by supporting the slab on some elastic material which will absorb the shock of the impact to a certain extent.

A good idea of the toughness or ductility may be formed by hammering or drawing out the end of a bar on the anvil, when the quality of the material may be judged by the amount of hammering or swaging that it will stand before disintegration is apparent. Imperfectly annealed work is easily detected by this means, as well as work containing an excess of carbon in the mixture. On the other hand, an over-annealed casting will sometimes exhibit a remarkable degree of ductility under the hammer, so that this test must only be used in conjunction with others.

Cracks or any description of rupture in a casting may easily be detected by "ringing," *i.e.*, by suspending and tapping with a light hammer. To anyone possessed of a good sense of hearing this test is infallible, and even if no flaw is visible, no casting of any importance should be accepted unless it rings true. The special merit of this test lies in the fact that no matter how artfully a fracture may be caulked, or how artistically any "stopping" has been applied, its presence is betrayed by this means.

A bending test only is sometimes applied to castings that will not under working conditions be subjected to sudden shocks, but have only to withstand variations in pressure gradually applied and released. The piece to be tested is gripped at one end in a vice, or the end is placed in a hole in an anvil or swage block; the other end is held in a pair of tongs, or has a piece of pipe fitted over it, and it is then pulled over until signs of fracture are noticeable. This is a simple method, used when no press is available, in which case the piece would be supported at the ends and pressure applied at or near the centre. It will be apparent that this test is not a severe one, and therefore its value as such is small, but it is suitable for long, light castings of a certain class.

It requires some experience to be able to detect hard or imperfectly annealed castings at sight, more especially when the annealing has actually commenced and has penetrated to a depth of $\frac{1}{8}$ inch or $\frac{1}{4}$ inch. If the work is distinctly hard it will not stand the test for ductility, but if only slightly annealed as stated the casting is enveloped in a soft ductile skin; this will pass through any of the tests already referred to, provided they are not severely applied, and although the interior or hard core will be broken up in most of them, it is concealed by the outer covering. An experienced eye can tell by the general appearance of a casting if it is hard; it has its outlines more sharply defined, and has a peculiar gloss on the surface, neither of which are to be found on well-annealed castings.

It is impossible to describe these points intelligibly in print, but should there be any suspicion of hardness it is well to test to destruction and judge from the character of the fracture. Under circumstances which will not allow the above method, such as large and important castings, the drilling test may be applied. This means drilling a small hole, not less than $\frac{3}{16}$ inch in diameter, at any point where its presence will not interfere with the utility of the casting; a twist drill of ordinary tool steel should be used, as a flat-pointed drill will work well in fairly hard iron if properly tempered. The hole should be about $\frac{1}{4}$ inch in depth, and if the drill will penetrate so far at a normal speed the casting will be found satisfactory, provided it is free from structural flaws. Exception must be made in castings of unusual length, which have probably been annealed in a case oven and are possibly harder at one end than the other; a difference in general appearance of the two ends will suggest this, and a drilling at each end will verify it.

Conditions exactly opposite to the foregoing are to be found in castings that have been over-annealed or subjected to too high a temperature during the process. The ductility or resilience are high, and will pass all tests except that for tensile strength, which is exceedingly low. The experienced ear will also note a dulness in the sound emitted when the casting is rung, which is very convincing, being totally different from the sharp metallic ring of a hard casting, or the clear, bell-like sound of a good one. The general appearance of the article is against it—the sharp corners are missing, and there is a lead-like sheen on the surface which is unmistakable. The fracture shows a dull grey iron of a finely crystalline nature, surrounded by a distinct skin of lighter metal, which may be up to $\frac{1}{16}$ inch in thickness, this is well defined and distinctly separated from the rest of the material in such a way that it can be easily detached.

Castings which present an attenuated appearance heightened by a distinct pitting on the surface, and which are palpably smaller than the pattern, with cored holes much larger than required, are those which have been subjected to the action of the flames through defective sealing of the pans. Excessive scaling takes place under the circumstances, with the result referred to. They are technically known as " burnt " castings, and are of little value, as apart from the bad appearance of the casting, the nature of the material is of an extremely doubtful character, being "short" and unreliable under stress.

A very deceptive test, but one that is sometimes resorted to in order to mislead the unwary, is to take a thin, flat bar, say 12 inches by 1 inch by $\frac{1}{4}$ inch, and by fixing one end in a vice and gripping the free end with a spanner, to twist it completely round into the form of a spiral. The result is an optical illusion which suggests a high degree of malleability in the bar, but which is dispelled upon investigation, which will show that the actual angle of bend in proportion to the length of the casting is so very small as to be practically valueless as a test.

In order to simplify calculations in the case of test pieces for tensile strength, the smallest diameter is usually made ·798 inch, which is exactly half a square inch in area, or ·564 inch, which is exactly one quarter. It has been found by experiment that a test bar cast separately is stronger than one forming part of the casting required, owing to the quicker cooling of the former, and the nearer a test piece lies to the casting of which it forms a part, the more accurately will it indicate the strength of the casting.

The strength of a test piece is also materially influenced by the temperature of the metal at the time of pouring or casting. The hottest metal will invariably give the strongest bar, provided the bar is cast to size and not afterwards turned down.

There is considerable diversity of opinion as to what constitutes a reliable test piece for malleable cast iron, which depends to a great extent on the outer skin or layer of metal for its tensile strength and ductility. As in grey iron castings, the strength decreases towards the centre of the mass, where the bulk of the carbon is concentrated, so that a test piece cut from a thick section, or a test bar cast, say 1¼ inch in diameter, will, when turned down to the required size, leave a section of metal that cannot possibly be relied upon to give any indication of the average strength of the casting as a whole. It follows, therefore, that a genuine test can only be made from a bar cast to nearly finished size, allowing only sufficient metal to take off a light cut down to standard size. A bar of this description will show an increase in tensile strength of from 30 to 50 per cent. over one from which a considerable amount of the outer metal has been removed. This fact is not so generally known amongst inspectors of engineering material as it ought to be, with the unfortunate result that many valuable castings, the quality of which is indisputable and which are suitable in every particular for the purpose for which they have been designed, are condemned on the misleading evidence of an improperly prepared test piece, which is a glaring injustice to the founder who is honestly endeavouring to meet the requirements of his customers.

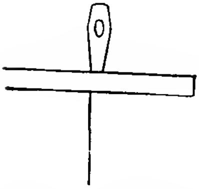


FIG. 81.—Shearing.

A very good test to apply for ductility or softness is to shear a piece right across, which may be done either under plate shears or with a sledge hammer and sett (fig. 81), the latter method being preferred. The piece used for this purpose need not be more than ½ inch square, and on examination the sheared ends will have the appearance of good mild steel plate if the material is of good quality, while an inferior grade will present a more broken surface, showing a lack of cohesiveness due to ineffective feeding or an excess of grey iron in the mixture, either of which detracts considerably from the value of the work.

FOUNDRY CHEMISTRY

To a great many ironfounders the analyses sent out with consignments of pig iron have little or no significance. The various percentages of silicon, sulphur, phosphorus, manganese, graphitic carbon, and combined carbon are meaningless figures apparently intended to confuse minds that are already overburdened with problems of a more practical nature. To such minds, imperfectly aware of the interaction or effect of one element on another, any attempt to regulate foundry mixtures by a systematic combination of so many variable and unstable factors must lead to complications, and the average foundry has troubles enough without seeking for more. There are foundries that have been working for generations on certain classes of work, using the same old brands of pig iron and getting excellent results every time, and it is in such places as these that any suggestion of mixing by analysis is ridiculed. But in hundreds of cases where these old-fashioned places have taken up new work they have failed badly when required to work to specification on an entirely new class of castings, and it is now generally recognised that in the best malleable-foundry practice some knowledge of foundry chemistry is essential, not only to gain and maintain a reputation for turning out good, sound castings, but also to remedy old troubles and effect substantial economies in working. Without the application of chemistry heavy losses are incurred through waste of fuel and iron waster castings, and castings returned by dissatisfied customers as unsuitable for the purpose for which they were ordered. Even if the services of an expert foundry chemist are not available, very satisfactory progress may be made under the supervision of an intelligent manager or foreman possessing only an elementary knowledge of foundry chemistry. It is only to the uninitiated that the subject appears complicated and involved, for the number of elements to be considered is so small, and the calculations are so few and simple for most purposes, that any one with an elementary Board School education can in a very short time learn the first principles of foundry chemistry, and though he may not be able to take up the onerous duties of a foundry chemist, he can at least produce a satisfactory iron mixture having any particular composition or property required by specification. He may not be able to analyse the pig iron, but he can use the analysis provided by the makers which is usually near enough for most practical purposes.

Let us consider first the nature of the various elements that are found in cast iron, and that have such important effects on its structure and characteristics. These elements, sometimes referred to as metalloids, will be dealt with in the order in which they generally appear in the tabulated analyses of pig iron sent out by manufacturers or their agents.

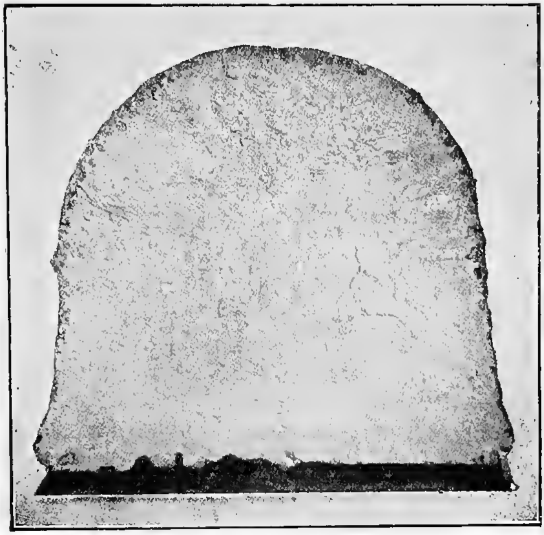
SILICON.—In combination with other elements silicon forms an important part in the formation of rocks. It does not occur free in a natural state, but aways in combination with other elements. The chemical symbol for silicon is Si, and it is a solid that may be crystalline and very hard, almost as hard as a diamond, or amorphous in the form of a fine reddish-brown powder. What is familiarly known as silicon is really silicon dioxide. White sand is nearly pure silica, and red and yellow sands consist of silica coloured with iron oxide. Flint is another form of silica, and rock crystal is silica in its purest natural form. British pig irons contain silicon in varying proportions according to their grade, usually from ·6 per cent. in white and mottled pig to 3 per cent. in soft grades of foundry iron. Higher percentages are sometimes met with, and there are a few soft irons that contain as much as 3·5 per cent. of silicon, but they are exceptional. Ferrosilicon made in the electric furnace may contain 30 to 50 per cent. of silicon. The form in which silicon is found in cast iron is as a silicide (FeSi). The influence of silicon on cast iron is very considerable, and it is usually considered to be the most important as well as the most convenient element to use as a base in making up mixtures for various purposes. A certain amount of silicon is lost in the cupola or furnace during the melting process through oxidisation, and the greater the blast the more oxygen is brought in contact with the iron, converting the silicon into silica. An iron having a high percentage of silicon will lose much more than one with a low percentage, so that while one iron containing 3 per cent. of silicon will lose as much as 15 per cent. of it, another iron with only a very small percentage of silicon will under similar conditions show hardly any loss. The influence of silicon on the shrinkage of cast iron is very marked and is greater than that of any other non-metallic element, and recent experiments have shown that an increase of ·2 per cent. in the silicon content will produce a corresponding decrease in shrinkage of ·01 in. per foot. The effect of silicon on the carbon content of pig iron is most important, but this matter will be considered when dealing with the latter element. The effect of silicon on the hardness or softness of iron is very noticeable, a low percentage of silicon having a distinct hardening effect, which reaches its maximum at about ·9 per cent. Above this is a decrease in hardness up to 2 per cent. of silicon, and beyond this, up to 3 per cent. the hardness increases again.

SULPHUR.—The influence of sulphur (S) on cast iron is governed largely by the other elements that may be present, more especially by the manganese. The sulphur exists in the iron as a sulphide of iron, and in melting an iron high in manganese the latter will combine with the sulphur and pass into the slag as manganese sulphide. The percentage of sulphur present in ordinary grey irons ranges from ·01 to ·2 but in white and mottled irons there may be as much as ·2 to ·35 per cent. Although the sulphur content of most irons is considerably lower than that of any other controlling elements its influence is very pronounced, and on this account it must not be neglected. The amount of sulphur in pig iron is usually increased by the absorption of a further quantity from the fuel during melting in the cupola, and a definite and unexpected increase in the sulphur percentage will produce sluggish metal in the ladle and greater contraction and chill in the mould. The gain in sulphur from contact with the fuel may be as high as ·04 to ·06 per cent., and if the iron is used for light work the castings will be extremely hard.

Further, owing to the sluggishness of the molten metal the occluded gases are not able to pass off freely ; thus producing blowholes and unsound castings, and leaving a heavy skull of metal in the ladle. The only remedy for this is to pour such iron very hot, because at a high temperature the sulphur has the effect of making the molten metal very fluid, and thus allow the gases to pass off. The readiness with which iron will absorb sulphur from the fuel indicates the necessity for having a reliable analysis of the coke, as well as of the iron, in order to be able to produce satisfactory castings from specified mixtures.

PHOSPHORUS.—The most familiar form of phosphorus (P) is a poisonous yellow substance that glows and smoulders when exposed to the air, and is so inflammable that it must be kept in water, because it burns spontaneously at a temperature of 111° F. It is not found in a free state in nature, but exists in several minerals as a phosphate. It is easily absorbed by the iron from the ore, fuel, and flux, hence there is always a slight tendency for the percentage to be increased each time the iron is melted, and when once absorbed it cannot be readily got rid of. When combined with iron it exists as a phosphide, a substance that is hard and brittle, but readily fusible, and it is owing to the brittleness of this phosphide that the pig irons containing a high percentage of phosphorus can be broken so easily. Very fine and intricate castings can readily be made from high-phosphorus irons containing up to 1·75 per cent. A small quantity of phosphorus will increase the fluidity of the molten metals, and so tend to produce a strong homogeneous casting. It has already been stated that sulphur has the effect of making the iron sluggish at normal pouring temperature, as well as increasing contraction and chill, all of which may be counteracted by a judicious adjustment of the phosphorus content of the mixture. Generally speaking it may be said that phosphorus has a weakening effect on most castings containing over 1 per cent., but as a compensation for this the shrinkage is reduced and the fluidity of the metal is increased, which tends to produce good sound castings.

MANGANESE.—Like many other metalloids, manganese (Mn) is found in nature as a compound, chiefly in the form of manganese dioxide or peroxide (MnO_2), which practically forms the base of all other manganese compounds. Commercially it is better known as black manganese or pyrolusite. The action of manganese on sulphur has already been explained, and although its influence on cast iron in general is as yet imperfectly understood, there is sufficient evidence to show that, owing to its action on the carbon, it is an undesirable element in the production of malleable castings by the Réaumur process. In other directions it is a very valuable and important constituent, and is used extensively in steel making in the form of ferromanganese and spiegeleisen.



Malleable Pig Iron.—White.

Approximate Analysis.

Graphitic carbon, ·25 per cent.; combined carbon, 3·28 per cent.; silicon, ·42 per cent.; sulphur, ·218 per cent.; phosphorus, ·05 per cent.; manganese, ·25 per cent.

One characteristic effect of manganese on pig iron must be mentioned to show clearly the value of mixing by analysis and the futility of judging the quality of cast iron by the appearance of the fracture. By the latter method it is assumed that a coarse open grain indicates a soft iron, and that hard iron shows a fine grain. Unfortunately for those who maintain this theory it is now known that pig iron high in manganese will, when broken, show a coarse-grained fracture; yet when melted down and run into castings the iron is extremely hard. Again, in judging the character of scrap from the appearance of the fracture it is assumed that hard close-grained chilled scrap will produce hard castings, whereas the contrary is usually the case. Good chilled castings are often made from very soft iron, the hardness and close grain being due entirely to the effect of the chill in the mould, which causes the carbon to assume a combined form, but when remelted the carbon resumes its graphitic form and the castings are as soft as the original iron.

Carbon.—Carbon (C) exists in many forms, from the hardest diamond to the softest graphite or black lead, but for present purposes it will be considered in the two forms in which it is familiarly classified in the analyses of pig iron, namely, graphitic carbon and combined carbon. In the cold state graphitic carbon exists as flakes of graphite in the spaces between the crystals of iron, and this is what gives the fracture of soft cast iron its grey colour. A finger drawn across the newly machined surface of soft grey iron is blackened in the same way as if drawn across a cake of the familiar household black lead that is used for polishing grates and stoves. When the iron is hot and fluid the carbon is apparently chemically combined with it, but as it gets cooler and begins to solidify, a certain percentage of the carbon separates and assumes the free or graphitic form. The excess of free carbon thus produced is familiar to moulders in the form of a scum, generally known as "kish," on the top of the cooling metal, and in some cases the flakes of carbon are thrown up from the surface of the metal in the ladle. The process of separation is affected by the rate of cooling, and if this is gradual there is a tendency to produce a greater percentage of graphitic carbon and a smaller percentage of the combined form. On the other hand rapid cooling has the opposite effect, resulting in a larger percentage of combined carbon. It is for this reason that chills are used to produce hard surfaces, the iron being cooled so quickly that the carbon has no time to separate out into the graphitic form, so it remains in combined form as a carbide of iron. The form in which carbon exists in any iron is also affected to a greater or less degree by the presence of other elements, some of which have a very decided effect on the carbon content. Speaking broadly, the effects of combined carbon on cast iron are more important than those of any other element, and the influence of other elements is chiefly due to their action in increasing or decreasing the amount of combined carbon in the iron.

The amount of total carbon in pig iron may be increased or decreased in the process of melting in the cupola. On the one hand the molten iron absorbs more carbon through coming in contact with the fuel, the quantity absorbed being in direct proportion to the temperature and the length of time it is in contact with the incandescent fuel. On the other hand a cupola working with small charges of fuel will cause a loss of carbon through oxidisation.

COMBINED EFFECT.—The influence of each of the elements, considered separately, is comparatively simple and definite so far as its own particular effect on the iron is concerned, but when we come to consider the influence of one element on another or on all the others, and their combined effect on the iron, the subject becomes highly complicated. The varying proportions of these elements in so many different brands of iron as there are in use introduces a multiplicity of combinations that are beyond tabulation. In these circumstances the founder can only with certainty consider the effect of each element separately, and if this is done judiciously the combined effect will not usually be detrimental. It is in regarding the effects of the various elements on the carbon content that most care is needed. A high percentage of silicon, within certain well-defined limits, has a tendency to maintain the carbon in graphitic form, and thus produce a soft iron; but a small percentage of sulphur will counteract this because of its tendency to convert the carbon into combined form. This tendency again may be counteracted by the presence of manganese, which in itself is a hardening agent having much the same effect as sulphur, but when they are present together in the molten iron they have not the hardening effect that each possesses separately, since they combine and pass into the slag. The effect of phosphorus on the carbon is practically negligible, but with manganese and sulphur present it tends to reduce the high shrinkage that is induced by these elements.

Having studied the effect of the various elements on the structure of the iron, it is not difficult to apply the knowledge thus gained to every-day foundry practice. Many engineers when ordering castings are content merely to state the purpose for which they are required, and leave it to the foundry to make up a mixture that will give the desired result. Very few customers specify the particular brand of iron or the mixture to be used, or the amount and quality of scrap that may be included in the mixture, but sometimes a limit is stated of the amount of sulphur or phosphorus, or both, which may be allowed. In any case the founder must first consider the chemical composition of the finished casting, and afterwards the composition of the various brands of pig iron that are in stock and suitable for making up the mixture that will produce a casting to comply with the requirements. The purpose or use to which the casting will be submitted must be considered before a suitable mixture can be decided upon; the most suitable mixture can then be found by a repeated process of trial and error in making the necessary calculations.

The following table shows the chemical composition of some of the principal pig irons used for malleable castings:—

Brand of Pig Iron.	Si.	S.	P.	Mn.	Total Carbon.
Barrow Hematite Co. B.H.S. white	·66	·348	·06	·08	3·4
Guest, Keen & Co. Dowlais mottled	·6	·2	·05	·36	2·9
Holwell. Mottled	·7	·175	·14	·55	4·2
,, White	1·12	·24	1·1	·55	3·77
Derbyshire. Mottled	·8	·165	1·44	1·33	3·26
,, White	·5	·18	1·36	1·33	4·0
Carnforth Hematite. Mottled	·7	·15	·035	·2	3·2
,, ,, White	·3	·2	·04	·2	3·0
Cumberland "Lorn." White	·25	·055	·112	·09	3·35

MIXING BY ANALYSIS

When the chemical composition of the casting has been decided upon, and this is a decision that must be based chiefly on experience, but occasionally on specification, the available stock of pig iron must be studied to see what brands can be selected, which, when mixed in their proper proportions, will approximate most closely to the analysis required. Sometimes the selection can be narrowed down to two brands and a proportional amount of scrap iron, in which case calculations are simplified considerably, but very often three or more brands will have to be used, in addition to scrap. Many founders who specialise in certain classes of work, such as components for motor cycles, etc., use only one brand of pig iron, such as Cumberland Lorn or H.C.M. These irons when melted in crucibles and annealed with care give excellent results.

Assuming that castings are to contain the following percentages, approximately: silicon ·7, sulphur ·3, phosphorus ·045, and manganese ·4; and that the iron in stock consists of Carnforth mottled, B.H.S. white, and Derbyshire mottled, together with some clean hard scrap to select from; assuming also that the total weight required is 10 cwt.; a trial calculation is made for a charge consisting of 3 cwt. Carnforth, 3 cwt. Derbyshire, 1 cwt. B.H.S., and 3 cwt. of scrap. The analysis of the latter must be found by reference to the order for castings from which the scrap was taken. Starting with silicon we get, by multiplying the amount of iron in the charge by the percentage of silicon :—

Amount.	*Silicon.*	*Cwt. per cent.*
3 cwt.	·7	2·1
3 ,,	·8	2·4
1 ,,	·66	·66
3 ,,	·7	2·1
10		10)7·26 ·726

This is too high, so another trial is made with the proportions varied thus:

Amount.	*Silicon.*	*Cwt. per cent.*
2 cwt.	·7	1·4
2 ,,	·8	1·6
4 ,,	·66	2·64
2 ,,	·7	1·4
10		10)7·04 ·704

This is near enough for the purpose. The amount of sulphur, phosphorus, and manganese is found in the same way, and in this example it will be found that the percentage of all elements is satisfactory except phosphorus, which is much too high. On inspection it will be found that this is due to the high phosphorus content of the Derbyshire mottled iron. By omitting this iron from the charge, a mixture may be made up consisting of the other two brands and the scrap in different proportions, and the complete mixing sheet set out as follows:—

Brand.	Cwt.	Si.	S.	P.	Mn.
B.H.S. white . .	3	·66 = 1·98	·348 = 1·044	·06 = ·18	·08 = ·24
Carnforth mottled .	3	·7 = 2·1	·15 = ·45	·035 = ·105	·2 = ·6
Scrap	4	·7 = 2·8	·35 = 1·4	·04 = ·16	·4 = 1·6
	10	6·88 = ·688	2·894 = ·2894	·445 = ·0445	2·44 = ·244

It will be noticed that the manganese content is low; this is an advantage, but if the amount specified is insisted upon it can easily be supplied by adding to the ladle at the time of pouring sufficient ferro-manganese to bring the percentage up to the required amount. The total carbon, being fairly constant in all brands, is usually neglected in making up charges by this method.

The fracture of the unannealed castings made from the foregoing mixture should have an appearance similar to that of spotted white pig iron, and any mixture that will produce this appearance in the fracture can generally be relied upon to give excellent results if properly annealed.

As an example of the method of working out a charge this is simple, but in actual practice there are irritating little difficulties. Having made up a trial mixture that gives a satisfactory silicon content, we may find that the other metalloids are too high or too low, in which case it will be necessary, as shown, to use different brands of pig iron, or else make repeated trial mixtures of the same brands in different proportions until we arrive at an analysis as near as possible to that required. After a little practice there is not much difficulty in making up a mixture to specification, especially in foundries where a variety of pig irons is kept in stock. In some cases, however, very close results are impossible of attainment by such simple methods. If a low percentage of sulphur is required in the mixture, say ·02, and none of the irons in stock contains less than ·05 per cent., it is obviously impossible to get the desired result by calculation, and the foundryman must either get some other more suitable pig iron or else try to reduce the sulphur content by using those irons that contain a high percentage of manganese, provided, of course, that the proportion of this element does not exceed what is required in the mixture.

When it is necessary to work to a close specification, there are certain gains and losses that occur during melting in the cupola, and these must be taken into consideration, for they often have a very marked effect on the final composition of the iron as it appears in the casting. These changes are not constant factors, but are affected one way or another by the conditions of melting, such as the quantity and quality of the flux, the volume and pressure of the blast, the thickness of the fuel bed, the quality of the fuel, and the size and position of the tuyeres, as well as by the chemical composition of the mixture charged into the cupola. The loss of iron itself is due to oxidisation, and is highest when a large proportion of the charge consists of rusty or burnt scrap, but for all practical purposes the loss of iron may be reckoned as 2 per cent., which is about the average. The probable loss of silicon may be taken as 10 per cent. of the original percentage when the original percentage is ·18 per cent. or higher. This means that if the original percentage was 1·8 the probable loss will be ·18 per cent., and for a percentage of 2·5 the loss will be ·25 per cent. When the original percentage is lower than 1·5 the loss will be much smaller in proportion, for with an original percentage of 1·3 the loss will be only about ·06, and at 1·0 per cent. the loss will be negligible.

The loss of manganese will depend on the amount of sulphur present in the charge and in the fuel, and where the amount of sulphur is excessive the loss of manganese may run as high as 30 to 35 per cent. of the amount originally present in the charge. Under ordinary working conditions, without the excess of sulphur referred to, the loss of manganese may be neglected if the original percentage is ·4 or lower. Above this there will be a probable loss of ·08 per cent. for iron that contained ·6 per cent. originally; ·15 for ·8 per cent.; ·25 for ·9 per cent.; ·3 for 1·0 per cent.; and ·4 for any percentage above 1·0.

The losses are thus represented by iron, silicon, and manganese, and on the other hand there will be a probable gain in carbon; if so, it is usually very slight, and generally speaking it is not sufficient to affect the composition of the charge to any appreciable extent. It is chiefly the low-carbon irons that are affected, the additional carbon being absorbed from the fuel during the process of melting and the passage of the molten metal through the fuel as it falls to the bottom. High-carbon pig irons are only slightly influenced, and at or near 4 per cent. of carbon ordinary iron reaches a point of saturation beyond which no more carbon can be taken up. With ordinary high-carbon pig iron that contains also a high percentage of silicon, and especially when there is a good blast and insufficient fuel, there may be a loss of carbon instead of a gain.

The sulphur content is almost invariably increased during melting, the additional quantity being derived from the coke, and as a further increase occurs each time the iron is melted a great deal of scrap iron contains a high percentage of sulphur which still further increases the sulphur content of the complete charge. On an average the increase in sulphur due to absorption from the fuel will be from ·02 to ·04 per cent. The controlling factors in this case are the quantity of flux used and the amount of manganese present in the iron. The effect of the manganese has already been explained, and a free use of plenty of good flux will have a similar effect.

The phosphorus content may be regarded as constant. There is no loss, and there may be a slight increase derived from the fuel or flux, but in any case it would be so small that it can be ignored. There are other losses in the cupola that cannot very well be tabulated, since they depend chiefly on the general composition of the charge and the local conditions. Among these are the losses in weight due to the rust, dirt, and sand that are weighed with the charge and enter the cupola with it. For this the scrap iron is chiefly responsible, thin scrap in the form of plates being particularly liable to excessive oxidation. From this it will be seen that the proportion of scrap used in any charge has an important influence on the calculation for total loss of weight of material, and in making up a mixture an allowance must be made for a loss of about 5 per cent. in apportioning the amount of scrap to be used.

MEASUREMENT OF TEMPERATURE

The high percentage of waster castings formerly produced in malleable-iron foundries has undoubtedly been reduced by adopting a more scientific method of making up mixtures according to chemical standards; but this alone is not sufficient to ensure a continuous output of good malleable castings. There has always been an undue amount of wastage in the annealing process, chiefly owing to irregularities in the temperature of the ovens. This is inevitable when there is no means provided for measuring the temperature, and preferably for recording it also. In the best foundries the hopelessness of relying on the purely human element has long been recognised, and it has now been proved that by the use of suitable pyrometers for checking the temperature a considerable saving in fuel may be effected, and the percentage of waster castings due to imperfect annealing is almost entirely eliminated. Even comparatively small establishments have gradually realised the value of keeping a more rigid check on the heat of the ovens by means of simple chemical pyrometers, but in larger and more advanced works more exact scientific methods are employed, under the supervision of trained and qualified works chemists.

There are two kinds of pyrometers in general use, known as the optical pyrometer and the thermo-couple or Chatelier pyrometer. Each type has its votaries, and as all seem to get equally good results, a brief description of each type and its application to the subject of this work will be sufficient.

The thermo-couple, sometimes called the thermo-electric pyrometer, is the type most widely used for industrial purposes, especially where, as in the case of annealing ovens, it is necessary to measure and maintain an even temperature for several days. The principle of construction is that if two wires of dissimilar metals are fused together at one end, and the free ends are connected to the terminals of a sensitive galvanometer, the application of heat to the fused junction of the wires will set up sufficient electromotive force to move the needle of the galvanometer, and as an increase in the temperature causes a corresponding increase in the E.M.F., the needle or pointer of the galvanometer can be adjusted to indicate the temperature on a graduated scale, or to record it permanently on a chart by means of a suitable recording apparatus. The wires used to form the couple are frequently made from rare metals such as platinum and iridium or platinum and rhodium for the measurement of very high temperatures, but for temperatures that do not exceed 1,000° C. or 1,832° F., baser metals, including iron, may be employed. Such instruments are less costly, but are suitable for use in annealing

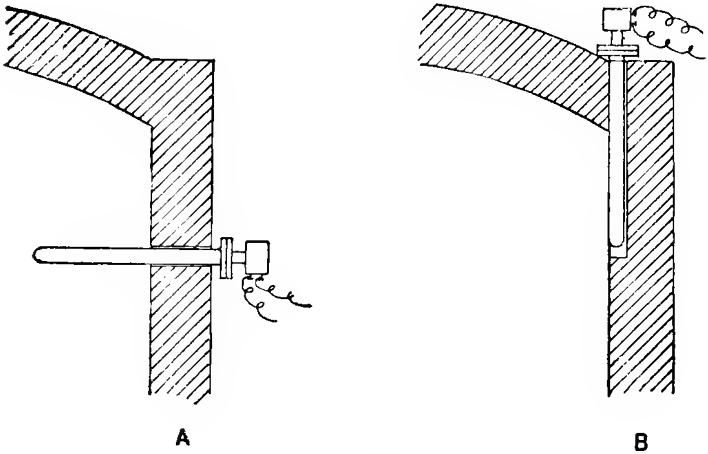


FIG. 82.—Chatelier Pyrometer.

ovens, where the temperature should on no account exceed 980° C. In order to protect the wires the couple is enclosed in a tube of quartz or porcelain, which is sheathed with asbestos and fitted into a steel or iron tube. The wires thus protected can be inserted in the oven through a hole in the wall or roof, the end of the tube to which the terminals are attached, and which is known as the cold junction, being outside the oven. In cases where the pyrometer is only used at intervals to check the observed temperature no special provision is necessary, one end of the tube being inserted in the oven as shown in fig. 82, A, where it remains until it has acquired the temperature of the interior. The temperature is then read off on a portable indicator that is connected by leads to the terminals, after which the pyrometer is removed and, if necessary, inserted in another oven in the same way. This method of checking the heat is not recommended, as there may be sufficient variation in the temperature during the intervals to spoil the castings, or at least to cause irregular annealing. A much more reliable method is to have a pyrometer fitted to each oven, so that the actual temperature is known at any moment from beginning to end of the annealing period. When this system is adopted the pyrometer is generally fitted in a permanent recess in the wall of the oven, as shown in B.

Fig. 83.—Temperature Indicator.

It is not necessary to have an indicator attached to each pyrometer, since by connecting the leads from each one to a switchboard a single indicator will serve for all the pyrometers in a battery or row of ovens. There are various types of indicators in use, one of which is shown in fig. 83. The figures on the scale indicate hundreds of degrees up to 1,000° C., and the construction of the instrument is such that it is particularly suitable for industrial conditions such as exist in malleable-iron foundries. Indicators should not be placed on the wall of the oven itself, but on a wall or support some feet away, where they are not likely to be affected by direct heat or by the magnetic influence of adjacent iron. If preferred, the indicator can be fitted in the manager's office, but it is better to have it fixed where the temperature can at any moment be noted by the foreman and the men in charge of the annealing ovens.

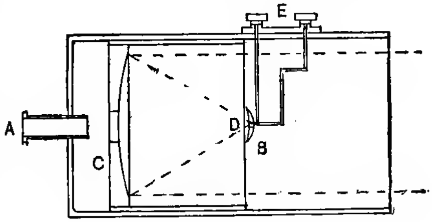


Fig. 84.—Féry Pyrometer.

As a rule optical pyrometers are more generally used for measuring temperatures higher than those attained in the annealing ovens of a malleable-iron foundry, but many works chemists prefer to use them for these and even lower temperatures, although it is generally admitted that these instruments are more sensitive to high temperatures than to the lower ones. The best known instrument of this class is the Féry radiation pyrometer, of which there are two distinct types, namely, the thermo-electric type and the spiral type. In both of these the optical arrangement is practically identical, and consists of a focussing telescope containing a concave mirror by means of which the heat rays can be focussed on a point within the body of the telescope. A small but very sensitive thermo-couple is fitted at the point of focus, and the concentration of the heat rays on this couple is utilised in the same manner as with the Chatelier pyrometer. The construction is shown diagrammatically in fig. 84. On looking through the eyepiece A the image is seen in a small mirror B, which has a hole in the centre. The image is focussed by turning a pinion and thus moving the concave mirror C, which also has a hole in the centre. This adjustment also focusses the heat rays at the point D, where the thermo-couple is situated, the free ends being connected to the terminals E.

In the spiral type the couple is replaced by a strip built up of two dissimilar metals and made into a coil. The centre of the coil is fixed, and to the outer end is attached a light pointer. An increase in the temperature causes the strip to uncoil, and *vice versâ*, causing the pointer to move across a scale and indicate the temperature.

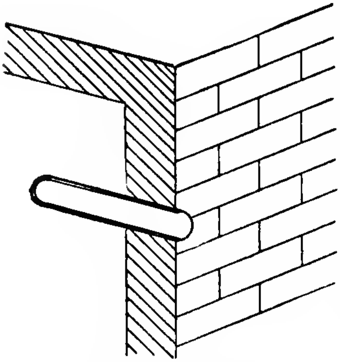


Fig. 85.—Observation Tube.

One form of pyrometer that is now becoming popular is practically a photometer. In the Cambridge optical pyrometer a beam of light from the heated body is compared with a similar beam from a small incandescent electric lamp, the intensity of which is known. On looking through the eyepiece an illuminated circle is seen, divided into two semicircles, one of which is illuminated by the standard lamp and the other by the beam of light from the oven. The intensity of the illumination in both semicircles is equalised by turning the eyepiece, to which a pointer is attached that indicates the temperature directly on an engraved scale.

In using any form of optical pyrometer it is necessary to exercise great care in selecting the most suitable point of observation to obtain a correct reading, and for annealing purposes the best method is to use a fireclay or cast iron tube with a closed end, the tube being built into the wall or door of the oven as shown in fig. 85. The temperature of the closed end of the tube is then that of the interior of the oven, and by sighting through the open end a very close approximation of the actual temperature can be obtained.

Fig. 86.—Optical Pyrometer in Position.

The optical pyrometer is usually mounted on a tripod for convenience in moving from one oven to another, but if preferred it can be mounted on a bracket attached to one of the buckstaves near the door of the oven, as shown in fig. 86.

ADDENDUM.—MALLEABLE CAST STEEL

Of comparatively recent introduction, this material, which is sometimes erroneously called "semi-steel," has made considerable headway; and as far as the author's experience goes it promises to become an important item in the somewhat limited list of engineering materials.

The process of manufacture is carried out on somewhat similar lines to that of malleable iron, but the result is a metal much stronger and harder. The fracture shows a fine crystallization closely resembling tool steel, and it has a tensile strength of from 30 to 35 tons per square inch; but as an offset to this the factors of resilience and ductility are much lower than in malleable iron, the elongation and consequent reduction of area being relatively lower. Thus, though it is not at all likely to displace malleable iron for all-round work, it will be found useful in many cases where increase of strength is required without a corresponding increase in weight, or as a substitute for the higher class of steel castings in cases where these cannot be utilised economically.

The principal drawback is a tendency to hardness, and in this state it is very severe on machine tools, but in any case it requires a coarser cutting angle than malleable iron. In some instances, however, this hardness is a distinct advantage on account of its great wearing properties, and for spur wheels and pinions with cast teeth it succeeds admirably, provided they are not subjected to very heavy intermittent shocks. It is not so easy to bend cold, as it is brittle beyond a certain point of flexure and breaks with an unexpected snap; but on the other hand it does not harden appreciably after being heated.

The foregoing chapters on design and patternmaking will apply equally well to this steel, its production being governed by the same natural laws as malleable iron, as will be seen from the following description :—

The pig iron, which is the same as that already described, is used in different proportions, there being a much smaller quantity of grey or soft mottled; a mixture of hard scrap, 12 parts; spotted white pig iron, 4 parts, and soft mottled, 2 parts, will be found suitable; if no hard scrap is available, it may be of white pig iron, 6 parts, soft mottled 1 part, while for some special purposes, such as high-class motor work, any good medium mottled pig iron alone will do. No annealed scrap is added to the mixture, as for malleable iron, otherwise the melting is carried out in the same way in either crucible, cupola, or air furnace. Just previous to tapping a small quantity of mild steel scrap—punchings are the most convenient—is thrown into the bottom of the ladle, and the metal is then tapped over it. It is essential that the steel scrap should be red-hot when put in the ladle, or it will not mix properly with the molten metal, and will be subsequently found in the form of bright spots in the casting, which will be uneven in density. The proportion of steel used is from 3 to 5 per cent. This must not be exceeded, or fusion will not be complete at the time of pouring, which should be done immediately, or the metal will become too thick or dull.

The castings are muffled as soon as possible, as, owing to their intense hardness, the cooling strains are very severe, and they are allowed to remain in the muffle until cold. Even if taken out when cool enough to handle, they are liable to spontaneous rupture. They may be annealed together with the malleable castings, preferably with those that require heating up slowly.

After they are cleaned and dressed the castings are put through a final process known as tempering, and for this a clear, smokeless furnace is necessary, in which a steady heat of about 1,500° F. can be maintained. The castings are put into this until they attain the same heat, and they are then withdrawn and left to cool in a pit where they will be screened from currents of air. When finished, these castings have a beautiful blue surface, which is practically rustless, and for this reason they are particularly suitable for all work exposed to atmospheric influences.

A better way of obtaining the same result is as follows:—Just before the time allowed for annealing is completed firing is stopped, and the heat of the oven is allowed to fall to about 1,000° F. Firing is then started again and the oven brought up to the full annealing temperature, after which it is allowed to cool down finally. This method of heat treatment is more reliable and gives more consistent results than when the castings are reheated after they have been removed from the annealing oven. In many cases the quality of ordinary malleable castings can be considerably improved by similar treatment.

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