GENERAL FOUNDRY PRACTICE.

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PREFACE.

THIS work is designed to give a condensed and crystallised account of the science and practice of iron, steel, and brass founding in such a way that it may prove of the greatest benefit to all connected with the production of castings. The field is an extensive one, but so far as possible the authors have drawn from their combined experience gained under normal foundry conditions and under the conditions of experimental laboratories and works. Practically every operation described has been personally followed, and the spirit of the book will be found to reflect the experience of actual workers and not merely spectators.

Although primarily intended for foundry managers and foremen, or those who aspire to such positions, the authors trust that their work may become as much the literary companion of moulders and apprentices during the time they devote to technical study as the tool-box is in their hours of moulding. Much of the matter should also be of interest and value to the engineer and designer as well as to the student of general metallurgy.

Reliability throughout has been striven for, and the intimation of even seeming error detected by any thoughtful reader with a knowledge of foundry practice will be welcomed; whilst suggestions from a similar source tending to increase the usefulness of a future edition will receive careful consideration.

Wherever possible, acknowledgments have been made in the text. Our heartiest thanks are here tendered to Mr Arthur Simonson for his description of the Tropenas process; to the several manufacturers or their agents who have supplied blocks for figures 8 to 12, 43 to 45, 123 to 125, 127 to 130, 132, 136, 169, 190, 191, 193, 194, 197, 199, 201, 203, 204, and 217; to the Iron and Steel Institute for 173, 175 to 177; to the West of Scotland Iron and Steel Institute for 236, 238 to 240; and to the Editor of *Page's Magazine* for 243, the last eleven being all from our own papers; also to Mrs A. M' William for preparing the index.

A. McW.
P. L.

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CHAPTER I.

INTRODUCTION.

THE art of founding has been described as making a hole in the sand and filling it with fluid metal. There is a simplicity and directness about the definition which entitle it to respect, and leave it suitable for the general reader; but for the practical moulder or founder looking for help in his work it is lacking in detail. Before proceeding to a more particular consideration of founding, it may be well to glance at its early history. Antiquaries consider that the art was known before the days of written history. Cold working probably preceded melting and casting; for example, meteoric iron and surface deposits of copper may have been utilised by roughly hammering pieces to the desired shapes. This stage may have been followed by that of liquefying the copper and casting it into baked clay moulds, for in many parts of the world both cast and hammered weapons of copper have been found which are probably of similar ages. The addition of tin to copper may have been made purposely, or the presence of the tin may have been due to the smelting of copper ores containing tin, but in either case the product is the ancient metal bronze. The general composition of this bronze is about 90 parts of copper to 10 of tin, and in later examples lead has been detected. Ancient Egyptian tools are reported to contain 12 per cent. of tin, whilst Greek and Roman tools have a composition varying between 88 and 90 per cent. of copper, 12 and 10 per cent. of tin, with traces of silver and zinc, the last two probably accidental. An old writer, Theophilus, gives as a composition of bell metal, copper containing one-fifth of its weight of tin, which, it is interesting to note, is the British Admiralty specification for bell metal to-day.

In England, according to Sir John Evans, the bronze period extended over several centuries, and in all probability it had merged into the iron age a century before Cæsar's invasion of Britain.

The ancient Egyptians were essentially stone-workers, and it is claimed that the tools employed were of hardened and tempered bronze; it is further stated that the method of hardening bronze to the same degree is now a lost art. This requires further confirmation, for, considering the advanced state of civilisation prevalent in early Egyptian times, it is not improbable that they may have been familiar with steel. Implements of bronze buried in the earth are fairly permanent, whilst those of steel or iron in the presence of air and moisture are rapidly rusted away; therefore the relative scarcity of the latter in certain deposits is no criterion of the relative numbers in use during the time these deposits were being formed. It is also of interest that the first cores were of iron, namely, bronze liners cast round a small iron shaft. In such a case the iron would be fairly permanent, and specimens so treated, dating from about 880 B.C., are now in the British Museum. The birth of cast-iron in Britain occurred between the years 1345 and 1355, and the first home of the new industry was in Sussex. Iron-founding was first practised in this country about the year 1500, and the first cast-iron cannons were made in 1543, while by 1595 cannons weighing three tons each were made; a record of progress illustrating alike the adaptability of cast-iron and the development of iron-founding. So far as this country was concerned, further progress was prevented by the limited supply of wood for conversion into charcoal, then the only suitable fuel available. In the seventeenth century, Dud Dudley successfully prepared coke from the Staffordshire coal, and James I. granted a patent for the invention. The coke was used as a fuel in the blast furnace, and cast-iron obtained. Owing to certain troubles and misfortunes, Dudley relinquished his process, and not much progress was made until in 1713 Darby revived Dudley's process at Coalbrookdale. This was put on a commercial footing, with such success by the younger Darby that in 1790 there were 106 furnaces in blast, 81 using coke and 25 charcoal, the weekly output of the coke furnaces being 17 tons and of the charcoal furnaces 10 tons of pig-iron. The revolutionary improvements in the steam-engine introduced by Watt in 1768 gave a further impetus to iron-founding, and from this the record is one of steady progress. The crucible process for the melting of steel (Huntsman of Sheffield, 1740), the introduction of the Bessemer process (1856), and of the Siemens furnace (1867), all had their effect in the steady advance of the foundry, and were each in their turn employed in the manufacture of steel castings, as is also the basic process (Thomas and Gilchrist, 1878), at least when worked in the Siemens furnace. In more modern progress in the founding of metals and alloys, the improvement in green sand, dry sand, and loam moulding are noteworthy, castings of almost any size and form being made daily, although the advances in machine moulding form the greater feature. Progress in founding must not, however, be judged solely by the usual rule, "the extent of the adoption of labour-saving devices," and many writers err in this direction and label the whole foundry industry as retrograde, simply because they may be acquainted with a few foundries in which moulding machines are not extensively adopted. In many foundries not controlled by foundrymen, moulding machines have been installed under unsuitable conditions, and the result has been the locking up of the capital involved. The whole question is considered in Chapter XVI.; but it may be mentioned here that the founder's art seems recently to have come in for more than its fair share of amateur advice and sweeping adverse criticism from those who do not realise that each new form to be cast is a new problem, that each new set of requirements necessitates a metal of different properties, that the successful practical and technical founder must be an ever-alert and living man of good judgment, and that the business cannot be reduced to the employment of moulding machines, motors, and a card index. The experience of the authors gained on the moulding floor, at the melting furnace, and in the foundry and research laboratory, together with their reading on the subject, leads them to the conclusion that advances have been, and are being, made of a magnitude commensurate with those of other industries.

In the last twenty years information as to the properties and uses of metals and alloys has greatly increased, as is testified by the high tension bronzes, the better qualities of cast- and malleable cast-iron, and the great development of steel castings. In the literature of the subject much valuable matter relating to the scientific aspects of founding has been published, but much also that is confusing and misleading, so that the founder must be on the alert to winnow the chaff from the grain and absorb the latter. The young moulder of to-day enters a splendid heritage, which, however, involves high responsibilities, and his aim should be to continue the work of the past. Every moulder may become a pioneer; and any real advance, however slight, will bring its own reward.

Given an ambitious young moulder, what ought he to do in order to become thoroughly conversant with foundry practice? Naturally, the first essential is that of moulding, and the greater the amount of practice the better. It need hardly be stated that practice in moulding must be acquired in a foundry engaged in the production of commercial castings. Further, moulding experience should include, if possible, the three branches of green sand moulding, dry sand, and loam work. If, during his apprenticeship, the young moulder can obtain experience of these three branches, he will be fortunate, and should eagerly seize every opportunity for acquiring it. Whilst undergoing this training his evenings will be free, and these, during the winter months, should be devoted to study. Evening classes are now within reach of all foundries, and the first classes taken should be elementary mathematics and machine drawing. Some acquaintance with mathematics is necessary; and whilst the ability to make a working-drawing is useful, it is absolutely essential that the student-moulder should acquire facility in reading working-drawings. Following these classes, the next in importance would be elementary stages of chemistry, mechanics, and heat. These subjects are essential for their own sake and as a preliminary training previous to entering on the study of metallurgy. In order that conditions may not be too severe, the young moulder might devote the first three years of his apprenticeship to the five subjects, and leave the winter evenings of the remaining four years for the study of metallurgical science.

Once a habit of study is acquired, the learner will work out his own path, and his training will have so increased his powers of observation that his daily experience will call for wider knowledge; when he has attained to this stage he may safely be left alone. It must not be forgotten that even seven years' apprenticeship, with attendance at evening classes and home study, will not make a complete foundryman. Knowledge is not easily gained, and training is never complete. It may be thought that the outline here given is too much for an apprentice after doing a full day's work in the foundry. Naturally, it involves considerable strain, but the authors are advocating no untested scheme.

CHAPTER II.

GENERAL PROPERTIES OF MATTER.

THOSE who have had the benefit of a good grounding in Natural Science may pass this chapter over, unless in so far as it may refresh their memories and perhaps be suggestive of application of their theoretical knowledge to their practical work. It is intended for the beginner, not only to show him the least he must study, if he would attain to the fullest development of scientific method in his present work and in the gradual attainment of his practical experience, but also, incidentally perhaps, to encourage him to begin the work by showing a few of the more obvious applications. In the future, such a chapter may, and most probably will, be unnecessary; but the wide experience of the authors leads them to insert it as at the present time desirable for the end they have in view, namely, to attract and help all who are thinkers and workers connected with the foundry.

The number of different kinds of materials dealt with daily, even in foundry work, might well appal the beginner when he thinks of studying their properties and chemical composition. The chemist has found, however, that all these substances, and, indeed, all substances examined, are composed of a comparatively small number (70 odd) of kinds of matter, each of which has so far resisted all the applications of his skill and perseverance to break it up into two or more dissimilar bodies. These he calls elements, and of these only a small proportion need be considered by the beginner as necessary for the study of everyday foundry work. Thus, slags and the non-metallic materials of construction are practically all made up of oxides (elements combined with the element oxygen), or combinations of oxides, mainly silica, alumina, oxides of iron, lime, magnesia, potash, and soda. The metallic substances in the widest practice mainly consist of the metals iron, manganese, copper, zinc, tin, nickel, lead, aluminium, mercury, or alloys of these, with bismuth, antimony, arsenic, generally in smaller proportion, and more or less of the non-metallic substances carbon, silicon, sulphur, and phosphorus. The list of elements that need be considered is thus not so formidable, and, although their combinations are practically infinite, this idea gives a foundation for studies on which may be built up a useful structure of knowledge to any extent, and of any degree of detail, embracing the whole range of metals, specialising in one or more branches, but all on the same fundamental basis and with a remarkable similarity of mental treatment. Thus, the beginner may look forward to building to any extent his attainments and opportunities will permit, and, at whatever stage he may arrive, feel sure of acquiring not only useful knowledge but mental power to record and take advantage of his own experience and that of others, as expressed in conversation, in books, or in technical periodicals. A little knowledge is only dangerous when it is viewed out of proper perspective and assumed to be a complete knowledge to be recklessly acted upon; and the authors meet with oft-recurring evidence that all stages of well-arranged knowledge, if used with discretion to throw light on practical experience, is daily and increasingly helpful as the underlying science of the founder's art becomes more and more clear. The real theoretical knowledge of the scientist is built on experiment, and his explanations or theories in all true scientific work are tested by further experiment. The practical man constantly meets with difficulties in his work, and he also must in some way group the results of his former experience, seek in these for an explanation of the case, and, after thinking the matter over, devise a remedy, and put it to the test,—truly scientific work. The apparatus may often be cruder than that found in laboratories, but frequently used with a more subtle judgment of the special needs of the case. The man who combines a scientific training with a sufficiency of real practical experience is gradually, but surely, becoming the dominant type of industrial captain in the working departments of the best equipped foundries. All youths looking forward to progress in foundry work in the future should study at least the rudiments of mathematics, particularly geometry and mensuration; physics, especially mechanics and heat; and inorganic chemistry in some of the elementary classes so liberally arranged in practically all towns having foundries. They will then be able to start their own special subject with the certainty of profitable work. It is hoped, then, that this chapter, unnecessary for those who have had preliminary training, will help those who have not, to understand what follows and lead them to make a study of chemistry and physics, as many things must here be merely stated, whereas, in special works on the subject, they would be reasoned out. Reverting to the elements, it has been found that when these combine with one another they always do so in definite proportions. Thus, iron filings and sulphur may be mixed in any proportion; if heated together they combine to form an entirely different substance, but always in the proportion of 56 parts by weight of iron to 32 parts by weight of sulphur; and, under these conditions, in no other proportion. A natural mineral known as pyrites, the "brasses" of coal, is a compound of iron and sulphur, but in the proportion of 56 of iron to 64 of sulphur, that is, double the proportion of sulphur. So the elements are found to combine in definite and, generally, also in multiple proportions. All this, and much more, led to the idea of the atomic theory, namely, that elements are composed of atoms of a definite weight, that all the atoms of the same element are of the same weight, but the atoms of different elements have different weights; hence each element has its own atomic weight. Also the smallest portion of an element, or of a compound that can exist in the free state, is called a molecule. The elements are for convenience represented by symbols, as iron Fe, from its Latin name *ferrum*; and the atomic weight of iron being 56, the symbol Fe not only means an atom of iron but 56 parts by weight of iron; and similarly S, the symbol for sulphur, means an atom of sulphur and 32 parts by weight of sulphur. It will now readily be seen that the first compound of iron with sulphur would be written FeS; while the formula, as it is called, for pyrites would be FeS_2, the small 2 indicating 2 atoms of sulphur. To represent what took place when the mixed iron and sulphur was heated till they combined, combining in definite proportions and rejecting any portion in excess, an equation is written thus:—$Fe + S = FeS$; this equation means not only that iron and sulphur have combined to form sulphide of iron, but also that 56 parts by weight of iron have combined with 32 parts by weight of sulphur to form (as matter is indestructible) 56 + 32, or 88 parts by weight of sulphide of iron. More complicated examples might be given, but all rest on the expansion of this simple case; and, although certain equations tell more than this, that need not trouble us at the present time. The symbol chosen is generally the first letter of the name of the element written as a capital; and where there are two or more with the same initial letter, the most important takes the first letter and the others add a second distinguishing small letter. The commoner metals have taken their symbols from their Latin names. Thus, Carbon, C; Chromium, Cr; Copper (Cuprum), Cu; Sulphur, S; Tin (Stannum), Sn; Antimony (Stibium), Sb.

SELECTED TABLE OF SYMBOLS AND ATOMIC WEIGHTS OF ELEMENTS. O = 16.

Non-Metals.		
Hydrogen	H	1·0
Carbon	C	12·0
Nitrogen	N	14·0
Oxygen	O	16·0
Silicon	Si	28·4
Phosphorus	P	31·0
Sulphur	S	32·1
Arsenic	As	75·0
Selenium	Se	79·2
Tellurium	Te	127·6
Metals.		
Aluminium	Al	27·1
Antimony	Sb	120·2
Barium	Ba	137·4
Bismuth	Bi	208·5
Cadmium	Cd	112·4
Calcium	Ca	40·1
Chromium	Cr	52·1
Copper	Cu	63·6
Gold	Au	197·2
Iridium	Ir	193·0
Iron	Fe	55·9
Lead	Pb	206·9
Magnesium	Mg	24·4
Manganese	Mn	55·0
Mercury	Hg	200·0
Molybdenum	Mo	96·0
Nickel	Ni	58·7
Palladium	Pd	106·5
Platinum	Pt	194·8
Potassium	K	39·2
Rhodium	Rh	103·0
Silver	Ag	107·9
Sodium	Na	23·1
Tin	Sn	119·0
Titanium	Ti	48·1
Tungsten	W	184·0
Uranium	U	238·5
Vanadium	V	51·2
Zinc	Zn	65·4

The elements in the table are classed as metals and non-metals, or the latter are sometimes called metalloids (like metals). This classification is convenient, but, like most others, there is no distinct line between the classes, as they merge into one another; arsenic, for example, sometimes acting as a metal and sometimes as a non-metal. The more obvious physical properties associated with the metals are familiar to all, such as their high lustre and their high conductivity of heat and electricity; but, as they also have certain well-defined chemical habits, the chemist extends the meaning to other elements having similar properties. Thus, when compounds of a metal with a non-metal are decomposed by a current of electricity, the metal always passes with the current or goes to the negative pole and is spoken of as the electro-positive element. Metals combined with oxygen generally form what are known as basic oxides, while the non-metals as a rule form acid oxides; the only feature we need consider in connection with these two is that acid oxides combine with basic oxides to form neutral substances known as salts. Thus, sulphur combines with oxygen in two ways; as sulphur dioxide, SO_2, when sulphur burns in air, or, by special means, forms sulphur trioxide, SO_3. These are acid oxides; and when combined with water, H_2O, form sulphurous acid, H_2SO_3, and sulphuric acid, H_2SO_4, respectively. A metal may replace the hydrogen in the acid, and form a salt; thus, iron

$$Fe + H_2SO_3 = FeSO_3 + H_2 \quad \text{or} \quad Fe + H_2SO_4 = FeSO_4 + H_2.$$

A metal combined with a non-metal has a name ending in *ide*, with a non-metal and oxygen in *te*, with the lower proportion of oxygen in *ite*, and with the higher in *ate*. Thus, FeS, $FeSO_3$, $FeSO_4$ are respectively sulphide of iron, sulphite of iron, and sulphate of iron. The acids may be looked upon as a combination of water and the oxide; thus, H_2SO_3, or H_2O,SO_2, and H_2SO_4, or H_2O,SO_3; hence, the SO_2 and SO_3 being complete acids, minus the water, are strictly not acids, but anhydrides (without water). In the high temperatures of metallurgy, where the water seldom has any part to play in the combinations, a little more freedom is used; and, although H_4SiO_4 or $2H_2O,SiO_2$ is silicic acid, we seldom speak of SiO_2 as silicic anhydride, unless to emphasise some special point, and, as with other very common things, generally refer to it by the older name of silica. Not only does the nature of the acid control one part of the name of the salt, but the nature of the basic oxide may also decide the termination of the other part. Thus there are two oxides of iron, FeO and Fe_2O_3, either of which may be called oxide of iron, but, to distinguish between them, the name of the one with the greater proportion of metal ends in *ous* and the other in *ic*; hence, FeO represents ferrous oxide and Fe_2O_3 ferric oxide; while a third, the black or magnetic oxide, is a combination of these two, being FeO,Fe_2O_3, or Fe_3O_4. In considering compositions of slags, bricks, etc., in foundry work, it is usual to think of the bodies in the second way shown for salts, namely, less as substitutions of metal for the hydrogen in acids than as combinations of acid and basic oxides. Thus, H_4SiO_4 represents silicic acid; substituting Fe_2 for H_4, we have Fe_2SiO_4, which is one way of looking at the composition of ferrous silicate; but, as it is generally formed at high temperatures, it is usually thought of as $2FeO,SiO_2$, that is, as two molecules of ferrous oxide combined with one of silica, and hence is known as ferrous silicate, a prominent constituent of the slags of the cupola furnace, the Bessemer converter, and the Siemens furnace, also of the black scouring slags of the ordinary blast furnace when producing white cast-iron. The chemical affinity, or the firmness of the grip that these substances have on one another, varies very much, some being much more stable than others; and, given suitable conditions, a metal that would form a more stable compound with a non-metal will replace it in the compound. We have spoken already of ferrous sulphide, FeS, which, if present as an impurity, is retained by iron when in the liquid state, and forms a very dangerous structure in the metal when cold; but if manganese be added, manganous sulphide, which is not nearly so dangerous, will be formed, and iron liberated, thus:—$FeS + Mn = MnS + Fe$. This reaction also forms the basis of the Massenez desulphurising process of adding ferro-manganese to cast-iron in a metal mixer, for the sulphide of iron is held by the molten cast-iron, whereas the sulphide of manganese thus formed gradually rises to the surface of the metal. Similarly the metal bath at the end of a Siemens heat or a Bessemer blow is charged with ferrous oxide, which dissolves in the iron and makes it quite unforgeable; but the manganese added again evicts the iron from its oxide and forms manganous oxide, $FeO + Mn = MnO + Fe$; as the oxide is insoluble in the iron, it gradually floats to the top, where it is taken up by the slag, forming manganous silicate, $2MnO + SiO_2 = 2MnO,SiO_2$.

The normal carbide of iron is represented by Fe_3C, and is found in fine plates in the pearlite of mild steels. If, however, these steels contain 1 per cent. of manganese, the nature of the pearlite is changed, most probably by the substitution of some carbide of manganese (Mn_3C) for an equal number of molecules of the iron carbide. "Most probably" may sound a strange phrase to the beginner who has heard of science as exact knowledge, but science is only organised knowledge as exact as we can get it, with continual striving after more accuracy in what we know and the unfolding of new discoveries; the former is illustrated by the enormous amount of work done since 1890 to get more reliable fixed points for high temperature measurements; the latter by the wonderful properties of Hadfield's manganese steels, steels with high nickel contents, and other special steels.

Chemistry, then, concerns itself with the composition of substances and with their reactions on one another, the changes taking place being generally very marked. Physics, on the other hand, although in its widest sense it includes chemistry, is generally restricted to the study of (I.) Dynamics, or the laws of force and the relations which exist between force, mass, and velocity, under the three heads Mechanics, Hydrodynamics, and Pneumatics, or the study of those laws applied respectively to solids, liquids, and gases; (II.) Sound; (III.) Light; (IV.) Heat; (V.) Magnetism and Electricity, under which heads combined we may be said to study the general properties of matter.

Dynamics deals with force, mass, and velocity, force being defined as that which moves or tends to impart motion to a body at rest or change of motion to a moving body. It is generally stated in terms of units of weight as lbs. or kilograms. When a body free to move is acted on by forces which do not move it, the forces are said to be in equilibrium; while, if the forces are not in equilibrium, the body is moved. The division called Statics treats of the former and Kinetics of the latter. One of the first points of importance that has constantly to be dealt with in practice is that there is never only one force but that every action has a reaction equal and opposite. Any number of parallel forces acting on a body can be replaced by one force known as the resultant, if applied at a certain point; and in the cases of the parallel forces of gravity acting on each particle of a body, the resultant force is the weight of the body and its point of application the centre of gravity of the body. This centre of gravity is an important point, for it always tends to descend; that is, to approach the centre of gravity of the attracting body; if in any structure the direction of gravitation falls outside the base, the structure tends to fall; also, if the base be small compared with the height, instability may arise with a small angle of movement; all of which may seem self-evident, but the neglect to give it adequate consideration has resulted in many an accident.

The principle of work is, perhaps, the most widely used in everyday simple problems. Work is defined as the power exerted in overcoming a force through a distance, as, for example, in lifting a weight against gravity, and is measured in foot-pounds, found by multiplying the number of pounds carried by the number of feet they are raised. In any system, neglecting frictional losses (where work is converted into heat and dissipated), the work put into the system is equal to the work given out by the system. This simplifies the consideration of all the mechanical powers, the lever, the wheel and axle, the pulley, the inclined plane, the wedge and the screw. Thus, for example, a block and tackle to lift one ton is so arranged that the hand chain moves 60 feet while the weight moves 2½ feet; then, neglecting friction losses, the force required on the chain × 60 = 1 ton × 2½ ∴ force on chain $= \frac{2240 \text{ lbs.} \times 2\frac{1}{2} \text{ feet}}{60 \text{ feet}} =$ 93⅓ lbs., and the mechanical advantage is $\frac{60}{2\frac{1}{2}}$ or 24.

Energy is a term continually in use, and is defined as the power of doing work. The energy stored up in a body in motion is called kinetic energy, or the energy of motion. When a body at rest has the power of doing work it is said to have potential energy. Thus a body of weight 1 ton, 10 feet from the ground, could do 22,400 foot-lbs. in falling to the ground. Energy may be changed from one form into another, static or potential into kinetic, kinetic into heat; but the total cannot be increased or diminished. This is known as the principle of the conservation of energy. All bodies have their dimensions more or less changed by the action of a force, and the property whereby they tend to recover their original dimensions is known as elasticity. If the force be gradually increased, there comes a point at which the applied force and the maximum elastic force of the body are equal. An increase in the applied force will produce permanent set, and the limit of elasticity is said to be reached, a point of great moment in mechanical testing and in determining the purpose for which a metal is fitted. It is practically universally agreed that the applied force shall be called a stress, and the deformation produced a strain; words which, though highly technical, conform to the everyday non-technical use of the terms, so that the phrase "breaking strain," at one time seen on test sheets, and given in tons per square inch, generally referred to maximum stress; but to show the persistence of error, this serious mistake in terms is found all through a very important recent paper given by scientific men to the Institution of Mechanical Engineers.

Friction.—When two bodies are pressed together, so that the pressure is not at right angles to the surface of contact, the pressure can be resolved into two, one at right angles and one tangential to the surface. The latter is known as the force of friction, and the relation between the latter and the former is called the coefficient of friction, which is nearly a constant for the same surfaces as the force of friction is nearly proportional to the normal force. When a body rests on a plane, and the plane is inclined until the body begins to slide, the angle that the inclined plane makes with the horizontal is called the limiting angle of friction, or the angle of repose for the two surfaces, an angle often of importance in practice. The tangent of this angle is equal to the coefficient of friction.

Hydrostatics.—The laws of force applied to liquids is known as the science of hydrodynamics, of which hydrostatics is one branch and hydrokinetics another. A fluid, either a liquid or a gas, at rest can exert no friction; but all fluids in motion exert a slight tangential or frictional force, and this is expressed by saying that all fluids are more or less viscous. The intensity of pressure at any point in a fluid is the same in all directions, and is also the same at all points at the same level beneath the surface of a liquid at rest, and the pressure on any horizontal surface is exactly equal to the weight of a volume of the liquid represented by the area of the surface multiplied by the depth below the level of the surface of the liquid, and this holds good whether the actual weight of the liquid be there or not. Thus the pressure on the bottom of a cylinder full of water to a depth of 3 feet is exactly the same as the pressure on the bottom of a cylinder of the same diameter 1 foot in depth, with a continuation pipe carried 2 feet higher up and the whole filled with water, a fact taken advantage of in testing certain boilers.

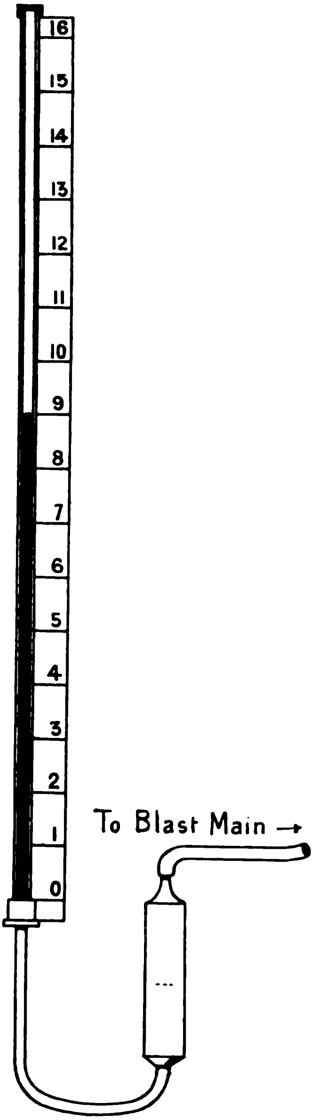

FIG. 1.—Pressure Gauge.

This point requires careful consideration with regard to the weighting of moulds, and is of interest in understanding the usual ingenious pressure gauge for measuring the pressure of the blast delivered to cupolas. The instrument is shown in section in fig. 1. The rubber tube connects the blast main to the small brass cylinder, so that the pressure of the blast is exerted on the surface of the water in the cylinder, and forces the water up in the glass tube till the difference in height between the two levels balances and therefore produces a pressure equal to the pressure of the blast. 1 cubic inch of water weighs 0·03612 lb., or 0·578 oz.; 12 inches of water in height will therefore produce a pressure of 12 × ·578, or 6·936 ozs. per square inch, and $\frac{12 \text{ inches}}{6·936}$ or 1·73 inch in height corresponds to a pressure of 1 oz. per square inch. In the gauge, however, as the water rises in the glass tube it falls in the brass cylinder; and as it would be extremely inconvenient always to have to measure the difference between the levels, the diameter of the cylinder is so arranged with regard to the diameter of the bore of the glass tube that when the water falls 0·23 inch in the cylinder it shall rise 1·5 inches in the gauge glass, so that a scale of equal parts, each part 1½ inch long, shall represent ozs. per square inch of blast pressure. For this to follow, the area of the brass cylinder must be to the area of the bore of the glass tube as 1·5 to 0·23, or as 6·5 to 1, and the diameters of the two as $\sqrt{6·5}$ to $\sqrt{1}$, or as 2·55 to 1. Hence, if the glass tube be of $\frac{5}{16}$-inch bore, the inside diameter of the brass cylinder must be $\frac{5}{16}$ inch × 2·55, or practically $\frac{13}{16}$ inch. As another example of fluid pressure, take the case of a steel casting, the top surface of which is 5 feet 9 inches long and 18 inches broad, and suppose that the runner is to be filled to a level of 12 inches above the top of the casting, and that there are two risers, each 6 inches square. As there can be no upward pressure where the risers are, the total upward pressure on the top part of the mould will be equal to the weight of molten metal that would be contained in the space represented by the total area of the top of the casting, less the area of the risers, and to a depth equal to the head of metal in the runner, or (69 inches × 18 inches − 2 × 6 inches × 6 inches) × 12 = (1242 − 72) × 12 =

14,040 cubic inches of metal; and taking the hot metal roughly at 4 cubic inches to the lb., then 14,040 cubic inches $= \frac{14{,}040}{4}$, or 3510 lbs., or 1 ton 11 cwts. and 38 lbs.; and at least this weight, including the weight of the top part, will be required to hold the top part down.

When a body is immersed in a liquid it displaces its own volume of the liquid; hence the weight of this liquid, by its tendency to regain its position, may be considered to be pressing the body upwards; and then its loss in weight, when immersed in the liquid, is exactly equal to the weight of its own bulk of the liquid. A familiar example of the case where the body is lighter than the liquid, and the upward pressure will therefore float it, is found in the case of cores, which, unless held down, are raised by the liquid metal and float on the surface. In determining the specific gravity of a body, or its weight compared with the weight of an equal bulk of water as a standard, it is only necessary to weigh the body in air, then weigh it in water, and the specific gravity $= \frac{\text{the weight in air}}{\text{the loss of weight in water.}}$ Thus, a certain piece of limestone weighs in air 13 lbs. 4 ozs., whilst it weighs in water only 8 lbs. 7 ozs. ∴ The specific gravity of the limestone $= \frac{\text{13 lbs. 4 ozs.}}{\text{13 lbs. 4 ozs} - \text{8 lbs. 7 ozs.}} = \frac{\text{212 ozs.}}{\text{77 ozs.}} = 2{\cdot}75.$

With vessels in communication, liquids tend to find their own level; hence the necessity in open sand moulding to obtain a perfectly level bed if a uniform depth of metal is required in the mould. Further, if it is desired to run metal through a mould by means of an overflow on the riser, care must be taken to see that the runner is at a higher level than the riser.

Capillarity.—The surface of a liquid at rest is a horizontal plane, and the liquid in vessels in communication finds its own level. That is not exactly the case when the diameter of one or more of the vessels is comparable to that of a hair and known as capillary. In that case, if the liquid "touches" or "wets" the vessel, as with water and glass, the height will be greater in the capillary than in the other vessels; and if the liquid does not "touch," as with molten cast-iron and a sand mould, the height would be less. Also, in the former case, near the sides, the liquid will be higher up in the vessel, and in the latter it will be slightly curved downward, a point that is clearly seen in the nature of the edges of an open sand casting where the surface is free, the corners of a similar closed casting being sharp, only because the liquid is forced up to the square by the pressure of the "head" of the molten metal above.

Pneumatics.—Gases have many properties in common with liquids, and many essentially different. Like liquids, they transmit pressure in all directions; but, unlike liquids, they always tend to expand; they completely fill the vessel that contains them, and, however small the quantity of gas, it exerts pressure on all sides of the vessel. Also, for a given quantity of gas at a given pressure, if the pressure be increased the volume will be less; in fact, if the temperature remain constant, for a given quantity of gas the pressure varies inversely as the volume. P being the pressure and V the corresponding volume, P′ the new pressure and V′ the new volume, $PV = P'V'$ or $\frac{P}{P'} = \frac{V'}{V}$.

Heat.— Heat, cold, and temperature are terms so well known that they hardly need explanation, but the measurement of temperature is one of the most important matters of the day. With very few exceptions, bodies expand as their temperature rises and contract as it falls; the expansion of the liquid metal mercury in a glass vessel is one of the commonest means used for measuring temperatures below the boiling-point of mercury. Two fixed points are necessary for the formation of a scale, and these are the melting-point of pure ice and the boiling-point of pure water at normal atmospheric pressure. In the Celsius or Centigrade scale, the former is indicated by zero, or 0° C., and the latter by 100° C., and the space between is divided into 100 equal parts; in the Fahrenheit scale, the melting-point of ice corresponds with 32° F. on the scale, and the boiling-point with 212° F., the intermediate portion being divided into 180 equal parts. The Fahrenheit degree is therefore $\frac{100}{180}$, or $\frac{5}{9}$ the size of the Centigrade, and thus:—

$$(T°C. \times \tfrac{9}{5}) + 32 = °F. \text{ and } (T°F. - 32) \times \tfrac{5}{9} = °C.$$

For the measuring of temperatures higher than the mercurial thermometer will bear, instruments called pyrometers are used; but, as this subject is of such immense importance, a special chapter is devoted to it, and so the matter will not be further discussed here. In a special table the coefficient of linear expansion, that is, the expansion of unit length for 1° C. for several metals is given, and the coefficient of superficial expansion may be taken as double and the coefficient of cubical expansion as three times the linear. For if the original length be 1 and the new length $1 + l$, $(1 + l)^2$ will be the new area and $(1 + l)^2 = 1 + 2l + l^2$. Now, l is always small, say $\frac{1}{10,000}$, hence l^2 or $\frac{1}{10,000}$ of this again will be negligible, $1 + 2l$ will be the area, and hence the coefficient of superficial expansion is practically double the linear. Similarly as $(1 + l)^3 = 1 + 3l + 3l^2 + l^3$ and $3l^2 + l^3$ are negligible, the coefficient of cubical expansion is practically three times the linear. Two curious exceptions to the rule of contraction in volume on cooling we find in bismuth, which expands on solidifying; and water, which contracts from 100° C. to 4° C., then slowly expands till 0° C. is reached, when it freezes with a considerable expansion, and then below 0° C., as ice, it contracts like an ordinary solid, an important exception in the economy of nature. Another exceptional case is the alloy "Invar," iron alloyed with 36 per cent. of nickel, which contracts and expands so little with the extremes of temperature found on the surface of the globe that a wire of it, 24 metres long, may be used in surveys of the surface of the earth practically without temperature corrections.

A given quantity of gas at constant pressure expands about $\frac{1}{273}$ of its volume at 0° C. for every degree rise in temperature, and also contracts $\frac{1}{273}$ for every degree fall in temperature. If this held good, absolutely, then, at $-273°$ C. all gases would be reduced to no volume, and this theoretical temperature is known as the absolute zero, so that absolute temperatures are found by adding 273 to the number of degrees C. If P, V, and T be the pressure volume and absolute temperature of a gas, and P_1, V_1, and T_1 a second series of the same quantity of gas, then all relationships between them can be worked out from the equation $\frac{PV}{T} = \frac{P_1V_1}{T_1}$.

Quantity of Heat.—The first essential in measuring a quantity is clearly to define the unit. The scale for the measurement of temperature may be somewhat arbitrary, but the unit of quantity is quite definite. There are several units in general use, but in Britain it is generally that quantity of heat that would raise 1 lb. of cold water 1° F., which is known as the British Thermal Unit, or B.T.U.; while the other units are the calorie, that is, the quantity of heat required to raise 1 gram of water 1° C., and the large or kilogram calorie, where the kilogram is the unit instead of the gram. The B.T.U. would raise 1 lb. of mercury about 30° F.; hence the specific heat, or, more elaborately, the specific thermal capacity of mercury, is $\frac{1}{30}$ that of water, or, more accurately, 0·032, as in the table on p. 316, where it should be noted that while aluminium stands at 0·212, iron is only 0·11.

Most solid bodies, including practically all the metals, when raised to a sufficiently high temperture, become liquid; and this change of state, spoken of as melting or fusion, must be clearly distinguished from dissolving or a change from solid to liquid produced by the action of a solvent, as when salt dissolves in water. If a piece of solid metal, such as lead, be put under the influence of a source of heat, as over a bunsen burner or in a small furnace, the metal absorbs heat, and its temperature rises until at a temperature of 327° C. the metal begins to melt; and if the solid and liquid portion be kept thoroughly mixed, or sufficient time be given to maintain a heat equilibrium between the various parts of the metal, the temperature will remain constant at 327° C. until all the metal has melted, when the temperature will again begin to rise. It is evident that heat is absorbed at 327° C. without raising the temperature of the metal, but has been expended in changing the metal from the solid to the liquid state. The amount of heat so absorbed is known as the latent heat of fusion, and this fixed point at which the metal changes to liquid is known as the melting-point. If the metal be allowed to cool by its heat being radiated into the air, then when it cools to 327° C. again it begins to solidify, and the temperature remains constant until the whole mass has become solid, the latent heat gradually given out on solidification balances the radiation of heat into the air. As very many seem to have rather a hazy idea as to the length of time during which the temperature remains constant, this will be about two or three minutes for 4 ozs. of lead in a room at about 15° C. When all the metal has solidified, its temperature again commences to fall at a regularly decreasing rate, until the temperature of the surrounding air is reached. It is obvious that in melting, if the source of heat be pouring heat into the metal at one point at a rapid rate, and if stirring be not possible, then the metal may not conduct the heat away quickly enough for all parts of the mass to keep a fairly uniform temperature; hence, when such a fixed point is used as a standard for pyrometric work, it is generally the freezing-point that is taken as more easy to attain correct conditions. If the metal zinc be used instead of lead, the melting takes place at 419° C.; and on still further heating, preventing the oxidation of the metal by a layer of charcoal, the metal will rise in temperature until it reaches about 920° C., when it begins to boil, and remains at this temperature until practically all the metal has been converted into vapour. The heat absorbed in this case is called the latent heat of vaporisation, and the fixed point is known as the boiling-point. These are the two types of fixed point used in the standardisation of industrial pyrometers. There is a curious phenomenon, known as surfusion, observed in the case of tin cooling from the liquid state. It will generally cool a few degrees below its true solidifying point, and yet remain liquid; but when it does begin to solidify, the temperature immediately rises to the true freezing-point, and remains steady until the metal has all become solid.

Examples of the latent heats of fusion, using centigrade degrees, are ice, 79·25; tin, 14·25; bismuth, 12·64; lead, 5·37. Latent heat of vaporisation of water at 100° C. = 537.

The change of volume in passing from the state of liquid to that of vapour is very great. Thus the volume of steam at 100° C. to the volume of water at 4° C. is about 1700 to 1; so that, roughly, a cubic inch of water is converted into a cubic foot of steam. The cause of the violent explosion when a mass of molten metal runs over even a small volume of water is thus made plain, even without allowing for the further expansion that takes place as the steam is superheated. That water becomes an explosive is only in accord with experience with general explosives which are practically all materials ready under easy and suitable provocation suddenly to expand enormously. Nitro-glycerine is a liquid ready to decompose instantly and form over 1800 times its volume of gas, and most of the actions between water and the metals have been imitated many times by the authors with explosives. A blasting gelatine cartridge exploded in shallow water sends up a great fountain of water, the particles moving with high velocity, the counterpart of the violent explosion when a stream of molten metal strikes a comparatively small quantity of water. A similar cartridge exploded in very deep water just produces a great bubble which comes up to the surface, raises a quiet rounded mass above the natural level of the water, and then, opening in the middle, breaks over, the particles moving with comparatively slow velocity; a counterpart of this happened when the dry core sand dropped out into the bottom of the mould for the large roll, the water of combination and the gases formed at the high temperature most probably came off in a large bubble. A cartridge exploded in a mass of boiler flue dust just produced as light general heaving of the surface, the gas seeming to come away at many points. This seems almost typical of what happens when molten metal is poured in a fine stream upon a large mass of water in making, say, shot copper or brazing solder (by braziers called "spelter," although mercantile zinc is also called spelter); the steam comes off from many points, and the action is comparatively quiet.

Another fascinating study is the conversion of the various forms of energy one into the other: heat into work, work into heat or into electricity, electricity back to work or to heat; but it may only be stated here that the relations between these forms have been very accurately measured; thus, to take one example, one B.T.U. = 778 ft. lbs. of work, or 774 according to some investigators. An example of potential energy has already been given. Another, all-important in metallurgy, is potential chemical energy. Carbon combines with oxygen of the air to form carbon dioxide, and heat is given out; thus the carbon is thought of as having latent within it the power to combine chemically with oxygen, provided the action is properly started by a suitable temperature, and the heat of the reaction keeps up the necessary temperature and evolves great excess which can be used in the various metallurgical operations, or converted into other forms of energy. This is expressed by saying that the carbon has potential chemical energy. The number of units of heat given out by the complete combustion of one unit weight of a substance is known as its calorific power; and if all the heat be supposed to be used in raising the temperature of the products of combustion and their companion gases under any given set of conditions, the temperature to which these materials would theoretically be raised is known as the calorific intensity of the original body under these conditions. The calorific power of a fuel gives a measure of the quantity of heat to be obtained from a unit weight of the fuel, and the calorific intensity an idea of the temperature or intensity of heat that might be obtained by the complete combustion of the fuel under certain ideal conditions. For those who would care to try a few of the calculations, it will be evident, on careful study, that as the unit of heat is the amount of heat required to raise 1 gram of water 1° C., and the specific heat of a body measures the amount of heat required to raise 1 gram of the body 1° C., that

$$\text{Calorific intensity} = \frac{\text{Calorific power.}}{\text{The several weights of the products of combustion and their companion gases} \times \text{their respective specific heats.}}$$

Examples of Calorific Powers.

Hydrogen to water at 0° C.	34,180	Marsh gas (CH_4) to CO_2, and steam at 100° C.	11,970
Hydrogen to steam at 100° C.	28,450	Sulphur to SO_2	2,220
Carbon to carbon dioxide	8,134	Silicon to SiO_2	6,420
Carbon to carbon monoxide	2,450	Manganese to MnO	1,650
Carbon monoxide to carbon dioxide	2,436	Phosphorus to P_2O_5	5,800
Marsh gas (CH_4) to CO_2, and water at 0° C.	13,400	Iron to FeO	1,170
		,, Fe_3O_4	1,560
		,, Fe_2O_3	1,750

The calorific powers of hydrogen, carbon, carbon monoxide, and hydrocarbons are of value in the study of ordinary fuels, and those of silicon, manganese, and phosphorus as special fuels of the Bessemer process.

Before leaving the subject of forms of energy, it is interesting to inquire whence it all comes. Our fuels, natural or prepared, with the possible exception of natural gas and petroleum, come directly or indirectly from vegetable matter or its decomposition products. Even the special Bessemer fuels, silicon, manganese, and phosphorus, have been reduced from their oxides by the action of the ordinary fuels. Living vegetation has the power, by the mysterious help of its chlorophyll or green colouring matter, to absorb the energy of the sun's rays, and to store it up as potential energy by changing carbon dioxide and water ultimately, sometimes into cellulose or woody tissue, at others into starch, somewhat in the following manner:—$CO_2 + H_2O = CH_2O + O_2$, that is, carbon dioxide and water produce a material called an aldehyde, and oxygen is given off again into the air. $6CH_2O = C_6H_{12}O_6$, $C_6H_{12}O_6 - H_2O = C_6H_{10}O_5$. Six molecules of the aldehyde have combined to form 1 molecule, and in the organs of the plant dehydration or a withdrawal of the substance of water takes place, forming ($C_6H_{10}O_5$) woody tissue, starch or other substance according to the way in which the plant has built it up. In any case, here is the energy of the sun's rays stored; and if as woody tissue, it may help the moulder to start his cupola or other fire, if as starch, its potential energy may still be used in the foundry, for the internal economy of the human being enables him to convert this energy into muscular power, while the fossilised decomposition products of woody tissue yield the bulk of all his fuels, and whether in the furnace or in the man the material is oxidised into carbon dioxide and water again. Thus, $C_6H_{10}O_5 + 12O = 6CO_2 + 5H_2O$. The gradual change of condition in the vegetable matter in a freshly made cutting of peat may be seen in various stages at the present day from the living mosses through the brown "fog" to the close-textured, almost black, substance which yields on drying the best qualities of peat. In other places the vegetable matter, though it has not necessarily passed through a peaty stage, has, at any rate, reached a more advanced stage of decomposition by losing water, CH_4 and CO_2, and the residue is therefore proportionately richer in carbon and poorer in oxygen.

As the oxygen in fuel is already combined, this portion of the fuel is useless as a source of heat. If, as is generally assumed, this oxygen is combined with hydrogen, then all the oxygen and one-eighth of its weight of the hydrogen must be deducted. The hydrogen that remains, being oxidisable, is called the available hydrogen. Thus the table shown below will give a rough idea of the value of the fuel, which, as will be seen, increases, for equal weight, the further the decomposition has proceeded. The following table has been compiled by taking a rough average by the eye of hundreds of analyses, omitting the ash and the sulphur, which are so variable, and calculating up to 100 again for comparison by percentages. That the figures tend to round numbers may seem suspicious, but this circumstance may help to emphasise the fact that fuels are found of every stage between those given, and they are merely to act as guides. Thus, for anthracite the most anthracitic type is chosen; coal may vary from the highest steam coal down to a type lignitic in its character, though black in colour, and so on. In the following table the C.P.s. are calculated on the $8134\,C + 34180\,(H - \frac{1}{8}O)$ formula, and the experimental results are selected from actual determinations of the samples in hand nearest in composition to the types given in the table:—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Available Hydrogen.	Calorific Power.	
						By Calculation.	By Experiment.
Cellulose ($C_6H_{10}O_5$),	44·4	6·2	49·4	...	...	3610	3600
Wood, . . .	50	6	43	1	0·6	4270	...
Peat, . . .	60	6	33	1	1·9	5530	...
Lignite or Brown Coal, . .	70	5	24	1	2·0	6380	...
Coal, . . .	82	5	12	1	3·5	7870	8000
Anthracite, . .	95	3	2	trace	2·7	8650	8530

Light.—A word must be said about light. White light, such as that from the sun, is not a simple radiation; for when passed through a prism and thus refracted or bent in its course, it is found that different parts of it are refracted differently, and thus the white light is seen to be composed of violet, indigo, blue, green, yellow, orange, and red rays, and by other means rays have been discovered above the violet and below the visible red. The radiation given out by a black body as its temperature is raised are, first, heat only while still black hot, then red rays, through orange to yellow, and, finally, white; these colours have for an unknown period been used to judge the temperatures of metals and furnaces by the unaided eye. The relations between the radiations of different bodies at different temperatures, the brightness and even the energy of certain portions of their spectra and like matters, have been studied with increasing care in recent years, with the result that numerous optical pyrometers have been devised specially suitable for measuring the highest furnace temperatures. The discussion of any of these relationships is not within the scope of this work, so that reference must be made, by those interested, to standard works of recent date, such as Le Chatelier and Boudouard's work on *High Temperature Measurements*. Meanwhile, this chapter will have attained its end, if it has clearly grouped some of the more obviously useful results and indicated the necessity for further study to those who would know their subject well.

CHAPTER III.

MOULDING SANDS.

Terms.—In foundry parlance, "sand" is a term of fairly wide acceptance; therefore, before examining types, it may be well to review briefly some of the more general features. For instance, a handful of any type of moulding sand, properly moistened, will, after squeezing, cohere, or retain the shape imparted by the pressure of the hand. Herein lies one of the most important properties of a moulding sand, namely, that of retaining a desired form. This property of cohesion may be likened to the plasticity of a fire-clay, a quality largely determined by the combined water present in the clay. Thus clays which are more or less pure silicates of alumina chemically combined with water may be dried at a moderate heat without losing their property of becoming plastic, for in this case they lose their uncombined water only, and, if again damped, the clay will be found to knead well; it may be pressed into various shapes and still retain the form on removal of the pressure. On the other hand, if the clay has been heated to a high temperature, the chemically combined water is driven off, and no amount of added water will restore the original plasticity, as illustrated in the fact that "burnt" bricks reduced to powder will not again serve the purpose of unburnt clay. So, too, with moulding sand; it may be dried at a moderate heat with no loss of cohesion; but, if "burnt," its plasticity cannot be afterwards restored by the addition of water.

The presence of alumina and combined water in the analysis of a sand indicates the amount of clay present, and hence the cohering power, as the clay acts as a binder. Generally, all moulding sands consist essentially of silica, with more or less alumina, lime, magnesia, and certain metallic oxides. Lime and metallic oxides, if in excess, make the sand more or less fusible; hence they impair its refractory qualities. Silica increases the refractoriness; but when in excess does so at the expense of plasticity. As already noted, alumina, if present as clay, increases the cohesion; but here, again, if in excess, an essential property, that of porosity, is destroyed. Evidently, then, in selecting a moulding sand, as indeed in all foundry operations, the happy mean must be secured; in other words, an effort must be made to obtain the best combination of dissimilar properties.

The essential requirements in a moulding sand are as follows:—

1. The sand of which the mould is formed must allow the free passage of air and gases generated at the moment of casting.
2. It must be capable of withstanding a high temperature without fusing.
3. It should be readily removed from the cold casting, to which it should give a clean and smooth skin.

4. When rammed into shape, it should be firm and sufficiently compact to resist the pressure of the liquid metal.

The following example will serve to illustrate these requirements. Fig. 2 sectionally shows the mould for a square block; it is formed in sand, held in position by an iron frame. Connected with the space A is a cylindrical opening B, funnel-shaped at the top. Now if A is filled with molten cast-iron by pouring it down B, the conditions are such that the air filling the space must escape through the sand; further, the increase in temperature generates a certain amount of gas which must also find an outlet through the sand. Supposing the sand was impervious to the passage of these gaseous currents, then the gases would find a path to freedom by ejecting the fluid metal through B. From the foregoing it will be evident that the sand in the vicinity of A will be heated to a high temperature. When considering the resistance of a sand at these temperatures, a sharp distinction must be drawn between "burning" and "fusing." The former, as already noted, represents a driving off of the combined water, resulting in the sand losing its power of cohesion. This being so, burnt sand may be readily removed from the faces of the casting. If, however, a fusion is effected, then the resulting casting will be extremely hard to clean, for fused sand will be as hard as the casting itself, and every particle of it will require chipping off before the casting at all resembles its pattern. In these properties of binding power, porosity, and infusibility, lie the primary essentials of a moulding sand.

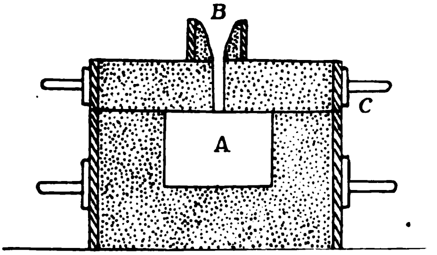

Fig. 2.—Mould.

In the construction of a mould, other factors come into play; for instance, the sand must resist the abrading action of a stream of fluid metal, particularly in the case of ornamental castings; for these the sand must also be of such a texture as to take and retain the sharp and delicate details of the pattern. In considering the washing action of the fluid metal, it will be seen that the nature of the sand should vary according to the character of the mould. If the surface is flat, a comparatively weak sand may be used; if, on the other hand, it contains a fine detailed pattern, a fairly strong one will be required, otherwise the small projections of sand forming this detail will be carried away by the rush of metal. Also the finer this detail the closer must be the texture of the sand, for, if too coarse, it will not enter into the fine interspaces of the pattern; much of the pleasing effect will thereby be lost, and the resulting castings will be lacking in sharpness.

These preliminary remarks indicate to some extent the conditions moulding sands have to meet. Naturally, in practice one kind of sand is not used for all purposes; but the necessary changes are made to adapt it for light and heavy castings, plain and ornamental work, etc. The terms applied to various sands indicate the purpose for which they are intended rather than their particular property. For instance, "dry sand" refers not to a moisture-free type, but to sands used in the formation of moulds, which, previous to casting, are dried in a stove. Green sand relates to moulds cast in the green or undried condition. In working both green and dry sand, the sand is rammed around a pattern, and must be sufficiently damp to hold together; but not wet enough to stick to the pattern, or, in the case of green work, to generate an excessive amount of steam when casting. A rough but fairly reliable test of dampness is to squeeze a ball of sand in the hand; on releasing the pressure, the sand should retain its shape without adhering to the hand. Should some of the sand stick to the hand, and the ball present a rough appearance, it shows the sand is too wet; whilst if the ball readily crumbles, it indicates a lack of moisture.

The term "loam" applies to a clayey sand worked at about the consistency of stiff slime. As distinct from green or dry sand work, loam moulding does not necessarily involve the use of a pattern. In the majority of cases, loam moulds are built up roughly to the desired form, and finally swept by means of strickles into the shape required.

"Core sand" usually means an open type of sand used in the formation of cores, and is often represented by a mixture of loam and sharp sand. "Parting sand," as its name indicates, is used for parting the various divisions of a mould. Thus in fig. 2 it will have been noted that a joint is formed at C. In order to prevent the sand of the top half of the moulding-box sticking to that of the bottom half, a layer of parting sand is spread on the joint C before ramming the top box. It has already been shown that when sand is burnt it will not again cohere even when damp. Evidently, then, a layer of burnt sand serves for separating the various joints of a mould, and thus constitutes a good parting sand.

In forming a mould, the sand in contact with the pattern is termed the "facing sand"; that not in contact, but used as a backing and for filling up the moulding-box, is known as "black" or "floor" sand. The purpose of the former is to give the casting its desired appearance, such as a good skin; that of the latter to complete the mould by supplying the necessary rigidity and a porous backing for the escape of gases. "Black sands" simply represent the accumulation of used facing sands, and play only a secondary, but none the less essential, part in the construction of a mould.

The terms "open," "close," "weak," "strong," etc., when applied to sands are used in a physical sense; thus, "open" indicates porosity, and such a sand is often "weak." "Close" indicates a diminished porosity, but such a sand usually binds well, and is therefore "strong." "Sharpness" indicates a lack of cohesion, an example being found in river or shore sand, which, when rammed, will not hold firmly in position.

Types of Moulding Sand.—A consideration of type is necessarily restricted to the most familiar varieties of moulding sands. Many foundries are so situated as to have ready access to a local sand, which, whilst not in general use, may still answer the required purpose. Obviously, black sands cannot be dealt with; for the black or floor sand of each foundry is necessarily characterised by the varieties of facing sand used. Not only is this the case, but the different sand heaps throughout one foundry may also vary in composition. A black sand from the floor of a foundry making light castings contained: SiO_2, 78·5 per cent; Al_2O_3, 4·75 per cent.; Fe_2O_3, 6·00 per cent.; CaO, 0·30 per cent. As black sand represents the accumulation of used facing sand, questions naturally arise as to its original source. In starting a new foundry, the moulding floor is formed by treading in an open variety of red sand, such as Worksop; or a yellow variety, such as Erith. The desirable qualities are that the sand shall possess moderate cohesion, be of an "open" character, and not too costly. Not infrequently such a sand may be found in the neighbourhood of the foundry. Turning to facing sands on which the appearance of the casting depends, it is not always good policy to secure the nearest at hand.

Facing sands are usually designated by the locality in which they are found; thus, familiar ones are—Belfast and Mansfield red sand; Erith yellow sand; Clyde rock sand, etc. The properties of any sand are largely influenced by its chemical composition, and it will be well to note briefly the more salient features. Free silica gives high heat-resisting properties to the sand, but it has no cohesive power. The latter can be overcome by the addition of a binding material, commonly clay water. An examination of many types of sand shows the contents of silica to vary somewhat after the following order, but this cannot be given as a general rule:—

Type of Casting.	Light Brass.	Light Cast-iron.	Medium Cast-iron.	Heavy Cast-iron.	Steel.
Content of Silica,	per cent. 78 to 80	per cent. 80 to 82	per cent. 82 to 84	per cent. 84 to 88	per cent. 90 to 95

We have also seen that clay acts as a binder, but when in excess it destroys porosity. The latter feature is due to the fact that clay consists of extremely fine particles; and hence sands high in alumina (if present as raw clay) have their pores clogged with this fine plastic material, and thus form a compact and impervious mass; such a sand would, at high temperatures, bake hard like clay. For light work the alumina may run up to 10 per cent. or thereabouts.

The actual impurities of a sand are the alkalies—soda and potash—which are usually present in insignificant quantities only; lime, which may be present as an oxide or carbonate; and organic matter, roots, etc., seldom exceeding 0·75 per cent., usually much lower, and when below 1 per cent. organic matter is not injurious. As will be subsequently shown, organic substances are frequently added to moulding sands for certain purposes.

Viewed broadly, the essential chemical features of moulding sands are found in the amount of free silica, as representing refractoriness; and the amount of silicate of alumina present as raw clay, representing binding quality. Small amounts of oxide of iron present, and forming a rough coating on the otherwise smooth particles of silica or quartz, materially affect the binding quality of the sand, so that such sand binds well with a minimum of clay. Oxide of iron, however, increases the fusibility of the sand, and excess must be avoided. Chemically, other constituents are injurious so far as they render the material too easily fusible, or give rise to the generation of excessive amounts of gas at high temperatures.

The analyses given on the following page are those of typical sands from various districts.

It will be noted that, chemically, the types of red sand given show comparatively small variations, a feature which emphasises the fact that a sand must be judged from a twofold point of view, viz., chemical and physical. The physical condition of a sand is, in the present state of knowledge, a matter to be judged by the moulder's experience. Instinctively he associates certain features with certain properties, and the greater his experience with various sands the more reliable will his judgment be.

In testing dampness, a rough method has been indicated. Following the same plan, if a ball of the sand is squeezed in the hand certain features are noted. Thus, the slight force required to break the ball into halves will indicate to some extent its lifting power, or coherence. The appearance of a broken surface will indicate the compactness of the sand when rammed and the facilities it will offer to the passage of gases. This may be readily tested by taking a sample of open and one of close sand, and comparing the crystalline arrangement, which is sufficiently large to be noted by the naked eye. The lifting power may also be estimated by squeezing a sprig in the ball and suspending it by the free end.

	Mansfield Red Sand.	Kidderminster Red Sand.	S. Staffs Red Sand.	Building Chips, Glasgow.	Clyde Rock Sand.	Glenboig Silica Sand.	Silica Sand.
SiO_2, . .	83·40	83·69	85·52	92·75	85·32	88·9	95·22
Fe_2O_3, .	7·47	6·26	5·47	2·56	7·10	7·43	2·66
Al_2O_3, .	3·14	4·10	3·72	2·50	3·74	4·17	1·04
CaO, . .	0·20	0·66	0·74	0·27	0·64	1·02	0·29
MgO, .	0·62	0·51	0·52	trace	0·31	0·86	trace

These tests, although rough and ready, are sufficient for the purpose; and the young moulder will, by the application of similar simple tests, gain much of value. The final test of a sand is naturally the character it imparts to castings, but, as here experiment is costly, a method of judging suitability before use is desirable. The best, and, in fact, the only method is that indicated; judgment founded on experience.

Mr C. Scott[1] has, however, devised a system of differential sieving in which the grade of sand is classed according to its fineness (state of division).

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[1] *Iron Age*, Nov. 1, 1900.

CHAPTER IV.

FACING SANDS AND FACINGS.

It has already been shown that the material of which a mould is constructed must permit of the free passage of air and of gases generated at the moment of casting. It must also be firm and sufficiently compact to withstand the pressure of the liquid metal. Further, it must bear a high temperature without fusing, and permit of ready removal from the casting to which it should impart a clean and smooth skin.

Without entering into the details of moulding, it has also been shown that the sand forming a mould may be divided into two portions: that forming the face of the mould, known as facing sand; and that forming the backing, known as the floor or black sand.

In the selection and use of facing sand, the moulder is guided by his experience, by the quality of sand available, and by the kind of work in hand. As facing sands vary very considerably, the following notes are intended as a guide only, in which form they will serve a better purpose than would be gained by detailing a series of mixtures.

Green Sand Facings for Grey Iron.—The majority of facing sands are mechanically milled and sieved, apparatus for this purpose being illustrated in Chapter V. The more intricate the detail of the pattern, the finer should be the grade of facing sand used; for light ornamental work such sand is milled very fine. Light work, but of plain surface, requires a weak sand; black sand will answer here better than a milled facing. Hence a stove-grate moulder in making a register front, part of which has detailed ornament, and part plain surface, only uses facing sand on the figured part, floor sand being used on the plain surface. Both facing and floor sand are mixed with coal dust in the proportion of one shovelful to each riddle of sand. This applies to work of comparatively thin section and large surface, such as is common in stove grate foundries. Coal dust is used in all green sand facings for iron, its object being to assist in peeling the sand from the castings. This object is achieved by the fact that the heat developed by casting converts some portion of the coal dust into gas, thereby preventing the molten metal reaching into the pores of the sand, and so retarding fusion of the sand or the binding of its particles into a compact mass. The example of a register front gives a key to the use of facing sands, namely, the more delicate the detail of the pattern the stronger must be the sand; and, conversely, the plainer the surface the more open should be the sand. Thus, for fine ornamental work, for wheels with fine teeth, and for all cases where small isolated bodies of sand have to resist the wash of a stream of metal, new sand is used. This is mixed with coal dust in the proportion indicated, and well milled. Less detailed work, such as large fluting on columns, is faced with a mixture of equal quantities of floor and new sand mixed with coal dust, and milled as before. The new sand may be any of the red or yellow sands, as Belfast, Mansfield, Staffordshire, or Erith, according to the locality. Mixtures of new sands are occasionally employed, but no decided advantage is gained; by far the better plan in green sand work is the use of one type of new sand only, diluting it to the required extent by means of floor sand. In jobbing iron foundries all new sand is rarely used for facing purposes, floor sand being added in amounts varying, according to the character of the work, from 25 to 75 per cent. In this class of work the amount of coal dust also varies, for both coal dust and strength of facing have a decisive effect on the appearance of the casting. Thus the teeth of heavy spur wheels require a stronger facing than the rim, arms, or boss. Generally the amount of coal dust varies from one part to six parts of sand up to one part of dust to twenty of sand. Without stating a definite rule, it may be taken that the heavier the casting, the higher the proportion of coal dust permissible in the sand. Facings for castings over three inches in thickness are usually mixed in the ratio of one part of coal dust to eight or nine parts of sand. If too much coal dust is present in a facing sand for light work, the castings will present a glazed and shiny surface; whilst an excess in sands for heavy work results in the castings being pitted ("pock-marked") and full of veins. The ideal colour for an iron casting as it leaves the sand should be a dull grey, and this is very largely determined by the coal dust present.

Dry Sand Facings for Iron.—Any sand which, in the rammed condition, will permit of drying into a compact and coherent but porous mass, will answer the purpose of a dry sand mixture. Many green sand facings dry into friable masses; hence their unsuitability. Various mixtures, partaking somewhat of the nature of loam, are employed; thus a close sand may be mixed with an open one and tempered with clay water to give the necessary bond. Mansfield, Staffordshire, or Erith may individually be used as dry sand facings, being, for this purpose, mixed with horse-dung and milled. Rock sand, of the type given in Chapter III., is exceptionally good for all classes of dry sand work. This sand, without admixture, dries into a hard, but very porous, mass; and castings from it have a clear skin, and are remarkably free from scabs.

Where weak sands have to be used for dry sand work, the requisite bond may be added in the form of clay, flour, or core gum. A clay-water pot is common to all foundries, and is a tank or tub in which clay is soaked in water; the consistency of the resulting "clay water" ranges from that of cream to that of treacle, according to requirements. A weak sand is tempered with this clay water, which gives consistency and body to the sand; such addition will often convert a weak sand into a passable one for dry sand work.

Green Facing Sand for Brass.—Although the alloys designated as brass are cast at a much lower temperature than grey iron, there is nevertheless a decisive action between the fluid alloy and the sand. Certain of the copper-tin alloys, especially phosphor bronze, possess in a very distinct manner the property of "searching." So much is this the case, that if two castings, one of grey iron and the other of phosphor bronze, are poured into similar moulds, the grey iron one will come out with the better skin, and this in spite of the fact that there may be a difference of some 300° C. in favour of the bronze. Another aspect of the same thing may be found by taking lead as an example. This metal, poured into a mould at full-red heat, will result in a casting of terribly rough skin and full of veins. Lead at a red heat represents a casting temperature of from 500° to 800° C., which is comparatively low for sand. None the less, the sand will adhere tenaciously to the casting, and in difficulty of removal will resemble semi-fused sand. Therefore resistance to heat alone does not always determine the suitability of a moulding sand, for it must also offer resistance to the penetration of a thinly fluid metal or alloy. All alloys containing tin possess this property of searching into the pores of the mould and binding the particles of sand together. Although searching does not necessarily indicate fusing, it will readily be seen that it has the same effect, for in either case the same difficulty is experienced in trimming the casting. This searching action imposes the following conditions:—

1. Coal dust cannot be used with green facing sands.
2. Sands for brass must be finer and drier than sands for grey iron.
3. The moulds must be rammed harder than similar ones for iron.

In certain cases, coal dust or plumbago may be mixed with facing sand; but, as a general rule, such admixture results in veined or pock-marked castings. Owing to the searching action, the sand must be in a fine state of division, and it must be rammed comparatively hard. Hard ramming necessarily involves a drier sand than one submitted to normal ramming.

The sands actually used are the finest qualities of Belfast, Mansfield, or Birmingham cemetery. Floor or bench sand is frequently renewed by additions of new sand, but it never reaches the black colour characteristic of an iron-moulder's floor sand. In grain it is comparatively fine, and this floor or bench sand alone is sufficient for facing plain work, such as valve bodies. With ornamental work new milled sand is used. Naturally between the extremes of plain and detailed ornament various intermediate stages are formed, and, as the pattern approaches either extreme, old, new, or mixtures of old and new are used.

Dry Sand Facing for Brass.—As with iron, the authors have found no better facing than rock sand, which has answered admirably on all grades of castings, varying in weight from 1 cwt. to 18 tons. Mansfield or Staffordshire also gives good results, but not with the same regularity. Very heavy castings may be made in moulds faced with steel moulding "compo," but the appearance of the casting is not equal to those made in rock sand.

Loam.—A combination of dissimilar properties is essential to a good loam mixture. This material is worked at about the consistency of stiff slime, and an essential property is that it must admit of drying without undergoing too great a contraction. It must also dry hard, and, in this condition, admit of carding (*i.e.* rubbing) without being friable; and yet be porous, in order that the molten metal will lie kindly on it. This involves that a stream of metal shall not cut the surface of the mould, which it may do if the loam is too compact. Mixtures of loam are infinite in number, each foundry foreman having his own particular one. A mixture of close sand, opened by the addition of sharp sand and brought to the required consistency by means of clay water, is exceedingly serviceable. Staffordshire, Erith, or Mansfield, opened by means of cow-hair or horse-dung mixed with water or clay water, make up into good loams. Finishing loam is simply a finer grade of the loam used for backing, whilst building loam represents unmilled floor sand mixed with water into a stiff sludge.

Green Sand Facings for Steel.—Only light castings are made in green sand, and an ordinary mixture as for iron is used. Any of the red sands answer well, provided a suitable facing is dusted on.

Dry Sand Facings for Steel.—The bulk of steel moulding represents dry sand work. Sands employed must, owing to the high casting temperature, be of a very refractory nature; and to meet this, silica sands are largely employed. The analysis of a silica sand given on p. 20 shows 95 per cent. SiO_2, but such a sand is deficient in binding power. To obtain the requisite cohesion, clay is added, as in loam. Various types of composition, technically termed "compo," are in use, and for the most part consist of old crucibles, fire-bricks, or similar "burnt" refractory material ground to the required fineness, and mixed with various binding agents. As a rule, it is better to purchase compo from a supply house than to grind and mix it in the foundry. Where home mixing is conducted, silica sands and clay may form the basis of the compo. Ground burnt refractory materials have the advantage that they reduce the contractibility of the mixture, and their use is not costly. The following mixtures give an idea as to the ingredients employed[1]:—

	For Castings of 20-50 mm.		For Castings over 50 mm.	
	A.	B.	C.	D.
Old facing sand,	4	12	1	...
Old crucibles,	1	...	10	...
Fire-brick,	1	...	5	...
White clay,	1	1	3	2
Coke dust,	½	...	1	...
Silica sand,	...	5	...	10
Graphite,	...	2	...	...
	Litres.	Litres.	Litres.	Litres.

Core Sands.—Owing to the fact that the majority of cores are entirely surrounded by metal, the sand of which they are made has more stringent conditions to meet than facing sands, which form the external part of a casting. Certain cores approach an S shape, and, except at the two extremities, are entirely surrounded by metal. For the present, three conditions should be noted: (1) the core has to stand much handling in fixing in the mould; (2) the gases generated on casting must find an egress through the core and not through the metal; and (3) the core has to be removed from the casting.

All cores, before entering a mould, are dried, and in this condition must be hard enough to permit handling, and porous enough to admit the free escape of gases. Yet the sand must not be burnt or converted into a compact mass by the heat, for, if so, it will be exceedingly difficult to remove it from the casting. Some of these conditions belong to core-making. Turning to core sands, and looking at them from a purely chemical point of view, one high in silica should yield the best results. To such a sand the necessary bond may be added by means of flour, rosin, core gum, etc. In other words, an ideal core sand is one in which silica is given bond by the addition of an organic substance which produces a firm core capable of withstanding high temperatures and resisting the penetrating action of fluid metal. Such a core is friable in the cold casting, and therefore readily removed. If bond is given to silica by clayey matter (hydrated silicate of alumina), then the metal bakes

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[1] *Stahl und Eisen*, vol. xxiv., No. 16.

the cores hard (the clayey matter becoming hard burnt clay), and therefore renders their removal a difficulty.

For ordinary small cores, red or yellow sands opened by means of horse-dung, and hardened by core gum or rosin, are chiefly used. Small intricate cores, surrounded by heavy masses of metal, should be made of rock sand, to which a small quantity of dung and rosin has been added. Larger cores are made from dry sand mixtures, or dry loam to which horse-dung or sawdust and core gum are added.

It will have been noted that various substances are used in conjunction with moulding or core sand. Thus the function of coal dust has been indicated; for heavy and coarse work, coal dust may be replaced by coke dust. Hair, horse-dung, and sawdust act as "openers," *i.e.* they increase the porosity of the sand or loam. Dung is dried and sieved for small cores, but simply riddled for dry sand or loam. The undigested hay of the dung, the hair or the sawdust to some extent carbonise on drying, thereby leaving tiny interstices in the sand. Core gum is a glutinous product derived from potatoes or other starchy substance. Core gum, gluten, and kindred substances act as binders, without increasing the fusibility of the sand. A hard surface imparted by ramming is fatal to sand, for fluid metal will not lie on it; but a hard surface resulting from the presence of core gum or rosin does not necessarily represent an impervious one, and fluid metal will usually lie quietly on it. Heat, instead of fusing, tends to loosen a sand made hard in this manner. In the case of green sand facing for grey iron, the presence of coal dust was indicated as tending to peel the sand from the castings. To assist this peeling, the surfaces of all moulds are lightly coated with either a refractory material, or one which, by the formation of a thin stratum of gas, retards searching by the fluid metal.

These facings in green sand work are dusted on the mould through a calico bag or stocking-foot, care being taken to distribute an even coating. The surplus is blown out by means of bellows, otherwise a collection of loose facing would act in the same way as dirt, namely, leave holes in the casting. Instead of blowing out, the facing may be sleeked, that is, smoothed on the surface of the mould by means of a trowel, or brushed by means of a camel-hair brush, if its surface permits. Should the surface be inaccessible to sleeking tools, then, after dusting on the facing, the pattern may be returned to its place and lightly tapped to ensure uniform contact. Such a method, termed "printing," ensures a very smooth casting, but can only be applied to facings which do not stick to the pattern.

In dry sand and loam work, facings are applied as a liquid, being painted on the mould either before or after drying. In the latter case, the mould is painted whilst hot.

All facings are in a state of fine powder, and, chemically, may be divided into either carbonaceous or siliceous materials. The former includes flour, pease-meal, charcoal, coal, and plumbago; whilst the latter includes silica flour, talc, and soapstone [both varieties are acid magnesium silicate, $H_2Mg_3(SiO_2)_4$, or $H_2O,3MgO,4SiO_2$], and silicates sold under trade names. "Plumbago" in foundry terminology is applied to the mineral graphite. "Blackings" represent mixtures of charcoal dust, coal dust, and fire-clay; or plumbago and fire-clay. Many of the white facings sold are silicates of magnesia, as, for example, floured talc. As facings, these silicates are very serviceable.

The property of adhesion is of some moment in considering the use of a facing, and this property is to some extent determined by the nature of the fluid entering the mould. Thus, with light green sand work in iron, charcoal answers well, and the powder lightly dusted on will give a casting which "peels" readily. For heavier work, plumbago blacking, and plumbago are desirable, and in turn they effectually peel the sand from the casting. Charcoal, plumbago, or blacking mixture are entirely unsuitable for green sand work in brass. If simply dusted on, these facings ball up in front of the stream of metal, thus forming dross, which, in the cold casting, is equal to so much dirt. These facings, if used on green sand moulds, must be carefully sleeked on; and, when this is followed, the skin of the castings is of a more or less black colour, which, from a brassfounder's point of view, is a disadvantage. For light brass castings, flour or pease-meal is decidedly preferable; these facings adhere most tenaciously to the sand, and, if lightly dusted on to sand of fine texture, very smooth castings of true brass colour result. For heavy green sand work in brass, white facings such as terra flake (floured silicate of magnesia) offers advantages greater than plumbago in that the same surface or skin is obtained without a loss of the true brass colour. Carbon facings are used to advantage on moulds for brass, if painted on in a liquid form and the mould subsequently skin- or wholly dried. Thus, so far as dry sand work is concerned, a facing suitable for iron will answer for brass; but such is not the case with green sand work.

All facings applied as a liquid come under the term "blacking," which, as noted, may represent mixtures of two or more of the following: charcoal, coal, coke, plumbago, and clay. This mixture in a floured condition is mixed with water to the required consistency, and applied to the surface of the mould by means of a "swab," a camel-hair brush being used for the finer details. Blackings are less costly than unadulterated plumbago. The latter facing, however, always yields the best results for either iron or brass. Wet blackings are sometimes sleeked, and in this case a light sprinkling of dry plumbago on the wet blacking before sleeking will ensure an effective skin. Unsleeked blackings answer well, provided swab or brush marks do not show; and to such blackings, salt, sal ammoniac, or core gum is added in order to make them set hard. Facings for steel moulds are either nearly pure silica or carbon, or mixtures of these. Green sand moulds are dusted with floured silica, whilst dry moulds are painted with plumbago. In some cases floured "compo" is also added to the facing, as in the following:—

Compo, ...	1 pail
Plumbago, ...	2½ lbs.
Silica flour, ...	3 lbs.

Both compo and silica should pass through a 60-sieve, and the three ingredients are mixed in water to the required consistency. Other washes for steel moulds are:—

Plumbago, ...	6½ lbs.	15½ lbs.
Silica flour, ...	10 ,,	3 ,,
Sal ammoniac,. . . .	½ ,,	
Water, ...	1 pail	2½ pails.

Plumbago and water yield excellent results on work of medium weight.

CHAPTER V.

FOUNDRY TOOLS.

In this and the following two chapters moulding and foundry tools are discussed in so far as they can be separated from actual foundry operations. Commencing with a moulder's tools, these will necessarily vary with the class of work on which he is engaged, and for the greater part represent home-made articles. Trowels, cleaners, sleekers, and gate knives are usually purchased as required; but the remaining tools are made by the moulder, who either casts them to shape or works them up from rod. In this case brass rod is usually employed, whilst cast tools may be of brass, iron, or steel. Brass tools answer admirably for brass or iron moulding; but in steel moulding, owing to the gritty nature of the compo, they are very rapidly worn away, and for this work steel or cast-iron tools are more serviceable. In passing, the authors may mention, as a matter of interest, that they have been watching the life of a trowel made from a 36 per cent. nickel-steel, an alloy that takes a high polish, does not readily corrode, resists abrasion well, and in other than foundry circles is known as "Invar." In ironfounding it stood better than any one previously tested, but, used regularly in a steel foundry on Sheffield compo moulds, it seems to be wearing more rapidly than an ordinary hardened and tempered steel one also in regular use.

Turning to the actual tools used, several steel cleaners are shown in fig. 3; they represent tools absolutely essential in all jobbing work. The lowest tool in this illustration represents a vent wire used for artificially opening the sand and forming passages for the escape of mould gases. In size, all tools vary according to the class of work. Small tools for a light iron or brass moulder are shown in fig. 4. These represent spoon tools, bead and button smoothers, and small trowels. Fig. 5 reproduces a few "sleekers," that is, tools used for sleeking or smoothing the face of a mould. These tools are used in places inaccessible to cleaner or trowel. The latter, the most indispensable tool in the moulder's kit, is shown in fig. 6. Trowels vary from 1 to 2 inches in width, from 5 to 8 inches in length, and are provided with a ball-form wooden handle. In working the trowel this ball handle fits the palm of the hand, and the index finger is pressed on to the blade. It may be well to note that the so-called Scotch trowel is provided with an iron handle only, usually $\frac{1}{4}$ inch square and 3 inches long, but the authors in this case prefer the English form of wooden handle. Turning again to fig. 6, three "gate knives" will be noted. These have usually a heart shape and an oblong blade. Two handy forms of "gate cutters" will be

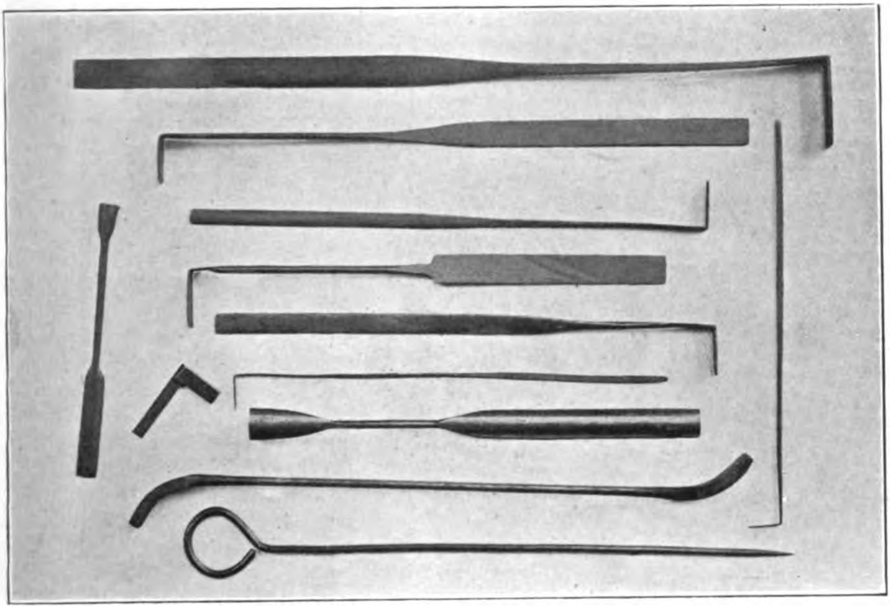

Fig. 3.—Moulder's Steel Cleaners.

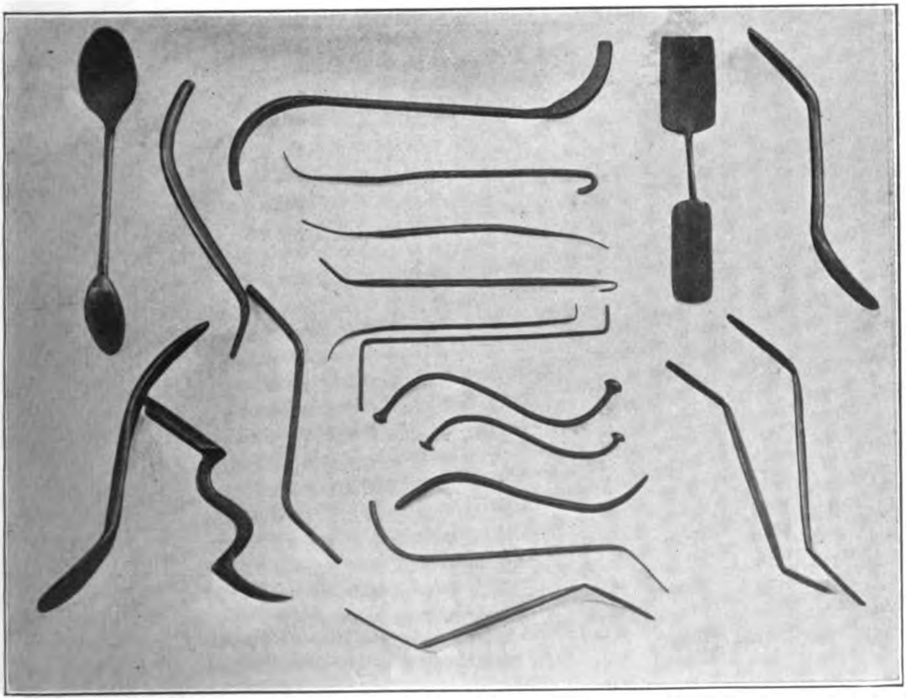

Fig. 4.—Moulder's Small Tools.

recognised in the teaspoon minus a nose, and in the strip of brass immediately to its left. A moulder's kit should contain various sizes of camel-hair brushes, one of which will be noticed in fig. 6. These are used for brushing dry plumbago on the face of a mould or for applying liquid blacking. Two forms of core pins will also be noticed, and these are used for picking up false cores in light work. One of these core pins is formed from steel wire and the other

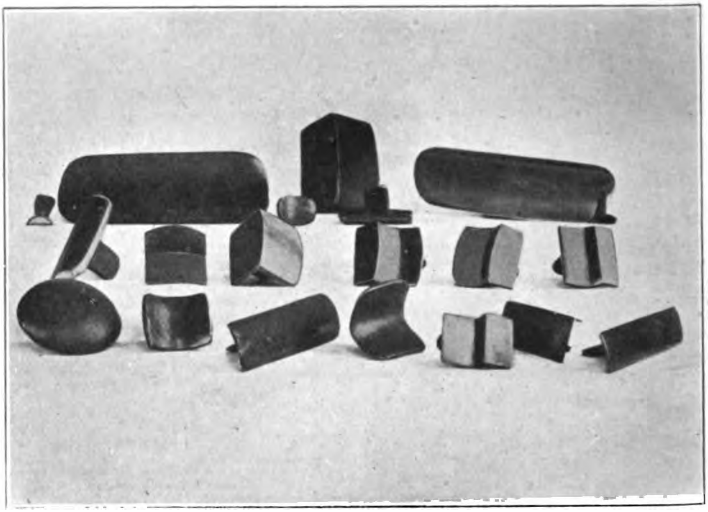

Fig. 5.—Moulder's Sleekers.

Fig. 6.—Moulder's Tools—Miscellaneous.

made by fixing two sewing needles into a tab of wood. The flat plate in the foreground is used for stopping off diaper patterns, gratings, trellis work, and the like, when castings of a different form to that of the pattern are required, and where space will not permit of the introduction of a straight edge. Amongst the miscellaneous items of fig. 6 will be noticed a water brush and lifting screws for drawing patterns. One with a **T** head is for wooden patterns, and is formed by casting the head on an ordinary wood screw. The spirit level is essential in many foundry operations, but chiefly on the sand bed for open cast work. A handy form of tool for working on the sand bed is shown near the spirit level. It consists of two tapering heads of different size, and is used for making channels. Thus, after a core grid has been marked out on the bed, channels are formed by pressing this tool to the required depth along the marked lines. To the foregoing tools should be added calipers for internal and external diameters, and large compasses or trammels for marking out. The latter may be replaced by a length of string and a nail driven into a block of wood, but trammels are preferable.

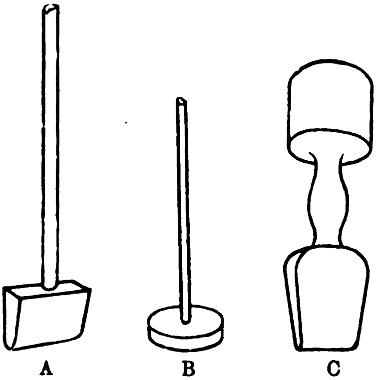

Fig. 7.—Rammers.

The tools indicated are, or should be, the moulder's own property. Tools supplied by the shop comprise dry brushes, bellows, shovels, riddles, sieves, hand lamps, rammers, etc. Floor sand, before use, is passed through a $\frac{1}{2}$-inch-mesh riddle; facing sand for large work is passed through a $\frac{1}{4}$-inch-mesh riddle; whilst, for fine work, an $\frac{1}{8}$-inch sieve is used. Parting sand is passed through a sieve of $\frac{1}{16}$-inch mesh. Nothing need be said of the shovel, further than that it should be treated and used as a tool. Shovels are maintained in good condition by cleaning them every night, and then daubing them with oil, which is burnt off on the following morning. A clean and bright shovel means sweet and light work.

Rammers are of various patterns, but are roughly of two classes, known as "pegging" and "flat" rammers respectively, the former being used for the preliminary and the latter for the final ramming. A in fig. 7 shows an ordinary pegging rammer formed by casting a head on to an iron rod ½ inch in diameter by 14 inches long. The head is about 2 inches in length by 1 inch in width, tapering down to about ½ inch at the nose. Owing to the short length of shaft, this is known as a bench moulder's rammer. Double-ended pegging rammers may be used, the two ends being of different size. The purpose of the wedge-shaped pegging rammer is to tuck or press the sand into the interstices of the patterns. Flat rammers, such as B in fig. 7, are employed for the final ramming. The flat end of this rammer is about 2½ inches in diameter by 1 inch in thickness, with a shaft of similar length to that of the pegging rammer. A combined pegging and flat rammer for bench work is shown at C in fig. 7. This is turned from hard wood, and the ramming faces may, in certain cases, be covered with a strip of gutta percha. Floor rammers only differ from bench rammers in point of size. Thus the head of a pegging rammer is about 3 inches in length by 1½ inch in width, and tapers down to about ½ inch at the nose. Flat rammers are about 4 inches in diameter, and the shafts of both are about 4 feet in length. Pit rammers represent a heavier type of flat rammer, and have usually wooden shafts fixed into a wrought-iron socket which is cast into the rammer head. In the case of large work, pits and the like, ramming is laborious, and an effort to lessen work in this direction is found in the introduction of rammers actuated by compressed air. These rammers are not extensively used in this country,

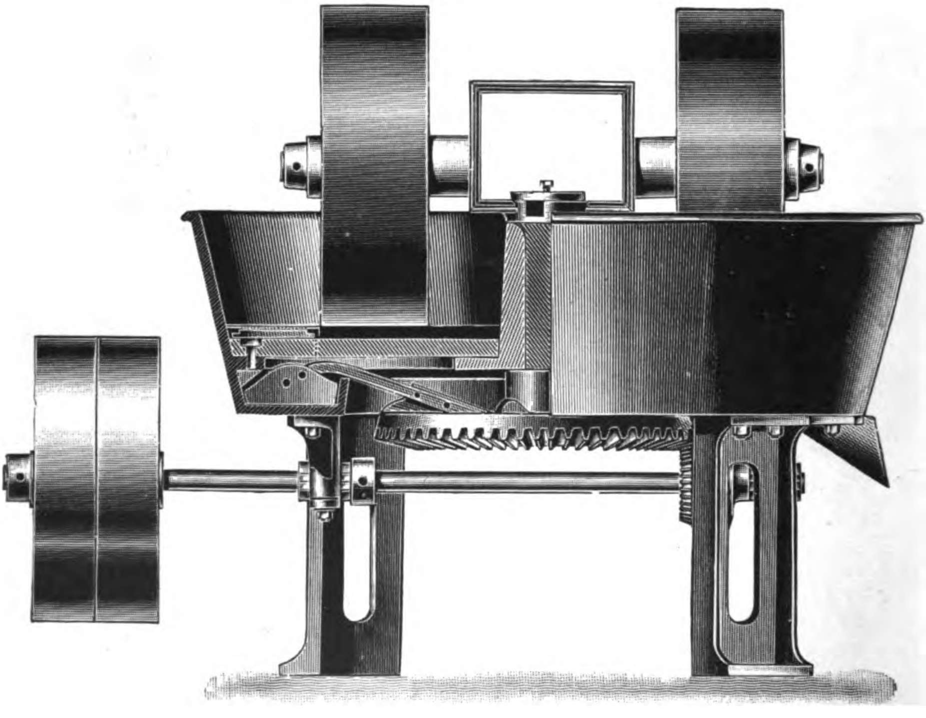

FIG. 9.—Sand Mill.

but they undoubtedly have a future, and the authors have found them exceedingly valuable when ramming up pits. Various styles of pneumatic rammers are on the market; a typical one is shown in fig. 8. Pegging, or flat heads, may be introduced, and the length of stroke varied to suit special cases. As a rule, the number of strokes per minute can be varied from 200 to 400, and the weight of the rammer ranges from 14 to 18 lbs.

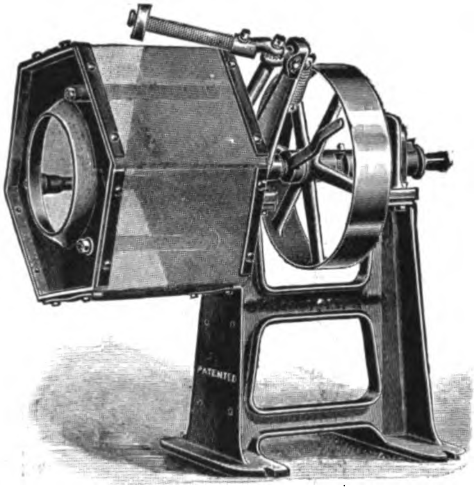

FIG. 10.—Rotary Sand Sifter.

This practically comprises all the sand-handling tools. Turning to the sand-preparing tools, these are mainly grinding mills and mechanical sifters. The most common form of grinding apparatus is the ordinary pan mill, slightly modified to suit foundry requirements. Fig. 9 shows a typical mill of this description. Mills fitted with two plain rollers tend to cake the sand, which, after delivery, requires riddling to break it up again. For a universal mill the authors prefer a plain and a cogged roller, as in this case the latter neutralises the caking action of the former. Such a mill is suitable for either sand or loam, and water may be led into the pan by means of a hose. Mills fitted with plain rollers may be used for grinding coal dust; but when this is attempted in the foundry, a ball mill is more convenient. It is, however, far better for the foundry to purchase coal dust ready for use, as in the end this is more economical than grinding it. Mills with solid rollers are also used for breaking up brass foundry slags, preparatory to washing, for the recovery of metal from the slag.

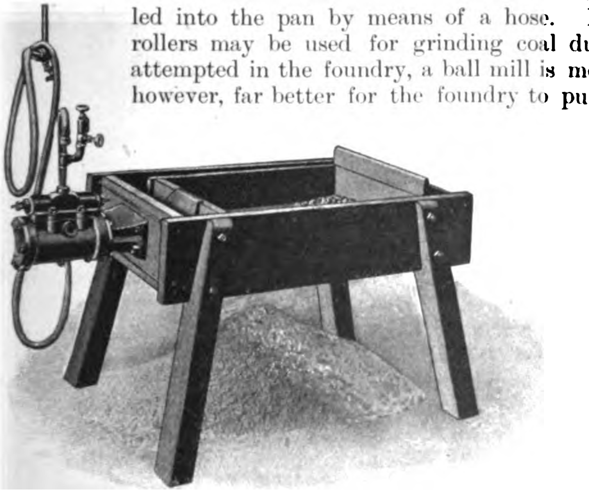

FIG. 11.—Battle Creek Sand Screen.

Mechanical sand sifters may be formed of a rectangular riddle suspended by slings and given a to-and-fro motion by means of a cam actuating the frame. A more familiar type of sifter is a rotating one, shown in fig. 10. Sifters of this description may be attached to a mixing trough in which a revolving worm mixes the material, breaks up lumps, and discharges into the rotating sieve. The sifted sand is collected in a bin below the sifter. In capacity these sifters vary from 30 to 50 cubic feet of sand per hour. They may be made portable by attaching them to a waggon; they are then operated by a motor, with flexible leads. Another type of portable sifter is the Battle Creek sand screen, fig. 11, which is operated by steam or compressed air. Reference to the illustration will readily show the action of this sifter. Portable screens are of advantage in dealing quickly with large quantities of floor sand in that the sand has not to be moved from the position in which it is required. Fixed sifters are most suitable for facing sand.

A type of mixer which screens and tempers facing or core sand ready for use is shown in fig. 12. This is known as the Standard sand mixer, and each machine is provided with a water tank and graduated glass to measure the water sprayed on the sand. The unmixed sand is charged into the mixer through a screen, water turned on, the charge effectually mixed and moistened by the revolving paddles, and then discharged into a barrow.

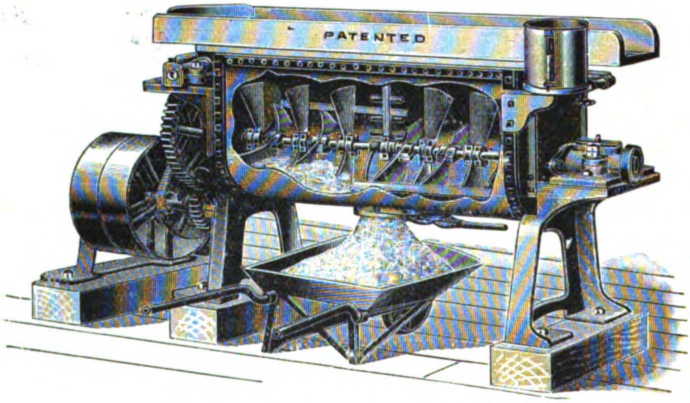

FIG. 12.—Standard Sand Mixer.

Where no mechanical facilities exist for treating facing sand, it is sieved by hand, coal dust is added and well mixed by repeated turning over. Water is added until the sand is sufficiently damp, the heap is then well "trodden," and at each step the treader gives a twisting movement with heel and foot which imparts toughness or grip to the sand. The toughening effect of this twisting movement of the feet may be accentuated by hand in the following way:—

A sieveful of sand is placed on a board, and the operator, on his knees, rubs it to and fro with a round toughening stick, a slight twisting movement being imparted to each rub.

The remaining tools are essentially shop ones, and are used as accessories to the mould, or in moulding operations, on the one hand; and, on the other, as accessories for handling molten metal. Excluding moulding-boxes and handling facilities, the following general tools demand notice here:—

Any mould, previous to casting, must be so fastened down that its top cannot be lifted by the pressure of the fluid metal, and one of the most familiar methods of achieving this end is by piling weights on the top. These weights sometimes take the form of pig-iron or heavy scrap, a method both unwieldy and inadvisable. It is far better to employ weights of suitable size, which permit of ready handling and correctly serve their purpose. The authors have found the two forms, shown in fig. 13, very serviceable for small boxes. This form gives a flat bearing across the mould, effectually preventing bursts when shallow top parts are used and the two recesses permit of handling without trapping the fingers. A form of weight suitable for snap-flask work is shown in fig. 14. The central cross, which is cored out, allows a fair latitude for placing runners, and at the same time, practically the whole surface of sand is covered. This is essential in snap-flask work, for, when casting, the moulds are not supported by a box; hence, weights of various sizes are required to suit the flasks used. A form of crane weight, with lifting hook cast in, is shown in fig. 15. Weights of this type are employed on floor work, and vary from 5 cwts. up to 1 ton. These weights are exceedingly useful, and every foundry engaged in heavy work will find them of value. As a general rule, the authors do not advocate weighting down; but where this practice is followed, quite apart from neatness or convenience, it is better to have weights, the sum of which can be readily reckoned, than to place on a miscellaneous pile of pig-iron, moulding-boxes, etc., the total weight of which can only be guessed at.

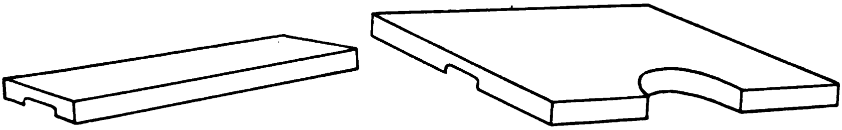

FIG. 13.—Flat Weights.

Where possible, moulding-boxes should be cramped; this may be effected by means of the box pins, or by cramps overlapping the full width of the box, and tightened by a wedge. Cramps are of cast- or wrought-iron, with toes of sufficient length to permit of a good grip on the box, whilst wedges are of wood or wrought-iron. The latter are safer, and are usually about 3 inches long by 1 inch broad, and taper from ¾ inch downwards. The less packing employed the better; hence a stock of cramps of varying size is essential. Adjustable cramps have been devised, and one of these is shown in fig. 16. Fig. 17 shows various methods of cramping, and it will be noted that in one case cramps are passed over the full width of the box; in another, the box pin has a cotter hole, through which a small wedge or cotter is passed; and in the last a nut and bolt pass through the box snugs parallel with the pin. Cramps may also be wedged on to the snugs or handles. Properly tightened cramps are effective up to rupture, but it should be remembered that a box of large surface may spring; hence, if the box is of light section and large size, it

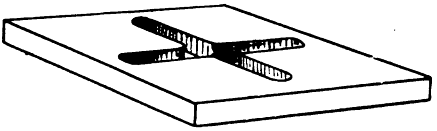

FIG. 14.—Snap Flask Weight.

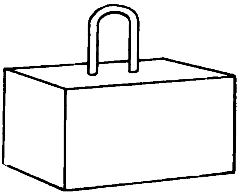

FIG. 15.—Crane Weight.

should be weighted in the centre in addition to cramping on the edges, in order to prevent straining. In light work, particularly small brass work, the moulds, after completion, are turned on end to cast. This involves the use of binding screws, which may be of wood, having large butterfly nuts; or of iron rod, with ordinary hexagon nuts. The usual style is shown in fig. 18. Flat boards or plates are also required, of a similar size to that of the boxes. A pair of plates, one on the bottom and one on the top of the mould, drawn firmly together by a pair of screws, will permit the mould to be turned on end for casting. In certain cases two or more moulds may be placed within one set of screws for casting. Apart from this, flat boards or plates have a wide use in bench or tub moulding. In floor moulding, similar boards are used for "turning over," or as bottom boards, when the bottom half of the moulding-box is not fitted with cross-bars. Large bottom boards of this character are formed of 1-inch timber, well stayed with cross battens. When nailing the planks on to the battens, a space of $\frac{1}{4}$ inch or thereabouts is left between each plank. If the planks butt one against the other, a series of holes are drilled through, the object of these spaces or holes being to permit of the escape of gases from the sand. Turning boards are similarly built up, except that no provision for venting is required, and the face should be planed. Lifters, or "gaggers," form a common, but most valuable, accessory to moulding operations, and are used for the purpose of strengthening the sand of a mould when the cross-bars of the moulding-box are insufficient for this purpose. They may be formed by bending an iron rod, so that one end will rest on the cross-bar of a moulding-box and the other carry or strengthen the sand. Fig. 19 shows a cast- and a wrought-iron lifter. As the sizes naturally vary with requirements,

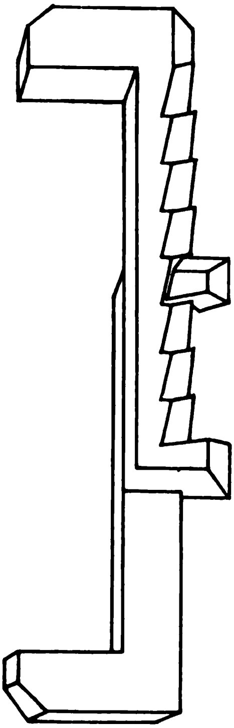

FIG. 16.—Adjustable Cramp.

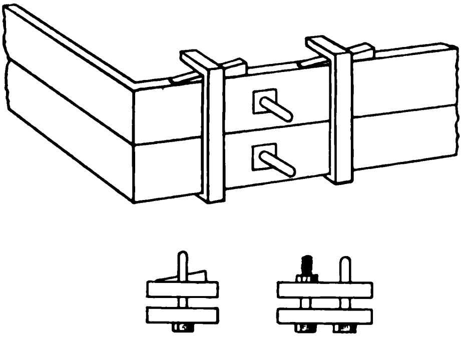

FIG. 17.—Methods of Cramping.

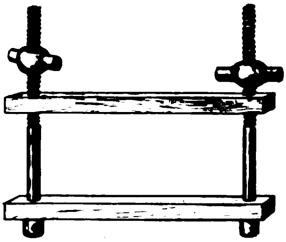

FIG. 18.—Mould Screws.

a large stock of assorted sizes should be kept in order to meet any particular need. In addition to lifters, iron rods and sprigs are largely used for strengthening moulds or cores. Sprigs vary in length up to 6 inches; whilst all sizes of rod are required, the variety used being a cheap wrought-iron known as nail rod. In some cases, lifters are replaced by pieces of wood, cut to size, and jammed in the top part; when used in this fashion the pieces of wood are termed "chocks."

Another type of miscellaneous tool is found in a portable fire-basket. These are, as often as not, formed by punching holes in a pail for a small fire or in a discarded oil drum for a larger fire. A more convenient type of fire-basket is formed by making a cage of iron rod supported by a framework of cast-iron, as illustrated in Chapter VIII. Fire-baskets, or "devils," are used for skin-drying sand moulds or for stiffening loam.

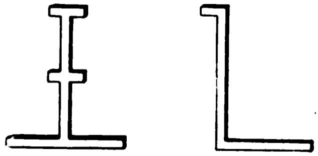

FIG. 19.—Lifters.

Trestles are chiefly used for running up cores, as illustrated in Chapter IX. Fig. 20 shows a typical trestle for this purpose. It is made in open sand, the two feet being cast on at a later operation. Small trestles may be used on a core bench, and for this purpose bar-iron bent to the required form, with the two ends let into suitable feet, offers a light, yet stable trestle. Turning to accessories for dealing with molten metal, these for the most part include carrying tongs, shanks, and ladles. Metals or alloys melted in crucibles are, as a rule, cast from the crucible by means of either teeming or carrying tongs. With teeming tongs the caster grips the centre of the crucible and supports some of the weight by resting the tong shanks on his knee during pouring. In this way the caster stands in line with the moulding-box. Brass and German silver are often poured by means of the pulling-out tongs, and then the caster stands in front of the crucible, the lip of which is rested on the moulding-box. In other cases the load may be supported by resting the tong shanks on a weight laid across the moulding-box. When the contents of the crucible exceed 50 lbs., carrying tongs are employed, and of these the three types shown in fig. 21 are the most representative. A and B grip the pot by bringing together the two handles of the single end, whilst the double end is used for turning up the crucible. Both these types are familiar in crucible steel foundries; whilst C, which has a solid ring, is chiefly used in brass foundries. In the case of brass foundries, crucibles range in capacity from 20 to 400 lbs., and naturally the diameter of the ring C is made to fit the particular size of crucible employed. This diameter is such that the ring wedges at about the centre of a new crucible; but as the latter lessens in diameter by use,

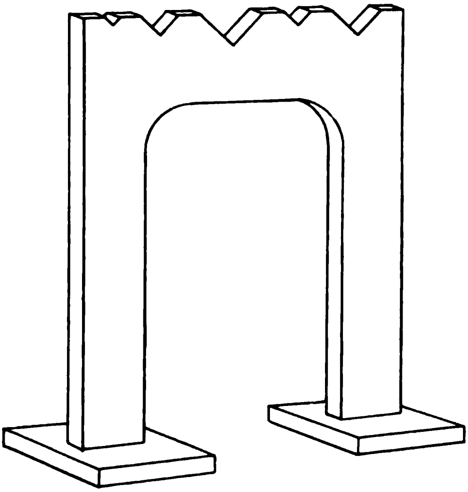

FIG. 20.—Trestle.

wedges are employed to prevent the ring coming too high. The crucible is placed in the ring of the carrying tongs, which are then lifted, and, just before the centre is reached, a wedge inserted, which tightens on further lifting.

A hand shank for catching cast-iron from a cupola spout is shown in fig. 22. In capacity these shanks range up to 60 lbs. For larger capacities the shanks have double ends, as shown in fig. 23. The sling shown on the shank of fig. 24 is intended for crane lifting; but a shank of this description may be

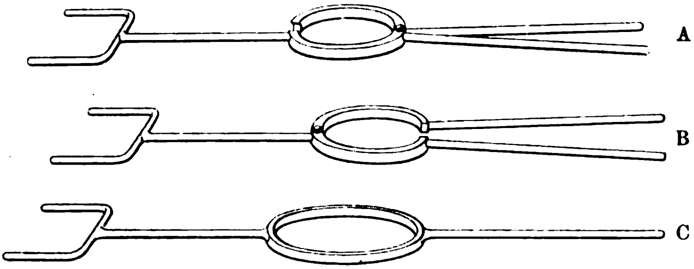

Fig. 21.—Carrying Tongs.

Fig. 22.—Hand Shank.

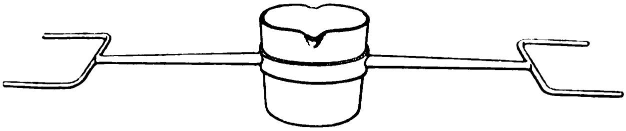

Fig. 23.—Shank.

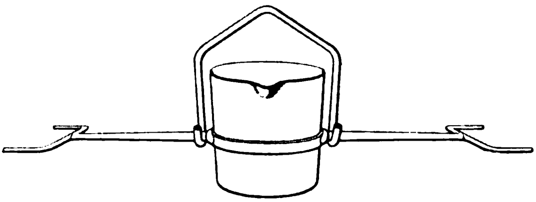

Fig. 24.—Shank with Sling.

mounted on a carriage, as shown in fig. 25. In this case the shank is filled at the cupola, and drawn along the track to the moulding floors, where the metal is distributed to the moulders, each man filling his hand shank as required. A small type of crane ladle is shown in fig. 26. This type of ladle is useful up to a capacity of 10 cwts.; but for amounts exceeding this, every foundry ladle should be fitted with gearing, otherwise unsteady pouring results, and accidents are likely to occur. When the catch of fig. 26 is released, the stability of the ladle is dependent on the man at the pouring end; and should he by chance lose command, the ladle will invert. The authors have seen disasters due to this cause, and their personal experience is such that they would not employ an ungeared crane ladle which has a capacity of more than 10 cwts.

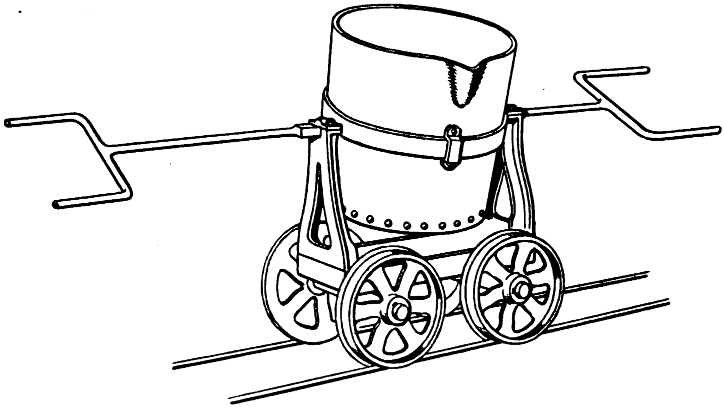

Fig. 25.—Shank mounted on Carriage.

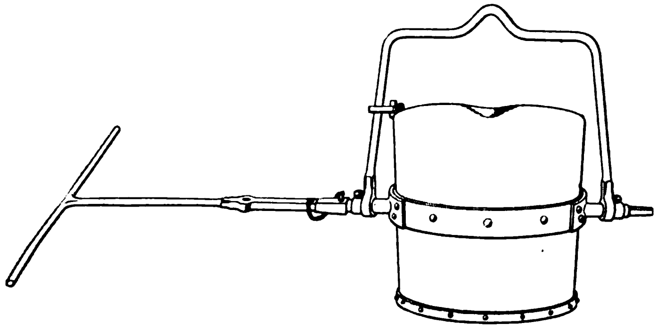

Fig. 26.—10-cwt. Crane Ladle.

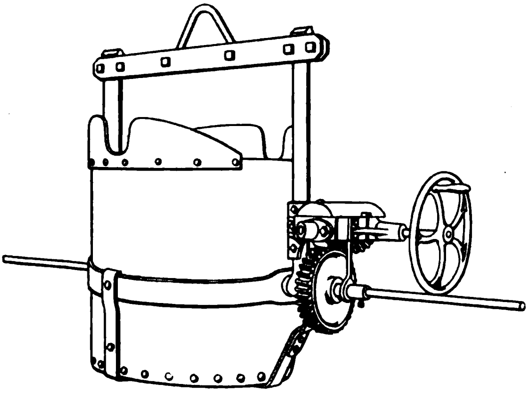

Fig. 27.—Geared Ladle.

Fig. 27 shows a geared ladle which, in capacity, may vary from 10 cwts. to 15 tons. The pouring lips shown are now fitted on most of the newer type ladles, and give a much cleaner cast. These ladles are specially applicable to cast-iron, brass, or bronze, or to surface-blown Bessemer steel. Open-hearth steel is not so fluid as surface-blown steel, and will not, as a rule, admit of pouring over the lip of a ladle; hence bottom pouring ladles are employed for this type of steel. A typical bottom-casting ladle, fitted with swan neck and stopper, is shown in fig. 28.

The shells of all ladles or shanks are built up of mild steel, and internally lined with sand, loam, or compo. Loam is the best lining for iron or brass ladles, and such a lining will give a comparatively long life. Hand shanks are lined with red sand, and inverted over a fire to dry. When daubing up a ladle, if the shell is not drilled with small vent holes, strings are laid in the lining and withdrawn when it stiffens. The whole is thoroughly dried by placing a fire on the bottom or suspending a fire-basket from bars laid across the top. After drying, any cracks are filled in, the surface blackwashed and again dried. The lining must be bone-dry before any metal enters the ladle, as even a mere trace of moisture will cause the fluid metal to bubble, and only a comparatively small volume of steam is required in order completely to eject the contents of the ladle. As a case in point, the authors have a vivid

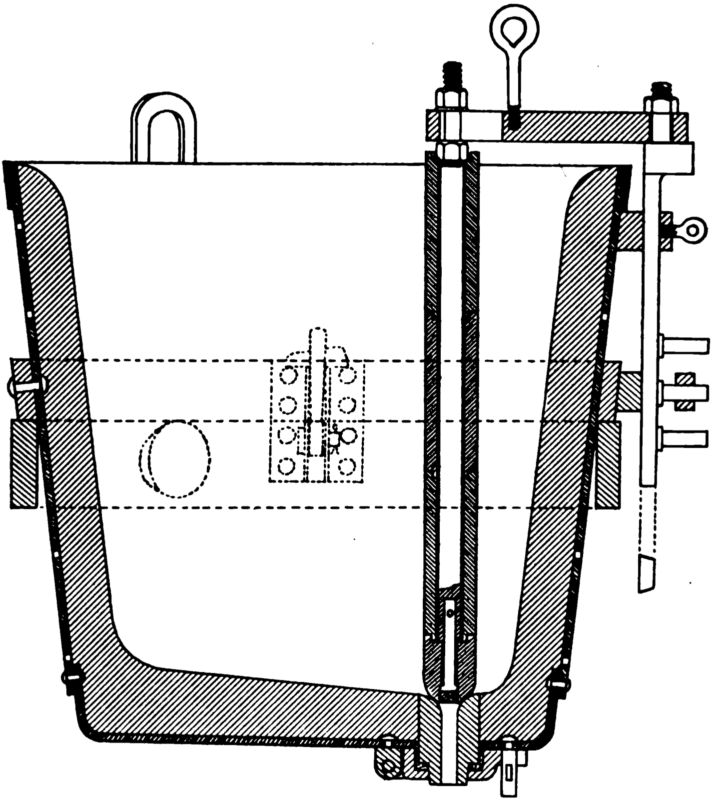

FIG. 28.—Bottom Pouring Ladle.

recollection of tapping 25 cwts. of gun-metal into a ladle, which, owing to carelessness on the part of the ladle man, had only been partially dried. A brilliant pyrotechnic display followed, and the metal was subsequently recovered in the form of fine shot scattered over a large area. Steel-casting ladles, if of large size, are lined with fire-brick; smaller ones are daubed with compo, and when of bottom-casting type, the stopper is carefully fitted to the nozzle after drying the lining. In exceptional cases, large ladles for cast-iron are lined with fire-brick; but for normal work and capacities up to 5 tons, a sand or loam lining is sufficient. In brass-foundry practice the authors have found a lining of rock sand very efficient in ladles up to 10 tons capacity. The capacity of any ladle is readily determined as follows:—

Owing to the taper from top to bottom being uniform, the diameter at the centre will represent the mean diameter of the ladle. Diameter squared and multiplied by 0·7854, will give the superficial area. This area multiplied by the depth of the ladle will give the volume or cubic capacity. This is, practically, the method of finding the volume of a casting. Assuming the ladle to have a mean diameter of 30 inches, and a depth of 54 inches, its cubic capacity will be:—

Area of Section. × Depth. = Volume.
(30 ins. × 30 ins. × ·7854) × 54 ins. = 706·86 × 54 = 38170·44 cub. ins.

For the moment, we may take it for granted that:—

A cubic inch of cast-iron weighs . .	0·26 lb.
Or a cubic inch of steel weighs . .	0·28 „
And a cubic inch of gun-metal weighs . .	0·30 „

The volume of the ladle multiplied by one of these factors will give the weight of metal held by the ladle. Selecting cast-iron, this weight will be:—

38170 × ·26 = 9924·2 lbs., or, roughly, 88 cwts.

When estimating the capacity of any ladle, the depth should be taken from the level of the metal and not from the actual top.

CHAPTER VI.

MOULDING-BOXES.

A MOULDING-BOX is essentially a frame for carrying sand; its chief requirement is therefore rigidity. Such a frame may be readily constructed of timber, a method largely followed in the United States, but only to a limited extent in this country, and then merely as a temporary expedient. Cast-iron frames, or "boxes," are not only more permanent, but, practically, also as cheap; they are readily made in the foundry, and offer all that is required in the way of rigidity.

The simplest form of a complete moulding-box is represented by a top and a bottom part (in American terminology a "cope" and a "drag"). One of these parts is fitted with pins, which correspond with guiding holes in the other part, thus maintaining the two parts always in a relative position to each other. In form, boxes may be square, rectangular, round, or, in certain special cases, designed to follow the contour of the castings to be moulded in them. The sizes vary greatly, and may be taken to range from a tiny "jeweller's box," three inches square up to any extent within the lifting facilities of the foundry in which they are worked.

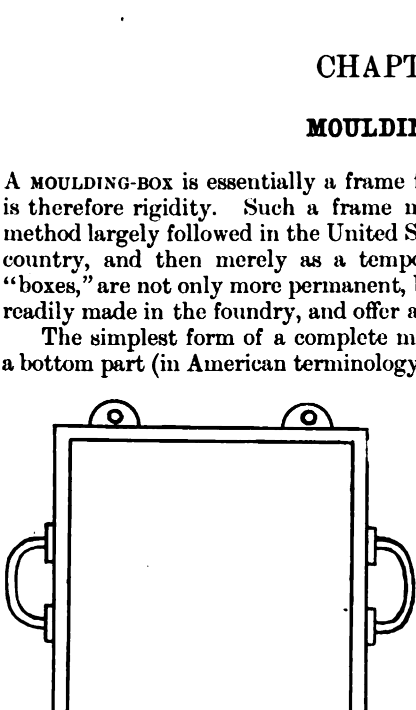

FIG. 29.—Bench Moulding Box.

Fig. 29 gives the outlines of a simple familiar type of bench moulding box. In this case the lifting handles are of wrought-iron, bent to shape, and cast in the centre of the opposite sides. Apart from the greater convenience of these handles, it is evident that a series of boxes, placed one on top of another, can be slung in a crane. With snug handles, which are often placed on this type of box, lifting by means of crane slings is impossible. Lifting snugs are usually ⅝-inch thick by 3 inches wide by 2 inches deep, and are cast in the centres of the opposite ends. Lifting handles are formed of ⅝-inch iron, bent over, as shown in fig. 29, while the ends projecting into the bosses on the side of the box are roughened in order that the metal shall take a better grip. The method of moulding such a box, and leaving the two ends of a handle projecting, so that they may be surrounded by fluid metal, will be readily seen in later chapters.

Pin snugs are, in form, similar to lifting snugs. They are cast on the sides of each box part, and placed about $\frac{1}{4}$ inch below the joint. In each box, comprising top and bottom part, one set of snugs is drilled to take a box pin, and the other set is drilled to pass over the pin. As a rule, pins are fixed in the bottom part of each box. Whilst the purpose of a pin is to serve as a guide in maintaining the two parts of the box always in the same relative position, the style of pins varies greatly. In some cases they simply represent lengths of rod iron rivetted into the snugs of the bottom part. This method is bad, inasmuch as a rivetted pin always works loose in course of time, and its chief function that of a true guide is thereby lost. A better form of pin is shown in A, fig. 30, in which it will be noted the end is reduced and tapped to take a nut. The best form of pin is that of B, fig. 30, the difference lying in the projecting shoulder giving a truer bearing than that of A. The snugs of the bottom part are recessed to take this shoulder and drilled for the screwed part. A nut readily tightens the pin, which, with the shoulder bearing, renders it a perfectly upright and true guide. The snugs of the top part are drilled to slide easily, but yet without play, over the pins of the bottom parts. With this type of box, members of each size should be interchangeable; that is, any top part should fit any bottom part of the series, a feature of special moment in plate and machine moulding. This uniformity is effected by drilling the whole of the snugs to one jig or template. Joint faces should be planed, in order that the top parts may lie evenly on the bottom parts without rocking.

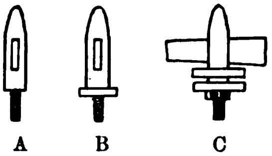

Fig. 30.—Moulding-Box Pins.

The two pins, A and B, of fig. 30, have cotter holes cut through them. This allows the box, when finally closed, to be cottered down, as shown at C in fig. 30. Obviously, the two parts of a box wedged together in this manner will not readily separate when stressed, as in the case when pouring metal into a mould; hence cottering, in many cases, dispenses with the necessity of weighting down the top part.

A two-part box offers only one joint, and certain castings may require two or three joints in order to mould them successfully. A useful type of box for this purpose is shown in fig. 31; each part has two sets of pin snugs, and, by the arrangement shown, any number of parts can enter into a whole box. Intermediate parts between top and bottom are known as "mid parts."

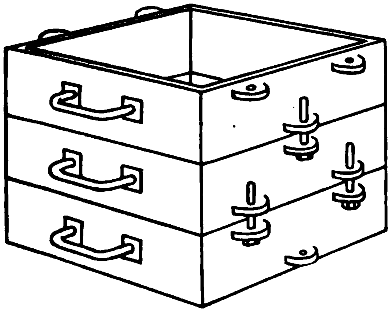

Fig. 31.—Nest of Boxes.

Usually bench moulding-boxes are made with straight sides, but this need not necessarily be the case in boxes which have much handling to stand, as in machine-moulding, where cross-bars are not always desirable, the sides of each part may be of < section. Each part of the box, therefore, has its greatest width in the centre, which results, to some extent, in the sand being wedged into V grooves, and thereby producing a more rigid mould.

The dimensions of bench moulding-boxes are naturally determined by the class of work to be made in them; common sizes are 12 inches by 12 inches, 12 inches by 14 inches, 14 inches by 16 inches, etc. The depth averages about 4 inches each part, but certain patterns may require an 8-inch bottom and a 4-inch top, or *vice versa*. Hence, if the patterns are not of a standard character, boxes are temporarily fixed together to serve as a complete box.

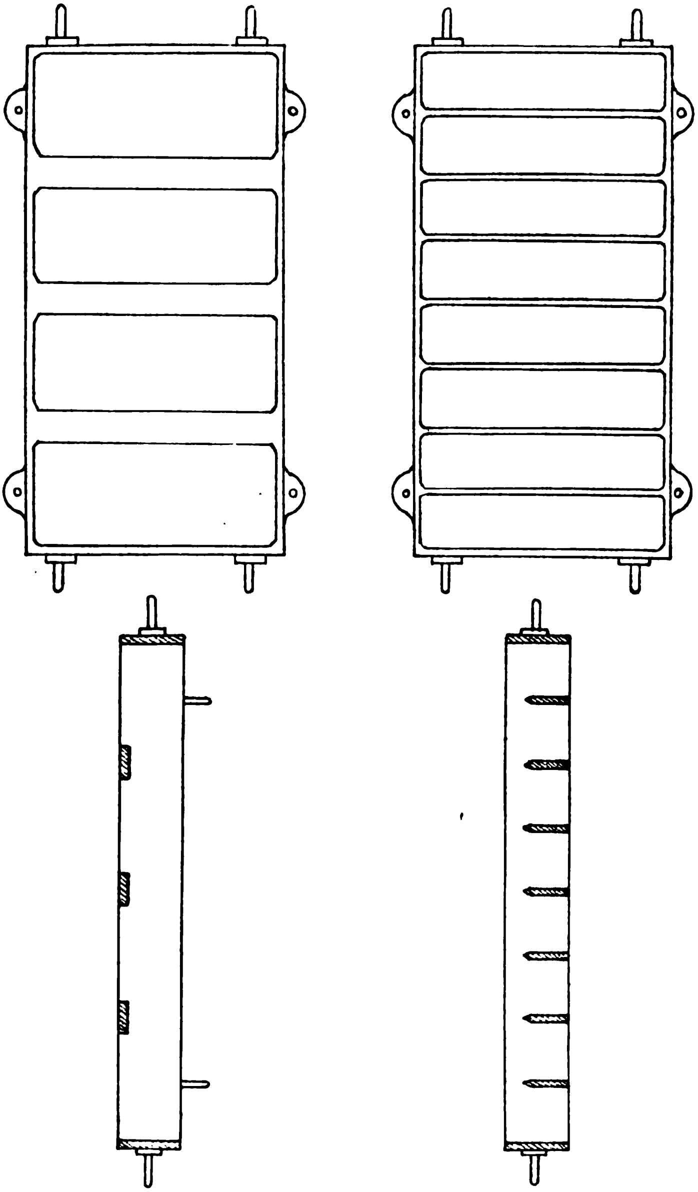

Fig. 32.—Floor Box.

Floor moulding-boxes range from about 16 inches by 18 inches upwards, and the first feature of note lies in the introduction of cross-bars for the purpose of staying the sand. A typical floor box worked by hand is shown in fig. 32.

Pins are the same as in smaller boxes, but of heavier build. As the bottom part may have to be lifted, but not turned over, the cross-bars are placed flatwise, in order to hold the sand in position when the part is lifted vertically. On the other hand, the top part has to be lifted off from the pattern and turned over; hence, in order to carry the sand and stand handling, the cross-bars must come down nearly to the joint. They are therefore placed edgewise. Lifting handles may be of cast-iron, forming part and parcel of the box. Such handles, however, are extremely liable to break off, and better ones are formed by casting pieces of bar-iron into the sides of the box, the section round the handle being strengthened by a boss. Bar-iron of from 1 inch to 1½ inch diameter, and projecting from the boss about 5 inches, is most suitable.

Boxes for hand-working are cast of as light a section as is consistent with rigidity, the usual thickness being ⅝-inch for the sides and ½-inch for the cross-bars. Actually, the sides will taper from ⅝-inch to ½-inch, and the cross-bars from ½-inch to ⅜-inch, the latter terminating in a rounded feather edge. Weight is of moment when all operations are by hand, as the authors have realised by painful experience. Boxes handled by cranes come under another category, for, as a rule, they have much severer conditions to meet. Not only are the casting stresses greater, but the boxes, in course of handling, may also be subjected to sudden shock or jar; hence the section of crane boxes is always heavier than that demanded by rigidity alone.

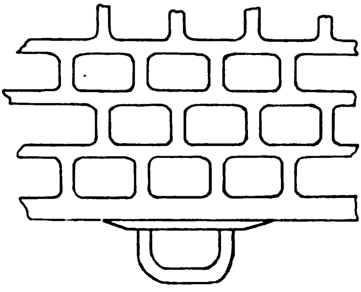

FIG. 33.—Heavy Type of Box.

Apart from the heavier section, other features of note are found in the replacement of the earlier type of lifting handles by swivels, the ends of which are enlarged by a collar to prevent the slings from slipping. As with handles, these swivels are cast in the box, the side of the box being strengthened, as in fig. 35, where the swivels enter. A specially strong type of box construction is shown in fig. 33, in which a new form of lifting handle will be noted. These handles vary, according to the weight of the box, from 1 to 2 inches in diameter; they are forged to shape and cast in the side of the box, being strengthened in the locality of the handle, as in preceding cases. A similar handle will be noted on the box shown in fig. 34, and it will also be noted that pin snugs are replaced by a flange running the full length of the joint. This box shows a departure from the flat type hitherto considered; it is intended for moulding columns, liners, and articles of similar form. The end is flanged similarly to the joint, and recessed in the centre. Thus, if a short casting is required from a long pattern, during moulding, the pattern may project through the ends of the box, which permits of the use of a short box suitable to the casting, and unaffected by the pattern. On the other hand, two or more lengths may be bolted together, end on, by means of the flanges and bolt holes shown. This permits of some elasticity, and dispenses with the necessity of stocking long boxes which may only occasionally be required. The joint flanges serve for the box pins, and also for bolting the two parts together when finally closed. Another type of flanged box is shown in fig. 35, which has no cross-bars, and is lifted by means of swivels. This, again, represents an "elastic" type of box in that any number of parts may be fitted together, a grid or grating being bolted on to the lowest one, and the uppermost one surmounted by an ordinary flat top part. The holes shown in the sides of the box serve for the introduction of wrought-iron cross-bars, which may be arranged to suit the pattern, and be wedged firmly into position.

Much ingenuity is exercised in jobbing foundries in fitting up stock boxes to meet the requirements of a varying class of work. The object of a jobbing founder is to make each box serve as wide a range of patterns as possible, in order to keep the stock within reasonable limits. One aspect of this is found in the built-up box. Thus, if the four plates forming fig. 35 are cast separately instead of as a whole, and the corners fitted with flanges for bolting together, then, by the introduction of two shorter end plates, a narrower box is obtained. Obviously, a series of pairs of plates, differing in length and depth, will offer any amount of latitude in size. An ordinary top part may be formed by bolting four plates together for the frame, and bolting the necessary cross-bars to opposite sides of the frame. Bottom parts may be formed in a similar manner, or, in certain cases, they may be replaced by grids, used as in the case of fig. 35.

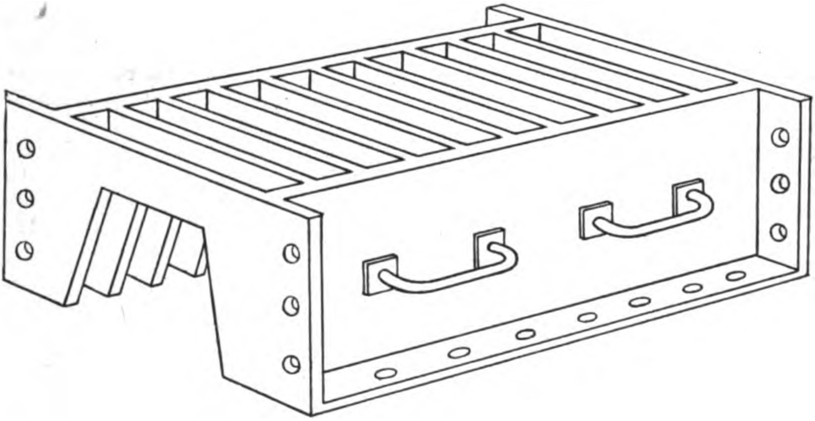

Fig. 34.—Column Box.

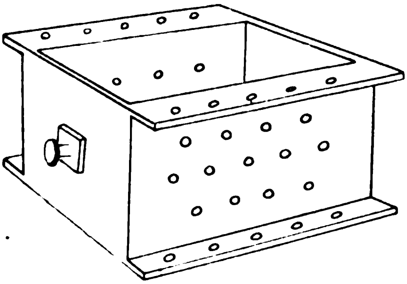

Fig. 35.—Flanged Box.

This method of bolting up has a distinct value, but is only applicable to the conditions cited, that is, to the jobbing founder, whose work is constantly changing in character.

Standard patterns are, or should be, made in standard boxes; in this case the keynote of standardisation is found in conformity of box to pattern. Circular castings, such as wheels, should be made in round boxes, large enough to take the patterns, but small enough to dispense with unnecessary ramming. The object of the founder engaged on repetition work, or work of standard character, is to produce a mould with the minimum amount of labour. The cost of boxes is in this case of less moment than in the case of the jobbing founder, for the simple reason that they are continually in use, and the economy effected in moulding more than covers the cost of boxes.

Owing to the fact that, practically, any form of moulding-box can be made, it is impossible to enumerate separately each particular shape in use. The following leading examples will, however, serve to show the purpose and design of special boxes, and they may be amplified by the reader to suit any particular case. Thus, fig. 36 shows an ordinary flat box, with an enlarged end for taking the head of a stanchion or other similar article. It also illustrates a method of cramping the two half-boxes together by means of hooks and eyes. In certain cases, as with columns or stanchions having central projections, a box with an enlarged centre may be used. Fig. 37 shows a flat box, with a cut-out central portion, such as is used for moulding flat register fronts. The economy in this case is readily apparent; for if, in moulding, the whole of the centre had to be rammed up, the day's output would be seriously curtailed. In fig. 37 the cross-bars come down to within ¾ inch of the joint, and the depth is usually about 4 inches for each part. In the case of a curved front, as, for example, the familiar tiled stove, the top part of the moulding-box follows the contour of the pattern, as in fig. 38, a portion of the centre being cut out, as in the preceding case. This form of box gives in the top part an equal depth of sand, resulting in the minimum amount of ramming, and, owing to the curvature of the bars, entirely dispensing with lifters or other auxiliary aids for lifting.

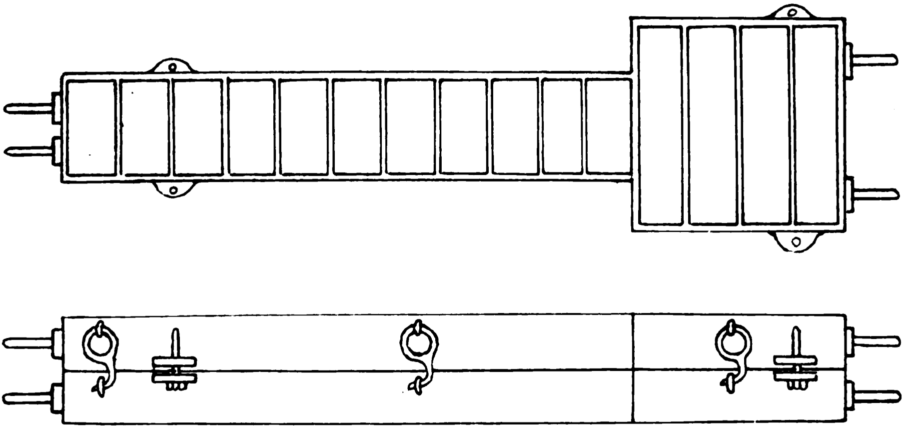

FIG. 36.—Box with Enlarged Ends.

In certain special cases, moulding-boxes are hinged, and the top, instead of being lifted off, is simply turned up and propped in order to draw the pattern and finish the mould. The hinges usually take the form of a ball and socket. Evidently such a lift will not be vertical—a matter of little moment in flat work, but of importance in other classes of work.

With some classes of work it may be necessary to make the middle part of a moulding-box serve the purpose of a core-iron, and, in certain cases, this method will permit of the use of a green sand core, and the one core-iron can be made to serve any number of cores. Without entering into details of moulding, it is somewhat difficult to describe the use of a mid part as a core-iron; however, the sketches shown in fig. 39 will illustrate one application of this principle. This box was designed to make a series of castings which were practically square pipes about 3 feet 6 inches in length, one end of the pipe being bent through an angle of about 45°. For reasons which need not now be given, the bent portion of the pipe had to be made uppermost. By

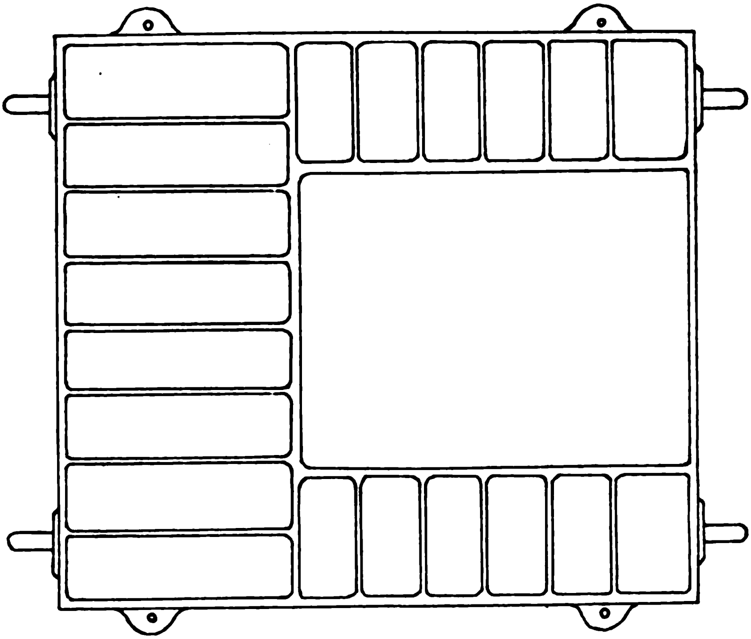

Fig. 37.—Flat Register Front Box.

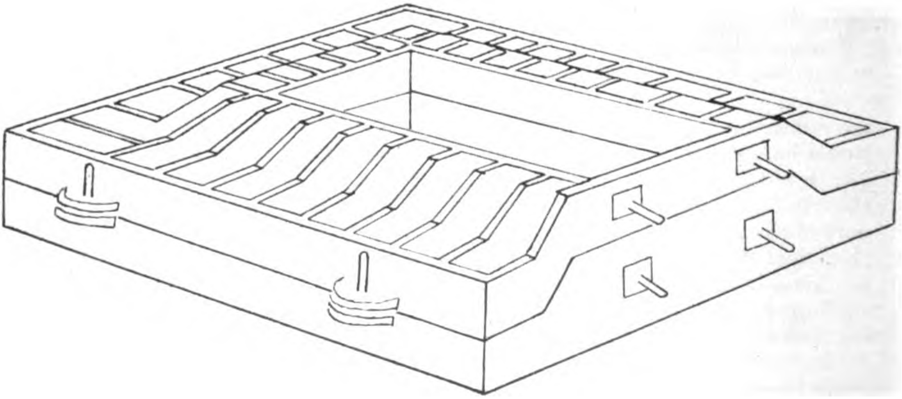

Fig. 38.—Tile Register Front Box.

the usual method of moulding with a dry sand core, fixing and maintaining the core in position by means of chaplets would be a matter of some difficulty. The box, as shown, removes this difficulty, incidentally reduces risk of wasters, and increases the output by 75 per cent. An examination of the details of the box will show that the middle part or core-iron consists of two pieces bolted together. The raised end of this middle part has the same width as the bottom part, and fits the two side pins shown on the bottom part. The actual core-iron enters into the bottom part, the end pins of which serve as guides. When the middle part is in position, the top part, which is provided with side handles, fits the four pins of the bottom part, and its upper surface is level with the raised end of the middle part. When the box is cramped, the middle part cannot possibly move; and, on cleaning the castings,

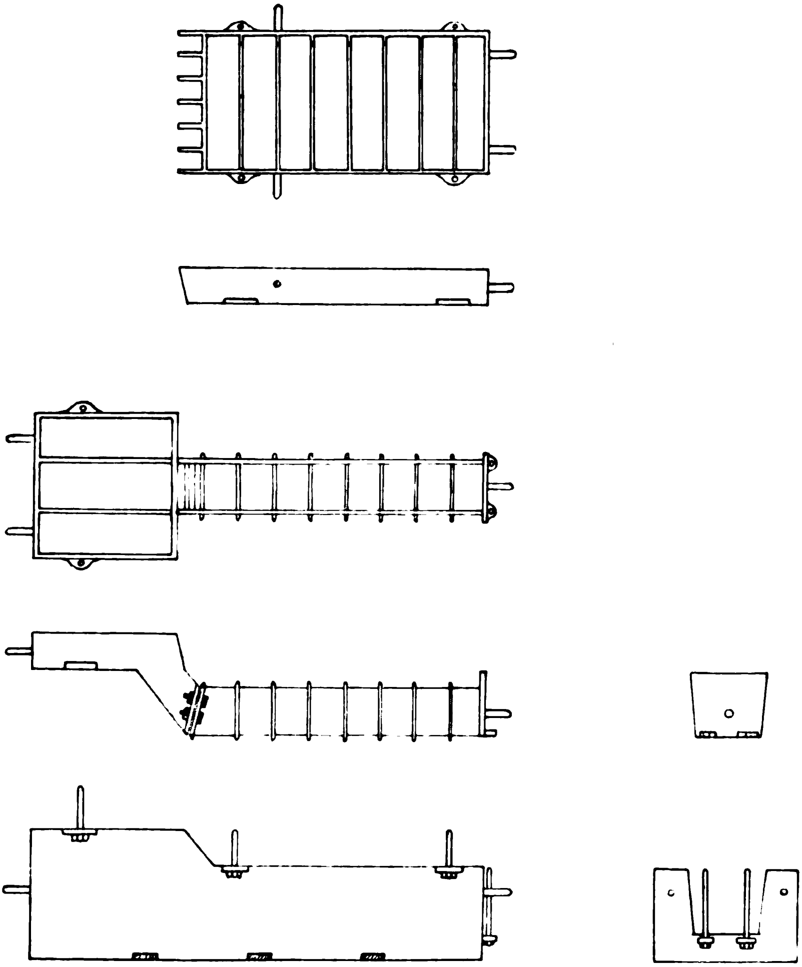

Fig. 39.—Special Box.

sand is first removed from the vicinity of the bolt heads, which may then be loosened by means of a T-headed key. On removal of the bolts, the halves of the middle part may be withdrawn from opposite ends of the casting, and bolted together again for further use.

Before leaving moulding-boxes, some reference is essential to an important class known as "Snap-Flasks." Such a flask is shown in fig. 40. It is built of wood, fitted with adjustable pins, hinged to open outwards, and provided with locking apparatus, as shown. In reality, a snap-flask is a moulding-box so constructed that on completion of the mould it can be removed, leaving the mould ready for pouring. Usually these flasks are rectangular in form, with flat joints; but, as with moulding-boxes, there is no limit to shape or contour; round flasks, and flasks having irregular joints, are used when the character of the pattern warrants such use.

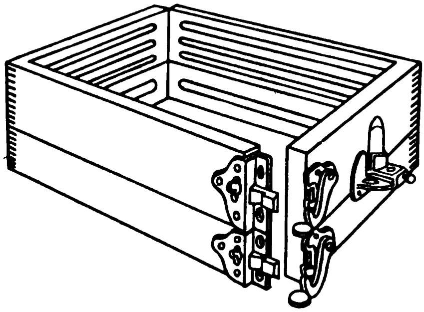
FIG. 40.—Snap-Flask.

CHAPTER VII.

HANDLING MATERIAL IN THE FOUNDRY.

FROM preceding chapters it is fairly obvious that a large amount of material has to be handled in the foundry, and, naturally, the better the facilities provided for this purpose the greater the output.

Taking first a light foundry, in which floor boxes are worked by hand, the best distributing facilities are found in narrow gauge tramways which admit of wide application. Thus they serve the purpose of distributing molten metal, moulding-boxes, and facing sand, the removal of castings, and so forth. This involves the foundry floor being divided into sections in direct connection with the cupolas, trimming shop, sand and box storage. The cupola hoists are, in turn, connected with the coke and iron stores. Naturally, the track arrangement will vary with the class of foundry, but, in general, it should be so laid out as to minimise hand carriage and to divide the floor into sections, each of which may be kept to separate classes of work. Turn-tables, which may work either on rollers or ball-bearings, are provided at each junction. Light flat-top trucks are most suitable for pig-iron and boxes, whilst tipping-skips are used for sand and coke. Molten metal is distributed by means of a bogie ladle, the moulders collecting from it in hand shanks.

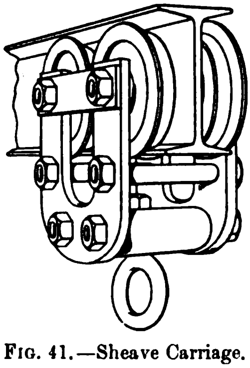

FIG. 41.—Sheave Carriage.

In certain classes of work, an overhead track, working in conjunction with an outside floor track, is of advantage. By means of the yard track, material is carried just inside the foundry and then handled by the overhead runway. In primitive form, such a track is found in many foundries, and is represented by a pair of sheaves running on either side of a beam. From the sheave a hook is suspended on which a chain block and tackle are hung. The beam of I-section is fixed on the roof girders, and the travelling distance of the sheaves is represented by the space between two girders. A type of carriage for such a beam is shown in fig. 41. A development of this system consists in suspending a track below the roof girders, thereby enabling a much larger portion of the floor to be covered, and also serving the purpose of distributing metal from the cupolas. A continuous line is thus provided; this system has met with wide adoption in agricultural-implement and stove-grate foundries of America. A suitable roof arrangement is shown in fig. 42. A further improvement consists in attaching a pneumatic hoist to the carriage, which is connected to an air reservoir by flexible piping.

There is, however, a limit to the applicability of overhead tracks; for whilst they possess many advantages in a foundry handling uniform, but not heavy, loads, they are certainly not advisable in cases where the loads vary between wide extremes, as in the ordinary jobbing or engineering foundry. Here cranes are essential. Viewed from a purely foundry point of view, a crane should be quick in action, always under perfect control, and give an absolutely steady lift. They may be operated by hand, steam, hydraulic, or electric power, and vary in capacity from 10 cwts. to 50 tons. Internal foundry cranes are confined to the jib and overhead travelling type. Locomotive cranes are, in certain cases, used for handling heavy castings, boxes, and molten metal, but these cases are extremely limited.

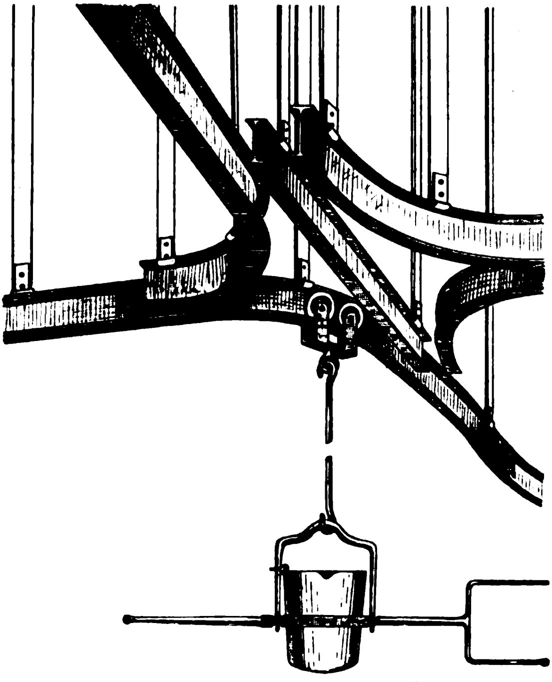

FIG. 42.—Overhead Trolley Track.

Taken generally, an overhead traveller is most serviceable for foundry work, and it may be operated by hand, steam, or electricity, or be driven by means of a shaft or rope drive. Steam may have advantages in certain cases, as, for instance, in an outside travelling crane; but, in a foundry, steam travellers are always a nuisance. Hand travelling cranes are also objectionable, and are certainly not desirable when the capacity exceeds three tons. Viewed from its best side, a hand-power crane will take eight men fifteen minutes to lift a load of fifteen tons fifteen feet high. From a practical point of view, a five-ton hand traveller will require three men to operate it, and, when loaded, will take a considerable time to travel, a point of special importance in casting, for molten metal should be handled quickly. One case within the authors' experience is that of a five-ton traveller, operated by four men, taking twenty minutes to distribute five tons of molten metal; whereas, under the same circumstances, a modern crane operated by one man would do the same work in eight minutes.

Therefore, apart from initial or operating costs, a vital point with all foundry cranes is that of convenience, and, if largely used, the cranes must actively respond to all demands. This response is obtained in the shaft-driven traveller operated by a rope drive. In this the slow and heavy drive of the shaft is replaced by a quick running rope, the crane being actuated from a cage by means of open and crossed belts. The introduction of the transmission of electric power has yielded a type of foundry crane exceedingly satisfactory from the two-fold point of view of use and operating cost. A modern electrically operated crane is capable of quick and steady work. Hoisting or lowering can be performed with an absolute absence of jerkiness, which is an essential feature in either drawing a pattern or closing a mould. The authors have found cranes like that shown in fig. 43, and manufactured by Messrs. Broadbent & Sons of Huddersfield, to be extremely serviceable in foundry work. This crane is of the four-motor type, has a maximum capacity of 20 tons, and is provided with an auxiliary 5-ton hoist. The working speeds are as follows:—

Motion.	Feet per Minute.	B.H.P. of Motor.	Speed of Motor.	Rating of Motor.
Main hoist (20 tons), . .	8	15	500	30 mins.
Auxiliary hoist (5 tons), .	30	15	500	30 ,,
Longitudinal travel, . . .	200	15	500	30 ,,
Cross travel, ...	100	5	500	30 ,,

Lighter loads are lifted and moved at quicker speeds without change of gear. The maximum capacity of a travelling crane should be such as amply to cover the heaviest work made under it; but in the majority of cases much of the work will, in comparison with the maximum, be of a light character. Hence, any traveller exceeding 20 tons total capacity should be provided with an auxiliary hoist in order to cater more efficiently for the lighter work. Whether this combination will effectually supply all requirements depends on the number of moulders working in the bay traversed by the crane. Often in closing a large mould the traveller may be tied up for several hours, and this will, of course, retard the progress of work on other parts of the floor. Difficulties of this character may be overcome by having two travellers running on the one set of rails. However, the authors prefer supplementing the overhead traveller by means of jib cranes fixed to the wall columns. An ideal arrangement is a foundry equipped with one traveller running the full length of each bay and capable of handling the heaviest loads dealt with; while to facilitate routine work, jib cranes are arranged below the traveller to cover practically the greater part of the moulding floor; these, by providing for all the lighter lifts, contribute largely to continuous work. Jib cranes also serve the purpose, when required, of connecting different bays of a foundry, as by their means loads may be passed from one traveller to another. This is a better plan than lowering the load on to a truck in one bay and running it through into the other bay in order to come within reach of the second traveller. The motive power for these cranes may be hand, electric, or hydraulic, the last being most suitable. The authors have found hydraulic cranes, such as those shown in figs. 44 and 45, manufactured by Messrs. Glenfield & Kennedy, of high service in the direction indicated. Fig. 44 gives the details of a 5-ton hydraulic crane by this firm. This type of crane takes up very little floor space, the pillar being carried from one of the shop columns, and the jib placed at a sufficient height to suit the class of work

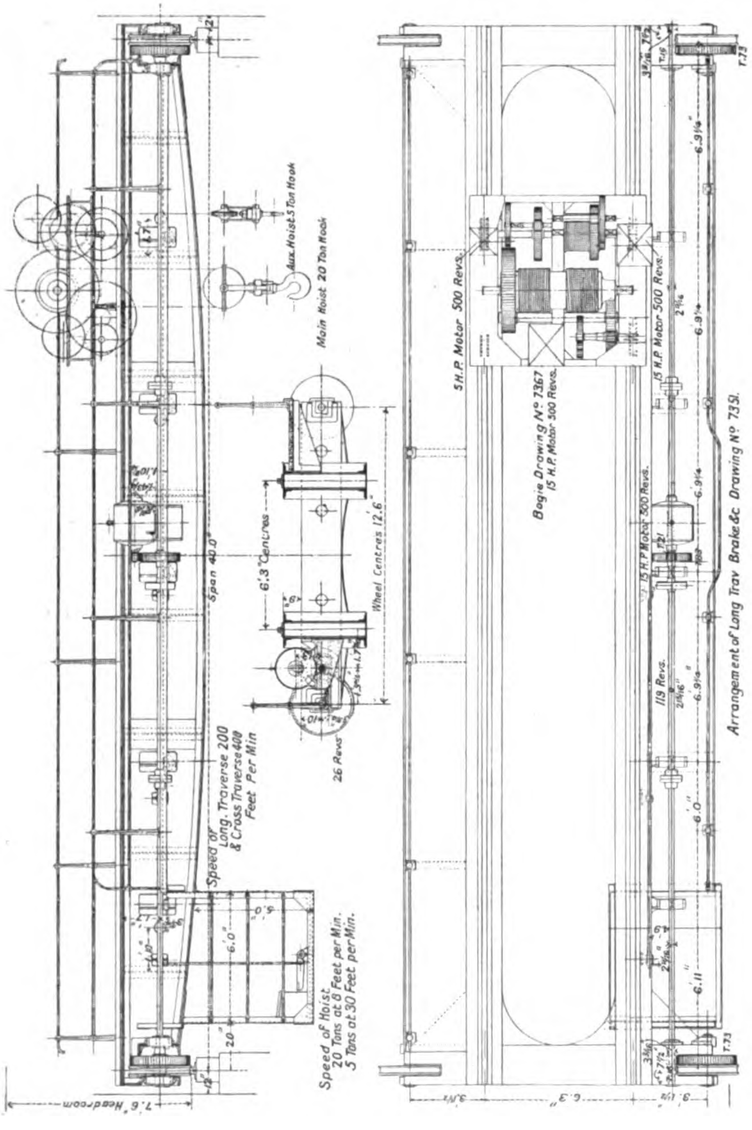

Fig. 43.—Overhead Travelling Crane.

being made. The lifting cylinder is shown bolted to the front of a column. The burden chain has one end fixed to the cylinder, then passes over the various pulleys on the ram head and cylinder cover up to the guide pulleys on the jib and along to the hook block, the other end of the chain being fixed at the point of the jib. Turning or slewing is also effected by means of hydraulic power. For this purpose there are two cylinders, one for turning in either direction. One of these cylinders is shown bolted to the side of the column, and

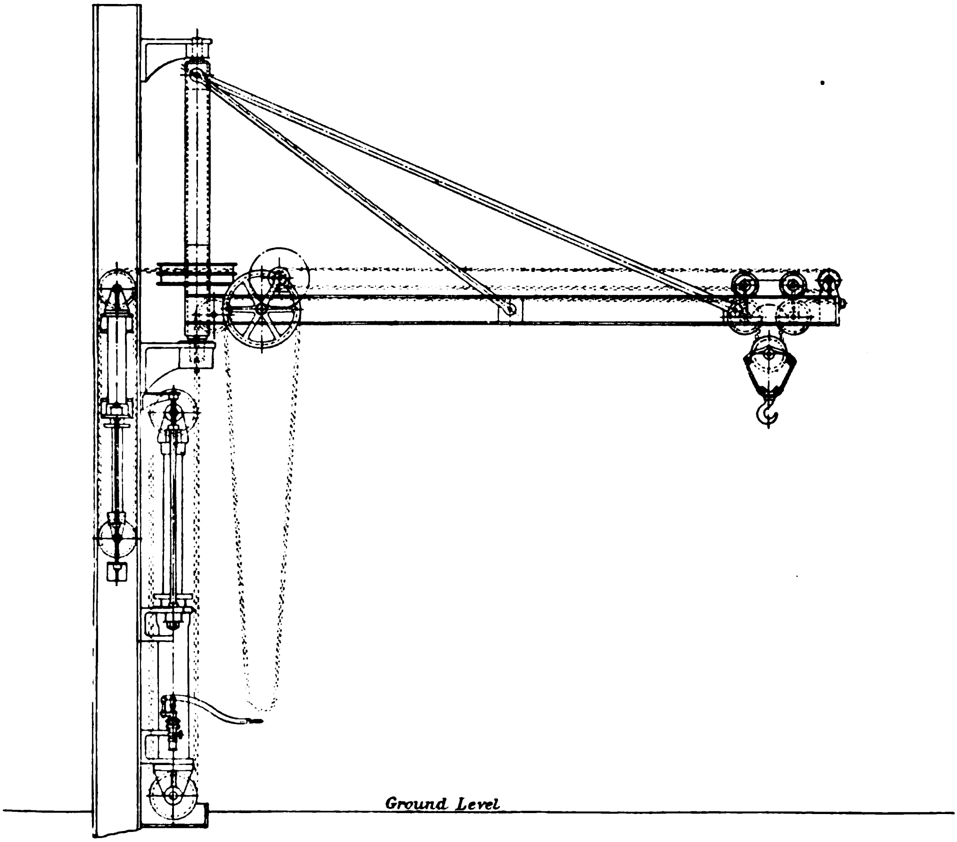

FIG. 44.—5-ton Hydraulic Jib Crane.

the rams in this instance are inverted, working towards the floor. One end of the slewing chain is fixed to the cylinder, then passes over the pulley on the ram head and cylinder cover. The other end is secured to the slewing drum shown round the mast above the bottom pivot bracket. Racking out and in of the load is in this crane effected by hand power. The bogie runs on four rollers along the jib, and the bogie frame carries two guide pulleys for the burden chain. The hook block consists of heavy cheek blocks to overcome the weight of the chain when lowering empty. Ball-bearings are arranged under the neck of the hook, so that the load can be easily turned round. The valves for lifting and slewing the load may be fixed at any desired place convenient for working, pipes being led from the valves to the various cylinders.

Fig. 45 shows another type of crane by Messrs. Glenfield & Kennedy, in which all motions, lifting, slewing, and racking, are performed by hydraulic power. This type is suitable for shops having no great head room or height, and is shown bolted to a wall. The cylinders are fixed to the crane structure, and revolve with it. The valves are arranged on a platform under the strut of the jib, so that the operator has full view of the load being manipulated. When there is a space available between the crane and the wall, the valve platform may be placed behind the mast, thus leaving all the floor area under the jib clear for working purposes. The lifting cylinder is placed between the mast uprights, the slewing cylinder behind the mast, and the racking cylinders along the jib. Supply water is led into the crane through the top pivot pin, and exhaust water is taken back to a return main through the same pin.

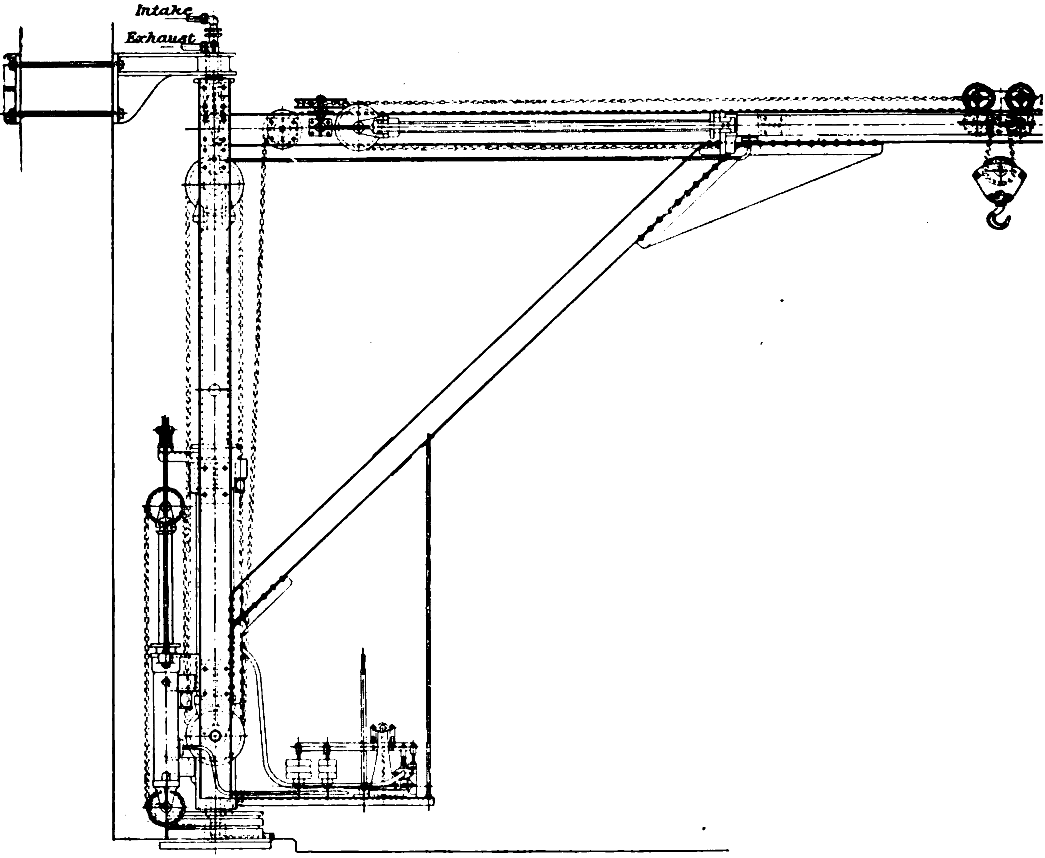

Fig. 45.—Hydraulic Jib Crane.

Whilst cranes have, as a rule, to be taken as they stand, and the foundryman must of necessity yield to the engineer, such is not the case with tackle employed for slinging a load. In considering lifting, apart from the weight handled, the first essential is always that of obtaining a true balance. A complete mould is not necessarily an evenly balanced structure, and its centre of form may not be the centre of gravity. Obviously, moulds of irregular contour require very careful slinging during carriage to or from the drying stoves or when otherwise handled.

A common type of chain sling has a ring in the centre which passes over the crane hook, and two chains attached terminating in hooks at each end. In lifting an evenly balanced mould, the two hooks may be passed over the central trunnions or on two diagonal handles. In other cases, the chains may be passed round the handles and the hooks caught in the crane ring, thus forming a loop. Such a sling does not permit of ready adjustment in its two members. To some extent one chain can be shortened by twisting or inserting sprigs between the links; methods which are, however, dangerous and inadvisable. Another type of chain sling consists of a chain with larger intermediate links, through which the end hook may be passed, thereby permitting of loops of various lengths being formed. However, the best sling is formed of a chain of equal links, but terminating in claw hooks (see fig. 48). These hooks readily grip any link, and offer very fine adjustment. In lifting, the chains are passed round the box handles and hooked on to equal links. A slight pull on the chain will readily show whether the balance is correct or not. If correct, both chains will be equally tight; if not, the pull is released and the slack chain adjusted until a balance is attained. These slings are made in various sizes, and the capacity of each size should be marked on the hook or ring. In many cases, as in turning over boxes, lifting castings from a mould, and so forth, it is difficult to estimate the stress put on a chain; hence it is important to allow a wide margin of safety.

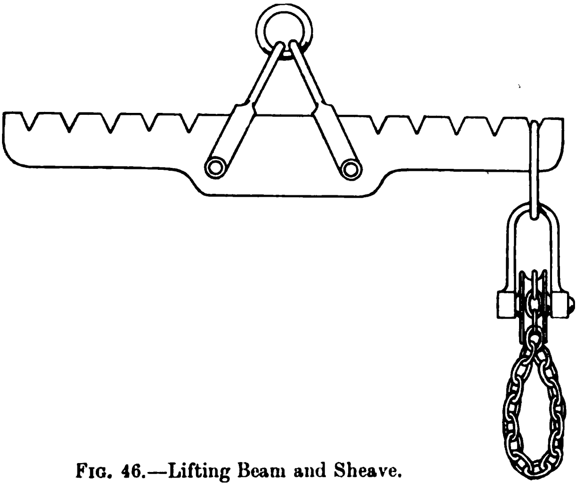

FIG. 46.—Lifting Beam and Sheave.

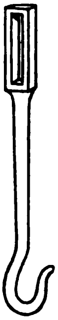

FIG. 47.—Solid Sling.

Above a certain size, chain slings will not span the box, and, further, it is often desirable that the slings should be vertical. This introduces the lifting beam, of which a very useful form is shown in fig. 46. Chain slings may be used on this beam by passing the top ring into any one of the V notches. When a mould has to be turned over, two slings of the type shown in fig. 47 may be placed in notches equidistant from the centre. With these slings only one part can be turned over; hence their use is limited. The endless chain and pulley shown on the beam in fig. 46 permit a full mould being turned over whilst suspended. When three box parts form a mould, the chains are passed over the two lower trunnions only, the mould is hoisted clear, and the whole turned over. With care, little or no jerking occurs in turning over, and slings of this type are of high utility in many foundry operations. The beam shown is preferably formed of mild steel or wrought-iron. Cast-iron and wooden beams are sometimes used, but are not very reliable.

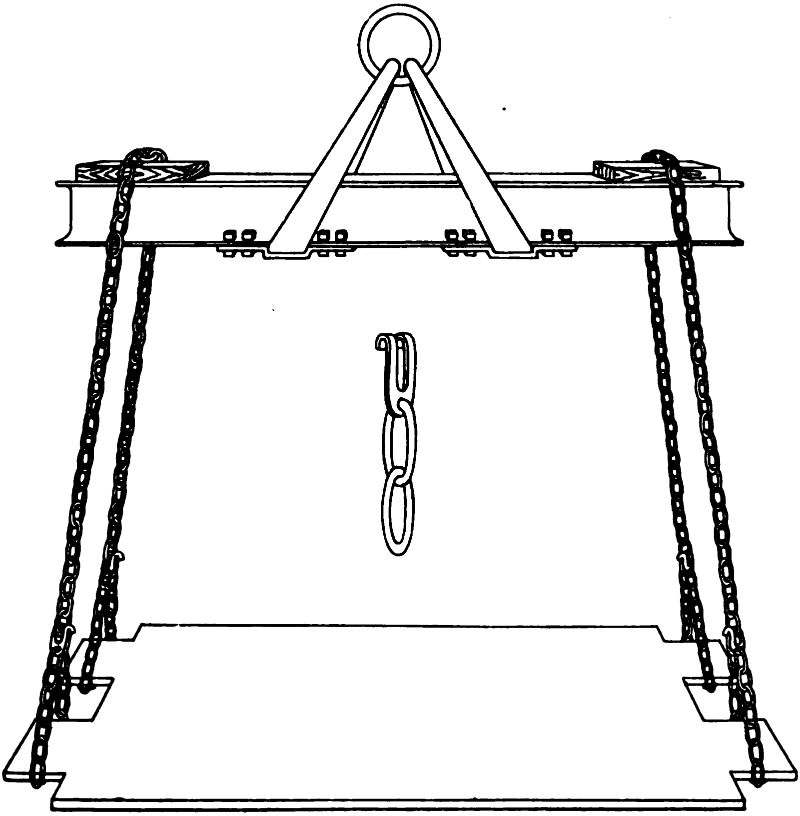

FIG. 48.—Heavy Lifting Beam.

A type of beam used in handling loam moulds is shown in fig. 48. This is readily formed by planing off the two projecting flanges on one side of a mild steel girder of I-section. Two lengths of from 6 to 12 feet, according to likely requirements, so treated, give][-sections, which, bolted together, give a double thickness in the centre and form a strong beam. Lifting shackles are fitted as shown in fig. 48, and two wooden battens fixed on the upper surface at either end. Chain slings fitted with claw hooks are used with this beam and passed over the battens on which they grip. The degree of adjustment offered is found in each chain member by means of the claw hooks and in the freedom of movement of the slings themselves to or from the centre of the beam. The slings being vertical do not catch the sides of the mould, and the adjustment offered allows an evenly balanced lift irrespective of the distribution of the load. By means of this beam, practically any form of loam mould can be handled, provided care is used in slinging it. Fig. 48 shows the method of suspending a load. In certain cases, beams in the form of a cross are employed. In construction these are similar to the one described, but have four shackles instead of two. In the case of a lifting cross, shackles are far better than a central eyebolt. Crosses are, however, not very largely used.

When handling large cores or drawbacks of irregular form, an adjustable sling is useful. These slings are composed of three chains attached to a central ring for passing over the crane hook, and fitted with ordinary hooks at each end. A shackle in the centre of each chain is provided with right-and-left-hand screws, and the chain can therefore be lengthened or shortened by means of the shackle. A sling of this description permits of adjustment without releasing the load. When a load has to be passed from one crane to another, a change hook, as shown in fig. 49, is used on the crane hooks. The applicability of such a hook is apparent, and, by its aid, ladles, etc., may be passed from one crane to another without being set down on the floor.

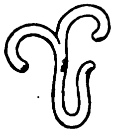
FIG. 49.—Change Hook.

All chains in foundry practice are subject to very severe service, and therefore require frequent examination. Owing to the dusty atmosphere, the wear is relatively rapid, and working temperatures vary within wide degrees. Further, chains are often subjected to very severe stresses; as, for example, when hauling out a casting from a pit, and they are often permanently deformed by such treatment. The danger is that after such deformation one or more of the links of the chain are liable to fracture under a comparatively low load. Without quoting the hackneyed "weakest link," frequent inspection of chains is obviously demanded. This inspection should be more stringent in frosty weather, or when the chains are used on hot castings. In addition to inspection for apparent flaws, a good rule is to anneal the chains at least once a year.

CHAPTER VIII.

OPEN SAND MOULDING.

As indicated by the name, an open mould represents one which has the upper face uncovered, and can therefore only be followed when the top surfaces are horizontal. This method is largely employed for making boxes, foundry tackle, floor plates, and the like, where one rough surface is immaterial. Patterns may be provided, but in the majority of cases the moulds are made up to size by means of straight edges and templets. Fig. 50 shows the pattern of a furnace top 1½ inch in thickness. In making the mould, part of the floor is dug over and riddled to a depth of 4 inches. The pattern is then bedded down until its upper surface is level and the under layer of sand uniformly solid. The top surface must be level, otherwise the casting will vary in thickness; hence a spirit level must be used in bedding down. When level, a weight is placed on the pattern to prevent it moving, and sand firmly tucked round the edges. The surplus sand is strickled off to bring it level with the top of the pattern, and then smoothed over with a trowel. A small basin or "runner" is formed at one end, and a channel ½ inch deep cut at the other. The pattern is then drawn and the mould ready for casting. The bottom of the runner is level with the top of the pattern, and fluid metal poured into it runs over into the mould, filling it, until at a height of 1 inch it flows out at the channel already mentioned, when pouring is at once stopped.

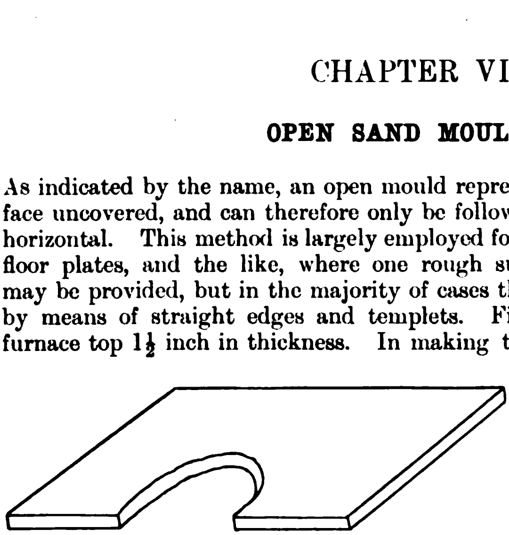

FIG. 50.—Flat Plate.

All open sand moulds are made thicker than the desired castings, and overflow channels are cut to bring the mould to the required depth. These channels at once indicate when sufficient metal has been poured in. If the mould had to be filled right to the top, it would be almost an impossibility not to overrun the edges, which in the cold casting would leave fins to be broken off. The provision of a run-off at once secures the right depth and a casting with clean top edges.

The foregoing method has been given, because it is often followed; but it is evident that by this method every separate mould has to be levelled by a spirit level. When more than one casting is required, this is obviated by "striking" a level bed, the surface of which will form the bottom of the mould. Such a bed is formed as follows:—

Two straight edges form its outside boundaries, and must be set absolutely level themselves and with each other. In the direction of its length each straight edge is set by placing the spirit level directly on it. The two straight edges are set to each other by using a third straight edge placed across them, and noting the indications of a spirit level placed in the centre of the transverse straight edge. As will be readily seen, if a large bed is being formed, this is a matter involving two pairs of hands and some little practice. The two straight edges set, they are then rammed firmly in position. The sand between the straight edges is passed through a ½-inch riddle, distributed equally and lightly rammed. Ramming should be light and uniform, the object being to obtain a compact but not hard mass. The ramming will vary according to the character of the castings to be made on the bed. If simply light thin plates, a suitable bed may be obtained by treading the sand. On the other hand, if the castings are heavy, the bed should be rammed by the pegging rammer. This is most effectively done by ramming one course about 3 inches below the level of the straight edges, and a second course slightly above their level. The surplus sand is strickled off down to the level of the straight edges. A layer of sand, about ½ inch in depth, is riddled over the surface, pressed down by a straight edge and strickled off. This should give a level bed of good surface. With a pattern such as already described, all that is necessary is to lay the pattern flat down, make up the edges with sand, and provide a runner and flow off. A series of moulds can be made on one bed, but they must be placed so far apart that the sand forming the sides shall not be carried away by the wash of the metal. These sand walls separating one mould from another may be strengthened by laying on small weights, the object of such weights being to prevent a side wash and not an upward lift. One complete mould is shown in fig. 51.

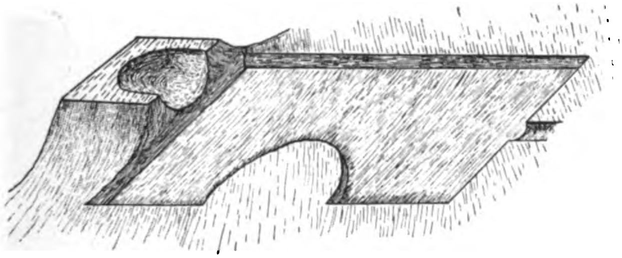

FIG. 51.—Mould for Flat Plate.

A bed such as described is, for the most part, used for making up tackle, in which case patterns are not provided. Thus, an ordinary building plate is made by preparing the bed as before, and marking the outline of the plate on the level surface. Such plates vary from 2 to 3 inches in thickness, and the other dimensions vary according to the class of work. A usual type, with four lifting snugs and central cross cored out, is shown in fig. 52. In making it up, two central lines at right angles to each other are marked on the bed. The outlines of the central opening are then marked out, the core formed by holding blocks of wood in position and ramming sand in the space so formed. If a 2-inch plate is being made, these blocks should be 3 inches thick and the sand rammed to the top. Two such blocks are held on each side of the outline, and the sand between loosened by a trowel, in order that the core shall have a better grip; handfuls of riddled sand are then placed between the blocks and firmly tucked in. Stability is further increased by pushing in sprigs, about 6 inches in length. The top of the sand is brought to the same level as the blocks, which are then moved down until the whole of the outline has been followed. Square corners are cut off with a trowel, in order to obtain the rounded form shown. Four lines are then drawn by setting a straight edge parallel to each central line, to form the outside of the plate. The snugs are marked out, and should be so placed that two diagonal ones will give an approximate balance to the plate when lifted. The outline is then made up, as in the case of the core, by holding a block of wood in position and ramming sand to it. Junctions between snug and plate are rounded off by hand. Two runners are made on the joint, as shown in fig. 52; and, before casting, the central core is further steadied by placing weights on it. The foregoing represents a simple case of moulding without patterns. Round plates are marked out by means of trammels, a small block of wood being set in the bed to serve as a centre, and from it a circle is described of the required diameter.

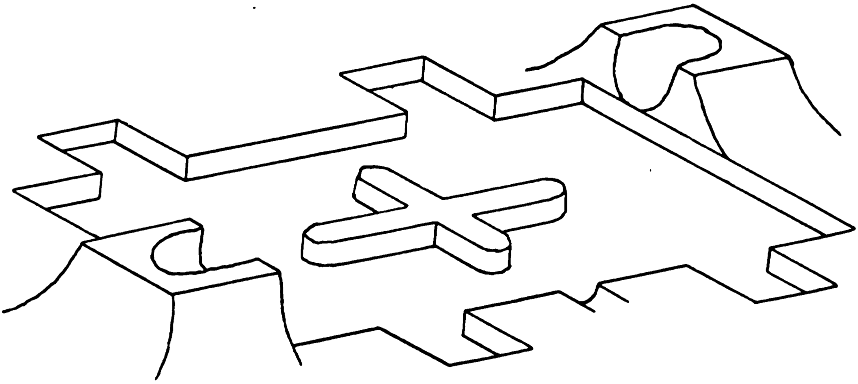

FIG. 52.—Mould for Building Plate.

For making up, a block of wood may be cut of the requisite curvature, or, as is more usually the case, the moulder bends a piece of sheet iron to serve as a segment, and uses it as a guide to make up the sand. Building rings are made in the same way, except that in this case two circles are struck, giving internal and external diameters. The inner and outer circles are made up with sand, as before. When these rings are required in halves, they are split across the diameter by inserting two iron plates in the mould, which is then poured as two separate castings. Plates $\frac{1}{4}$ inch in thickness are effective. They are cleaned and rubbed with dry plumbago, and bedded in the mould so as effectually to isolate the two halves.

When several plates are required of the same size, they can be cast in one mould, as follows:—The sides of the mould and any cores are made up to a greater depth than the thickness of the total number of plates required. The first plate is poured, care being taken not to exceed the required depth. The surface is covered by a layer of parting sand, and the plate allowed to solidify. When solid, the second plate is poured, and so on. When cold, the separate plates are easily parted from one another, and, although their surfaces are rough, the plates make very serviceable building plates, and, moreover, are very quickly made. It may be well to note that plates made in this manner seldom exceed one inch in thickness.

Obviously, by the use of straight edge and trammel, quite a variety of shapes can be readily marked out on the bed, and such shapes can be readily made up by using strips of the required contour to follow the outline marked.

A method introducing another principle is found in making core gratings from a combination of wrought- and cast-iron. This subject really belongs to core-making, but the method may be illustrated in the case of a fire-basket. These baskets may be round or rectangular; taking the latter form, a frame is made up, as shown in fig. 53, ½-inch nail rod (a variety of cheap wrought-iron largely used in foundries) cut to the required length, is spaced 1½ inch apart, as shown. On casting this frame the rods are firmly fixed; a second and similar mould is made, the first casting inverted, and the free ends of the rods placed in the mould. Two eyes are sunk in the sand, with ends projecting. On pouring in metal, the rods and eyes are fixed, and the complete casting presents the appearance shown in fig. 54. A series of loose bars laid across the bottom at once gives a convenient and portable fire grate.

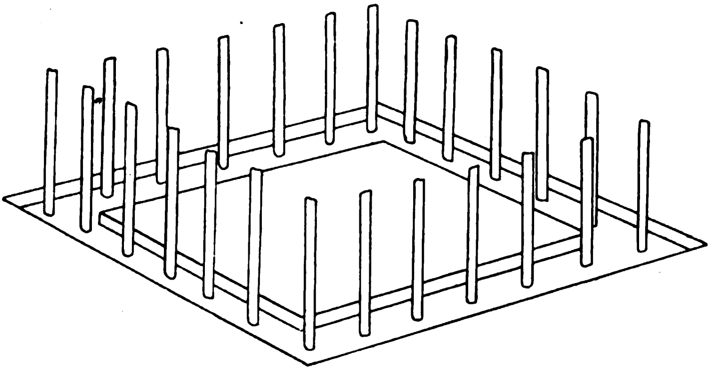

FIG. 53.—Mould for Fire-Basket.

Further examples of open sand work are found in making moulding-boxes. In this case a full pattern may be provided, or simply an outer frame. Assuming a complete pattern is at hand, the first step is to dig a trench and set the pattern level. It is then weighted to prevent displacement, and is ready for ramming up, an operation requiring care. All moulding-boxes are cast joint-side down. Thus, in the case of a top part, the cross-bars do not reach so far down as the outer frame. Sand must be carefully tucked under the outer frame and the cross-bars, and the best tools for this purpose are the fingers. Any soft places will result in swelling, and if these are on the joint their removal is necessary before the halves of a complete box will lie truly. Given a pattern set perfectly level, and the sand solid below the joint edges and bottom of the cross-bars, the whole of the inside may be rammed up. Floor sand passed through a quarter riddle is sufficient, and in ramming, the pegging rammer alone is used.

Ramming is not mere sand pounding, but rather an operation requiring skill and judgment. The ideal is to compress the sand into a compact but not hard mass. Ignoring other conditions, it will be seen that if the sand between the cross bars is rammed into a dense hard mass, the pattern cannot be removed without doing considerable damage to the mould. On the other hand, if the sand is not rammed compact, the casting will swell; in other words, there will be a lump on the casting corresponding to every soft place in the mould. Uniformity is best obtained by lightly ramming thin layers of sand between each bar. This is continued until the sand is level with the top; it is then strickled off and smoothed over with a trowel. The pattern is then tapped all round the outside with a mallet, in order to loosen it and facilitate its later removal. The outside now remains to be rammed, and provision made for the lifting handles and pin snugs. The position of the pin snugs is marked on the pattern, and is usually slightly above the joint. Sand is levelled off to the lower mark, and a loose snug pattern laid on. Sand is rammed flush with the top, and the whole levelled off for 2 inches round the snug, which is then withdrawn. On this level joint a piece of flat core is laid butting close up to the pattern. Instead of a core, a piece of flat cast-iron, daubed with oil and sprinkled with parting sand, may be used. The object of this covering is evident, and the ramming is continued above it until the top is reached. The whole of the snugs are formed, and the two sides rammed up. The position of the handles is marked on each end of the box. Occasionally, box handles are of cast-iron; in this case a round bush, 8 inches long, is rammed up with sand, and a peg 1 inch in diameter driven down its centre to a distance of 5 inches. On withdrawing the peg, the sand round the top of the hole is sleeked away in order to form a fillet. The bush is then laid in position flush against the pattern. Two conditions are of moment: (1) in making the core for the handle the peg must be driven in straight, and parallel with the sides of the bush; (2) the bush must be placed horizontal, and true to mark, otherwise the handles will be askew.

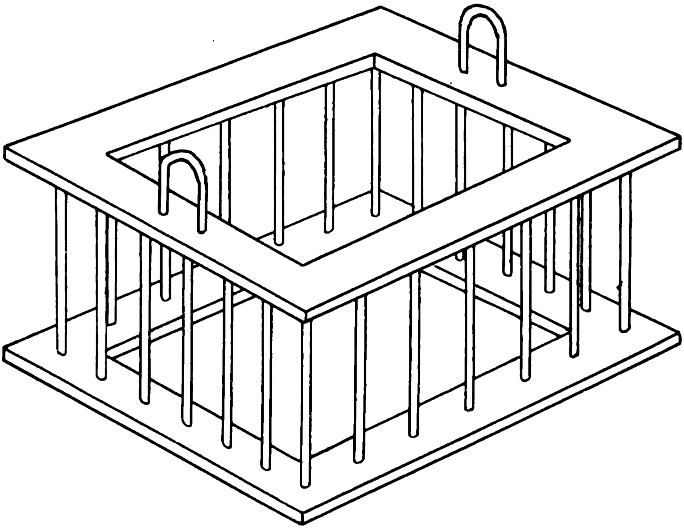

FIG. 54.—Fire-Basket.

Cast-iron handles are not safe for heavy boxes, and a piece of round bar iron is far more effective. In this case cores are made to give an increased thickness on the side of the box, and a boss of metal to surround the handle. The core shown in fig. 55 is placed in position, and a piece of bar iron 1 inch in diameter by 6 inches long is pushed through the round hole.

Handle cores are rammed up with the two ends, the whole is strickled off level with the top, and the pattern is ready for drawing. All loose sand is swept off with a dry brush, and the surface of the sand slightly moistened by sprinkling water with a "water brush." It will be remembered that the inside has already been loosened somewhat. Further loosening is effected by jarring the four lifting pegs shown on the pattern, and tapping the sides. The pattern must be drawn perfectly level, and, according to its size, will require from one to four men. During drawing, the box is continually tapped by a boy on either side; and if the ramming has been properly done, this jarring, assisted by the taper of sides and cross-bars, will result in a clean lift without starting any of the sand. All loosened sand is replaced, using a strip of wood as guide, and smoothing down with a trowel.

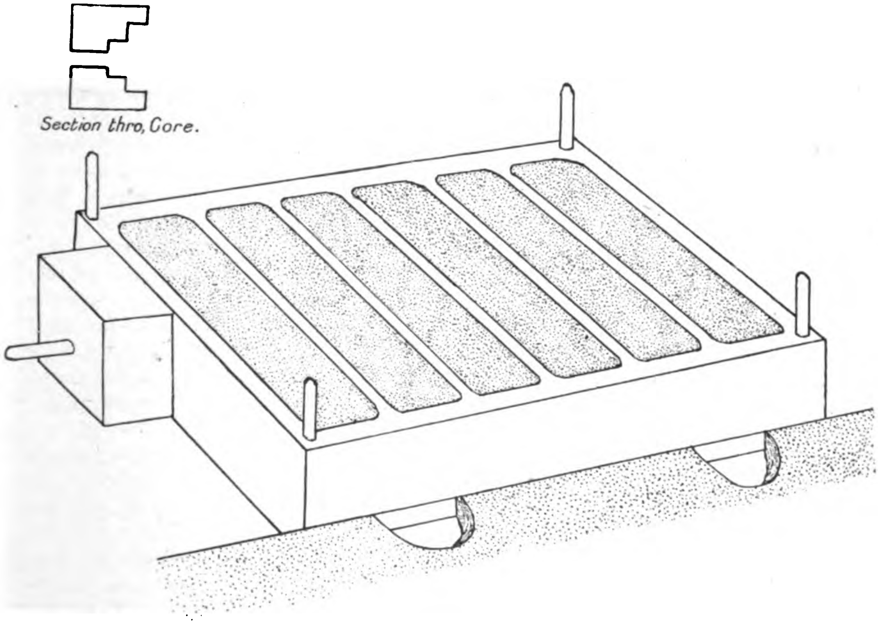

FIG. 55.—Mould for Box.

Handles and snugs are already provided for, and, after the loosened sand has been all replaced, the mould is ready for casting. Two runner bushes are placed over two opposite corners, weights are placed on the sand between the cross-bars to prevent a side wash, and over snug and handle cores to prevent an upward lift. The mould is made $\frac{1}{2}$-inch deeper than required, and a flow-off cut to this depth indicates when the right height of metal has been obtained, and gives a clean top by preventing an overflow.

Practically, the foregoing applies to any box having a horizontal top surface. Bottom parts are made similarly, except that the cross-bars are placed flat instead of crosswise. If trunnions are required, they are formed in cores, as in the case of handles. If flanges replace snugs, the flange is moulded precisely as a snug, but the bearing for the covering core is carried further back.

Middle parts are often made with an inner projecting strip. On the pattern this strip is loose, the inside is rammed up first, the pattern drawn, and the strips removed by drawing them outwards. The pattern is then replaced and the outside rammed up.

A full pattern is not always provided. Often an outer frame serves for top and bottom parts. In this case two loose cross-bars are made, and, after levelling the outer frame, the inside is formed by placing the loose bars in position and ramming them up. The first bar is drawn, set in its next position, rammed, and the process continued until the inside is completed. As in all moulding operations, it will be seen that a certain elasticity is permissible. From an outer frame with guide strips for cross-bars, any type of box can be formed. In certain cases where the top surface is not a horizontal one, or where flanges and inner strips are required, as in a middle part, on both joints, open sand moulding cannot be followed.

CHAPTER IX.

CORES.

Cores are employed to cut out metal, as in the boss of a wheel; or to form the internal portion of a casting, as in a valve body. In character they vary infinitely, and may be of such a nature that a young boy will produce hundreds in a day; or, on the other hand, so intricate that a skilled man will require days of hard work to produce one.

The inherent requirements of cores are similar to those of moulds, *i.e.*, the core must resist the washing action of a stream of metal; it must admit of the free escape of gases, and impart to the interior of the casting the required contour. These determining conditions are, however, intensified by the fact that cores are often almost wholly surrounded by molten metal, and therefore offer more difficulty in the way of providing an escape for gases. For this reason, and also to secure stability in handling, the majority of cores are dried before they are fixed in the moulds.

Cores may be made from tubes, the internal diameter of which corresponds to that required in the core. Such tubes are serviceable for odd sizes, and the authors have found simple sheet-iron tubes made by a tinsmith, and ranging in diameter from 3 to 12 inches, of use when standard core boxes could not readily be obtained. Generally, boxes built of wood are employed, and for round or square cores a series of standard sizes should be stocked. Three simple core boxes are shown in fig. 56; it will be noted that B and C are fitted with pins, which serve the same purpose as the pins in a moulding-box, viz., that of ensuring the two halves always being in the same relative position to each other. A in fig. 56 represents a type of box for making flat cores; the box is laid on a flat plate, and core sand rammed flush with the top, which is then strickled off and smoothed with a trowel. The hole shown in the side is for the purpose of venting, and a vent wire may be placed through the box before ramming the sand, or, as an alternative, the vent wire may be pushed through after ramming. In the latter case, the trowel blade, or a flat plate, is laid on the sand to prevent it starting upwards. Flat boxes of this character are largely used for rectangular cores. Boxes such as B and C, if of short length, are held together by one hand, and rammed and vented with the other. The halves are then separated, and the core laid on a plate, which, when filled, is transferred to the drying stove.

Long cores require strengthening by the insertion of a piece of wire or iron rod. Such cores, when of small diameter, are made by packing sand in the two halves of the box and strickling both level. On one half of the core a stiffening wire is placed, and parallel with it a vent wire is laid, the sand of both halves is claywashed, the two half boxes brought together, tapped, and the vent wire withdrawn. The purpose of claywash is to stick the halves together, and, when using it, a thin coating down the centre will be sufficient. Should claywash get near the outer edge of the core, it is liable to make the sand "clag" or stick to the core box, resulting in a rough core. Claywash may be replaced by blacking, plumbago, core gum, or flour; any one of these substances, when mixed with water, will successfully stick portions of cores together. However, claywash will be found the cheapest, and, on the whole, the most efficient.

Long cores of large diameter are made by fastening the two half boxes together by means of cramps or dogs driven into the sides, placing an iron or piece of wire in the centre, and ramming sand round it until the requisite height is obtained. The core is then vented by means of a vent wire. The object in pasting a core of small diameter is simply to get a straight vent. This may be readily appreciated by trying to pierce a core $\frac{5}{8}$-inch diameter by 12 inches long; the chances are that the vent wire will be sent into the box; hence the reason for laying the wire in and pasting. In a larger core this difficulty vanishes, and it is fairly easy to drive the wire straight through the core. Straight cores are easily vented by either of the methods given; but when the cores take a curved form, the difficulties of free venting increase with the curvature. In a slightly curved core, a single string vent may be used, and, when drawn from one end of the core box, will follow the bend of the core without breaking through. An elbow core, the half box of which is shown in fig. 57, should be vented by means of two strings so laid that their ends slightly overlap at the bent portion. These strings admit of withdrawal from each end of the core, thereby leaving two straight passages, which, meeting at the bend, give a continuous passage through the core. Elbow cores

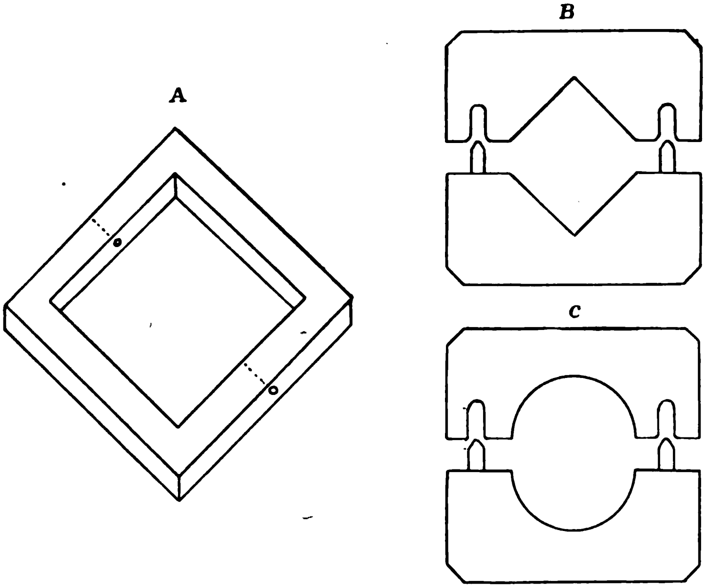

FIG. 56.—Three Simple Core Boxes.

exceeding 3 inches in diameter are most effectively vented by means of an "ash vent." To form this, the two halves of the core box are rammed up as usual, and a strengthening iron, bent to the required contour, is bedded in one half. Alongside this iron a channel is cut out, and loosely filled in with small coke, about the size of a pea, but sieved free from dust or fine dirt. The halves are pasted and closed as usual; after drying the core, such a vent will offer a most effective route for the egress of gases. When the diameter of the cores is sufficiently large, ash vents are not only the most convenient, but also the most effective, and, no matter what the shape of the core, channels can be readily cut to follow its windings. Ash vents cannot be applied to cores of small diameters; strings must be used for these. In the case of very small cores, as, for example, an elbow of the form shown in fig. 57, but only ¼ inch in diameter, a string vent would be difficult to manipulate. A material is therefore required which may be made up with the core, and will, on drying, "char," thereby leaving a passage through. Strands of cotton soaked in tallow were used for this purpose; but of late years "wax wire vents" have been introduced, and serve the purpose better. These vents are flexible, and will readily bend to follow the contour of any core they are bedded in; on subsequent drying, they melt, and the liquefied wax is absorbed by the core, thus leaving a clear channel. In diameter, wax vents may be obtained from one-sixteenth of an inch upwards, and are therefore suitable for a variety of intricate cores.

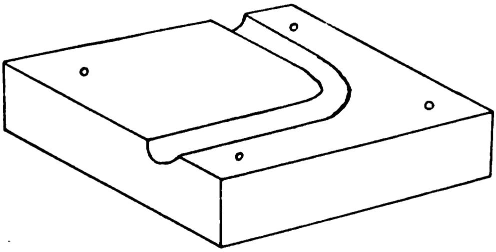

Fig. 57.—Elbow Core Box.

Green cores are fairly tender, and will not admit of much handling until dried. A core of simple form may be turned out of the half box on to the hand, and then laid on a plate for drying. When the core cannot be handled, it is removed from the box by bedding it on to a sand bed. Thus, on removing the top half of the core box, a sprinkling of parting sand is thrown over the core, and a layer of floor sand riddled on until a level bed is obtained. A plate is then bedded on, and the whole turned over and the second half of the core box removed. The core remains sitting in a sand bed, and need not be disturbed until the whole is dry; it can then be handled. In certain cases the sand bed may be replaced by a wooden cradle, the core being subsequently removed from the cradle, by means of clips, on to a drying-plate.

So far, core boxes have been considered as consisting of two parts only, but, under certain conditions, the boxes may require dividing into three or more parts, in order to make the required core successfully. The joint between the boxes B and C, fig. 56, is such that when one half is lifted vertically it clears the core, and does not catch or tear the sand; but when seats or fitting strips are added to a core box, these would, if lifted vertically, undercut or tear away the sand. Such pieces are therefore attached to the core box as "loose pieces," so that, on removing the main portion of the box, they remain in the core, and may be drawn away in a horizontal or other direction which will not tear the sand. As an example, the case of a round core in which a series of longitudinal strips are required may be selected.

Reference to fig. 58 will at once show that a vertical lift would tear away certain portions of the sand. Therefore, the core box is so constructed that, on removing each half, the strips remain in the sand and can be removed laterally. In order to keep the strips in place, they may be fitted on to the main box with pins, which are removed during the process of ramming; or the strips may be jointed into the box in such a manner that they readily fall out on a straight lift. This method of loose pieces is applied to core boxes for asbestos-packed cocks. The strips forming recesses on the barrel of the core are fitted loosely in order to permit of removal after the main part of the box is lifted away. The core box for a two-way cock is divided across the barrel; but, in the case of a three- or four-way cock, division of the box across the barrel of the core would be attended with difficulties; hence a division is made across the diameter of the "ways." In order to get a clean parting on the barrel, this portion of the box is divided into segments. Thus, looking on the top of a half box, fig. 59, the segments indicated by lines remain in position on lifting the main part of the box, and are afterwards removed by drawing them out in a horizontal direction. The whole is bedded on a plate with floor sand, turned over, and the process repeated for the second half. Such a box would, therefore, consist of ten pieces; and a limit for the subdivision of core boxes is only found when the loose pieces cannot be held together for ramming. When this limit is reached, the core is made in separate portions, and fitted together in the mould. This method often involves that each separate piece of the core be held in position by means of a chaplet. Whilst chaplets are very necessary in many cases, it is none the less a fact that, when they can be safely dispensed with, better results follow. To some extent, this may be achieved by constructing core boxes in such a manner that when the various pieces come to be fitted together in the mould they all have a direct bearing in the main core. For example, if a body core has a series of branches bending from it, a corresponding series of pockets in the body core will offer a means of fixing one end of the branch cores, the other end being carried by a pocket in the mould. Such pockets are termed "core prints," and their use is shown in Chapter XIII.

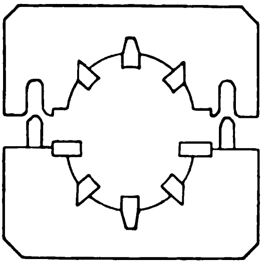

Fig. 58.—Core Box with Fitting Strips.

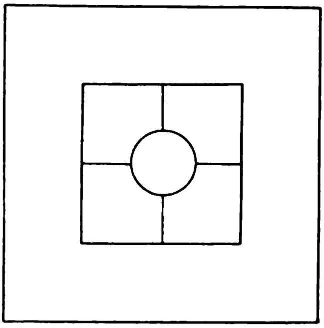

Fig. 59.—Core Box for 4-way Cock.

On the other hand, separate pieces of a core may be pasted together before placing in the mould as a complete core. This method often reduces an intricate core to a series of simple ones, and, further, the fact of the core entering the mould as a complete one may to some extent dispense with the use of chaplets. Pasting mediums have already been given, and claywash indicated as the best for sticking the halves of a green core together. When pasting a series of dried cores together, core gum, boiled in water, will be found the most efficient.

Fig. 60 shows a type of core usually employed to form the interior of a valve body. This is made in two portions, and a bearing is made at X, which is, however, insufficient for keeping the core in position, owing to the thickness of metal between the two cores forming the valve seat. Hence, used in this way, a chaplet is required to prevent the top portion of the core floating from its seat. If the two portions could be stuck firmly together, not only could the chaplet be dispensed with, but a joint is also saved in making the mould. Fig. 61 shows one method of attaining this result, and it will be noted that the core is made in three portions. This requires a box for the main core, including the seat, and boxes for the smaller pieces which complete the inlet and outlet portions of the valve. The pieces are dried separately, and, before pasting, a channel is scraped down the centre to form a vent. This method simplifies core-making and moulding, and readily lends itself to a large output.

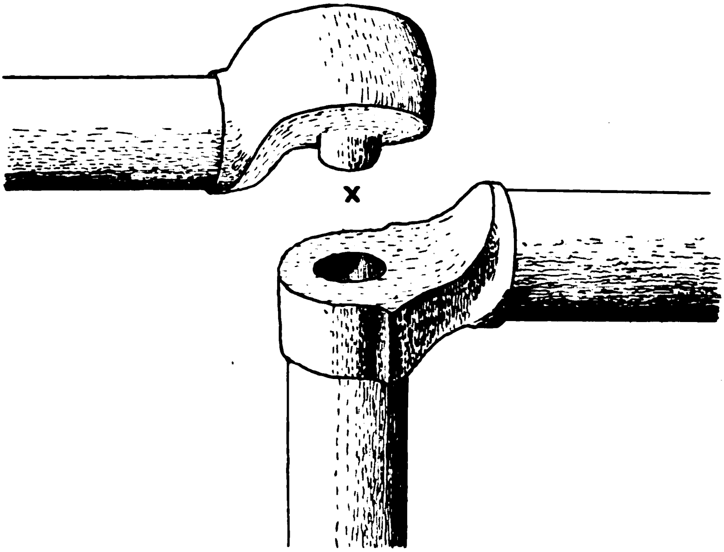

FIG. 60.—Valve Core.

After drying, all cores are coated with black-wash or plumbago. Blackening is usual for cast-iron and brass. Owing to the greater searching action of bronze and gun-metal and the higher casting temperature of molten steel, plumbago gives better results, *i.e.* cleaner skins. Small cores may be held between the thumb and forefinger, so as to close up the vent hole, and dipped bodily into the black-wash; large cores are painted by means of a swab or brush.

Core irons are used for the purpose of strengthening the sand of a core, and, naturally, vary in size and character with the size and form of the core. They may, therefore, vary from wire one-sixteenth of an inch in diameter to round or square rod of comparatively large size. Further, large cores may require strengthening by the insertion of several irons. When possible, rod is always used, because it can be readily cut to size and bent to the required shape. These rods are returned from the trimming shop, and may be repeatedly used.

An iron, when bent to follow the outline of a core, should be free from "spring"; this is of special importance in the case of wire for small cores, as otherwise the object of the strengthening wire will be lost. Examples of the use of core irons are shown in fig. 62; it will be noted that branches are attached to the main core by bending an iron to follow the shape, as in the **T** and **Y** cores. A core with two branches, as in the cross, has two irons laid in at right angles to each other. In fixing core irons, not only must they be bent to shape without springing, but they must also be bedded solidly in the sand of the core. Hence, where two rods overlap, as in the cross, it is usual to bed one rod in each half of the core box. Obviously, above a certain weight loose rods will not sustain a core and its branches. For stability, the core iron must then be in one piece, and such pieces are most conveniently made of cast-iron on the open sand bed. With cores up to 3 inches in diameter, an iron such as A in fig. 63 is sufficient; but with larger cores projections are formed, as shown in B and C. The method of moulding these irons has been sketched

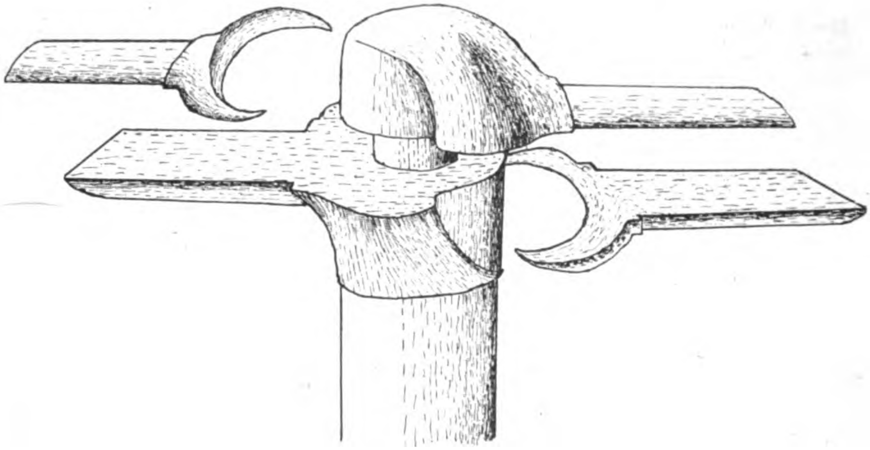

FIG. 61.—Valve Core.

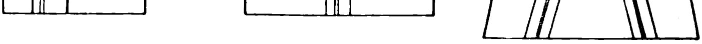

FIG. 62.—Use of Core Irons.

in the previous chapter; it consists in marking the required outline on a level bed, and cutting channels to suit the outline. In the case of standard core irons, a pattern may be made and stamped in the bed. This saves marking out; or a chill mould may be used. Chill moulds are only advisable when large numbers of core irons are required, owing to the cost of the preliminary mould. The hardness induced by pouring molten iron in a metallic chill is not a drawback in the case of core irons, for, in trimming the castings, these irons have, as a rule, to be broken in order to clean out the core.

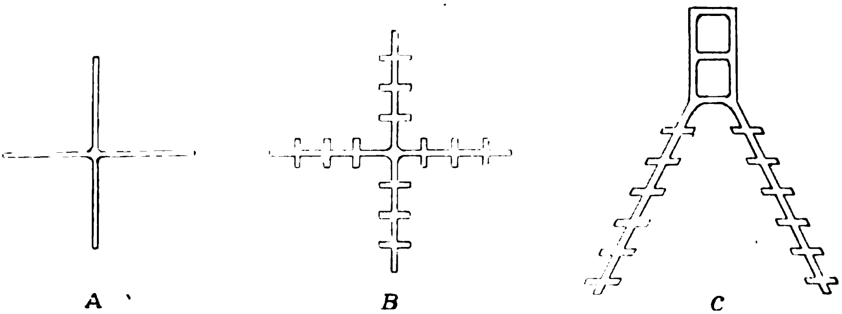

FIG. 63.—Cast Core Irons.

Obviously, on a level bed only flat core irons or gratings may be made, but, whilst the upper surface is necessarily flat, the lower one may be of almost any contour. Thus, after marking out the grating, a series of holes may be made in order to form "dabbers," as, for example, in fig. 64. The purpose of these dabbers is to distribute the effect of the grating into all parts of the core; they may be vertical or at any inclination required by the contour of the core. The latter also determines the length of the dabbers. Therefore, when making such a core iron, all requirements must be clearly realised; for, though bits may be broken off, none of the projections will admit of bending. For this reason, sprigs or lengths of iron rod are often cast in a grating, since they will admit of bending to shape. A composite core iron of this character has many applications. For example, a series of rods cast in the foundation grating may be afterwards bent to follow the inclination of any core. This method is specially applicable for supporting projections from the core, which,

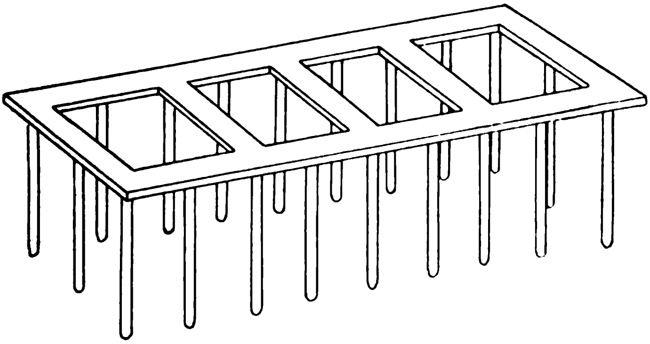

FIG. 64.—Cast Core Iron with Dabbers.

if on a higher level than the grating, cannot otherwise be readily reached. The method given for making a fire-basket in the previous chapter may also be taken as illustrating the making of a composite core iron. By this plan, practically any form of cage may be made, and the requisite internal support for any type of core readily obtained. In addition to casting lengths of iron rod in core gratings for the purpose indicated, nuts or hooks are also cast in. The object in this case is that of offering a means of bolting two or more gratings together, or of suspending the core in a crane. When a nut is used, an eyebolt is screwed in for lifting; or, if used for tying two gratings together, the screw from the first grating is passed through a corresponding hole in the second one, and tightened by means of a loose nut and washer. Hooks, when cast in the grating, are connected together by means of eye bolts; when used for lifting, an **S** hook offers a means of connection with the crane slings. According to the size and form of the grating, two or more hooks may be required to balance the core effectively when slung in a crane. In making the core, tubes are placed over the hooks or nuts, as the case may be, which, on withdrawal, leave a space for the insertion of a lifting hook. These spaces are filled in when the core reaches its final position in the mould, and are dried by means of a red-hot plate. It need hardly be added that a sand core is not usually slung in a crane until dried, and then only for the purpose of lowering into the mould.

So far, sand cores made from core boxes, core vents, and core irons have been considered. Vents and irons are essential in any core, no matter how made; core boxes are, however, in certain cases dispensed with, and many sand cores are made by processes technically known as "sweeping" or "strickling." Strickled cores are familiar in the case of curved pipes of odd sizes, or where the number of castings does not warrant the outlay for a complete pattern and core box. Swept cores are confined to round straight pipes, and are familiar in all classes of pipe moulding.

Strickling involves the use of a guide and strickle, as shown in A and B, fig. 65. A is simply a flat board cut to the required curvature; it will be noted that by sliding the strickle B along the length of A, the dotted outline shown on A will be traced. Therefore, sand roughly packed by the fingers to this outline, and brought down to shape by passing the strickle over it, will in final form give one half of the core. The sand should be solidly packed, and strengthened by bedding in one or more irons bent to shape. On obtaining a rough outline, the sand is examined for soft places, which are made good, and the strickling continued until an exact half core is obtained. In using the strickle B, it will be noted that the checks cut at C serve as a side guide only; therefore, the strickle must be pressed down on to the guide board; if this is not done, an irregular core will be the result. A layer of parting sand is sprinkled over the half core, floor sand riddled on in order to bed a plate, and the whole turned over. The second half of the core is then strickled, and for this the opposite face of the guide board is required. After drying, the halves will come together, forming the complete core; hence the reason for strickling one half from each face of the guide board. Before jointing, a channel is scraped down the centre of each half, to serve as a vent, and the two are then pasted together by clay wash or core gum. Simple pasting is sufficient for small cores, but those of large size should be tied together by means of wire. This is effected by having the core irons slightly longer than required, and looping them together by means of iron wire. If support is required in the centre, a groove is cut down to the core irons, which are bound together by iron wire, and the groove then filled in. The joint between the halves is made good; the core, after black-washing and drying, is then ready for the mould.

This method of strickling is applicable to any core, the outline of which may be obtained by means of a guide; further, these cores can be made to serve the purpose of a pattern, as will be shown later. However, whilst the method of strickling sand saves pattern costs, it enhances those of the foundry, and is therefore chiefly applicable in the case of castings which are not of a standard character. Swept cores are usually run up in loam. There are, however, various cases in which swept sand cores are of advantage. The authors have found swept green sand cores of advantage in the case of castings in which provision for contraction could not otherwise be made. These cores are placed in the mould in a green, *i.e.* undried, condition, and are therefore difficult to handle. Apart from this, greater skill is required in sweeping sand than loam, though essentially the two processes are similar. In the case of sand, the method is as follows:—A core barrel, formed by drilling holes in a tube of the required length, is set on trestles, then a winch handle is fixed into one end and keyed by wedges. The barrel is tightly wrapped with tow, or, in its absence, with frayed rope and then clay-washed. Riddled green sand is packed on as the barrel is rotated; and when a uniform layer is obtained, the strickle board is set in position across the strickles and weighted to prevent movement. Sieved green sand, not too wet, is then packed on the rotating barrel until the core assumes the form imparted by the stationary strickle. The difficulty lies in getting such sand to hang whilst the barrel is being turned. Practice in green sand sweeping is the only way to overcome it; as soon as skill has been gained, cores are readily made by this method. When setting the strickle, its position must be such as to give the exact size of core required. Sizes are marked, or should be marked, on the strickle when it reaches the foundry. Usually two recesses indicating the diameter are made at each end of the strickle, and the core-maker can set his calipers to these recesses. In setting the strickle, allowance must also be made for the diameter of the core barrel. Green cores of this character are used without drying, and are of service in the direction indicated, *i.e.* where contraction cannot otherwise be met than by providing a yielding body of sand to meet it. In this respect it may be noted that in intricate castings of zinc and aluminium the authors have found the substitution of a green for a dry core the only possible solution for the difficulty arising from contraction.

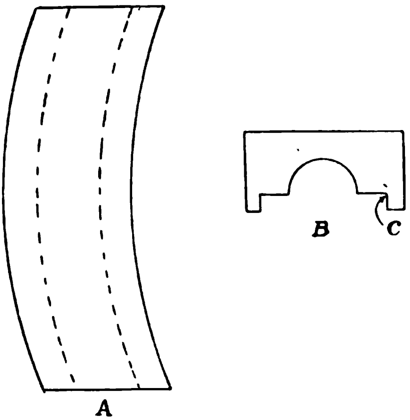

FIG. 65.—Strickling Board.

In running up loam cores a barrel is provided, as in the foregoing case, and wound tightly with straw rope. Straw ropes are twisted strands of straw, and were at one time spun in the foundry either by means of a hand winch or a spinning machine. They are now more efficiently obtained from supply houses, and any variety of size is offered. Wooden ropes have been intro duced as a substitute for straw, but they have not yielded any special advantage, and general experience is in favour of straw. Having wrapped the barrel with rope, it is clay-washed and daubed with loam, the latter being pressed well into the interstices of the rope. A strickle is set across the trestles, and weighted in a position for giving a slightly smaller diameter than that required by the finished core. Loam is pressed on the rotating barrel, which acquires the form imparted by the strickle. The first coat of loam is then stiffened by a few hours' exposure in the core stove; after which the finishing coat is applied. Finishing loam is in a finer state and wetter condition than that first applied. In running on the finishing loam, the strickle must be set to the exact position required by the final size of the core. The core is then finally dried; after which the diameter is tested by calipers, and, if correct, the core is black-washed. Should the diameter be too large, the core is "carded down" to size, that is, whilst rotating in the trestles the surplus loam is rubbed off by means of sand-paper or card wires. The latter consists of strips of leather belting pierced by a number of wires projecting about ¼ inch, and are specially useful in all cases of carding. On the other hand, if the diameter of the dried core is too small, a further coat of finishing loam is given. Naturally, when applying the final coat the exact size should be, and as a rule is, caught the first time.

The principle of sweeping cores is, therefore, that of applying sand or loam to a revolving barrel, the desired form being obtained by rotating the sand or loam against a fixed board with a bevelled edge. Tow or straw rope serves as vents, and connects the whole of the core with the holes drilled in the barrel. The fact that sand cores are more difficult to run up than loam is due to the former containing less clay and thus having to be worked comparatively dry; it, therefore, does not "hang" well. Loam worked at about the consistency of stiff sludge readily hangs, and easily takes the form imparted by the strickle. An arrangement of core barrel, strickle, and trestles is shown in fig. 66. This strickle will give a core of larger diameter in the centre than at the ends, but strickles can be cut to give any form of circular core.

Obviously, core barrels should be of a suitable diameter, that is, large enough to give the requisite support to the loam, but not too large to hamper contraction of the castings. The barrels may be made from gas-pipe, boiler tubes, or of cast-iron made specially to the required size. In the last case, trunnions are fitted to the ends. When a small barrel has, of necessity, to be used for a large core, several layers of straw rope are applied, in order to increase its diameter. Each layer must be tightly wound, and its interstices filled in by rubbing loam over the whole surface before winding on a second layer. In repeat work, such as large pipes, loam is applied directly to the core barrel. These barrels are some two inches less in diameter than the core, the surfaces are covered with dabbers or small projections in order to give a grip to the loam, and are penetrated by numerous small holes for venting. To overcome contraction of the pipe, the barrels are made collapsible, and, after the casting has solidified, the barrel is "released" by removing the keys which hold it in position. Thus, if the barrel is formed of three segments, keyed together from the inside, when contraction commences, these keys may be knocked away by passing a bar down the interior of the barrel, thus permitting the casting, as it cools, to force the segments inwards.

The method of strickling sand, shown in fig. 65, is equally applicable to loam, and in the case of large irregular pipe cores is widely used. The only differences of note are that the guide plate should be of metal, as the half core must be stiffened in the position in which it is swept. Stiffening may be, and often is, effected on wooden guide plates; but there is always a tendency for the plate to warp; hence, metal plates are better. These may be made on the open sand bed, using the wooden guide as a pattern, in which case a contraction allowance should be made on the pattern. In order to obtain two smooth faces, the guide board is turned over to make the second plate. Two suitable core grids are made, and, if the pipe is of large size, lengths of nail rod are inserted in the grid. These are afterwards bent over to follow the sweep of the core. On each end of the core grid a snug is made in order that the two grids may be bolted together by passing a bolt through the snugs. A layer of loam is spread on the face side of one plate, and the clay-washed core grid bedded on to it. The right position is obtained by passing the strickle along the full length of the plate. The grid is then partly filled in with loam, and an ash vent laid along the centre of the half core. The filling is completed, and the final form obtained by the use of the strickle. Plate and core are carried bodily into the core stove and allowed to stiffen. The process is repeated on the second plate; and the two half cores, when stiffened, are jointed and securely fastened by passing a bolt through the end snugs of the core grid.

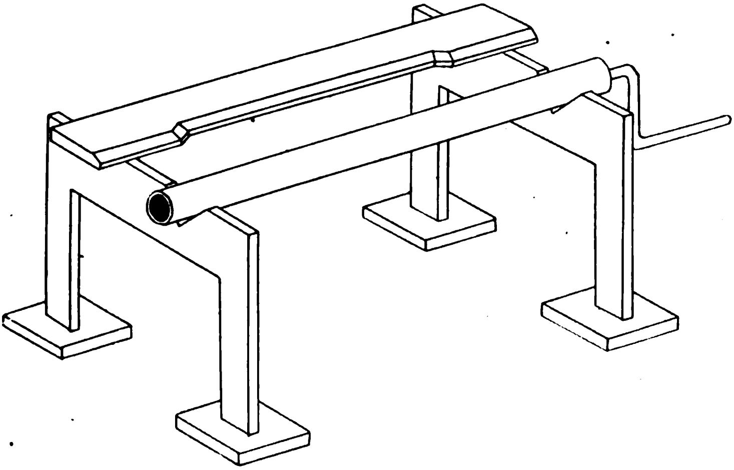

FIG. 66.—Coré Barrel, Strickle, and Trestles.

Core Drying Stoves.—Drying stoves vary according to the style of cores, from large brick structures down to small ovens, but little larger than those of ordinary kitchen ranges. The larger type are more conveniently discussed under the heading of stoves for drying moulds. The smaller type are, as a rule, built of cast-iron, fitted with a series of shelves provided with iron doors, and fired from a grate placed in the bottom. A sheet-iron flue leads from the top to a convenient stack. One of these stoves, of a compact and convenient type, is shown diagrammatically in fig. 67. It consists of four compartments, and the products of combustion are drawn from the grate between each compartment before finally entering the flue. Separate doors to each compartment permit of access to any one without cooling off the other three. Small doors placed in the sides of the stove give access to the flues for cleaning.

Various patent drying stoves are on the market, the Millett core stove being probably the most typical. This stove may be built into a wall, or fixed in any position convenient to the core bench. One of its best features is found in the fact that each shelf is independent. Each shelf and door are so attached that on opening any door the shelf comes with it, thus bringing the cores into a readily accessible position. An iron plate fixed on the back of the shelf effectually closes the stove when a shelf is drawn forward, thereby preventing a loss of heat.

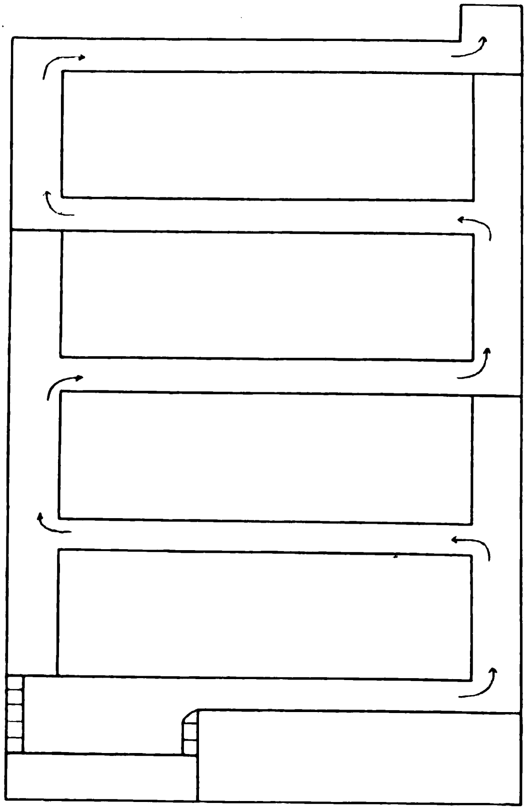

FIG. 67.—Small Core Drying Stove.

CHAPTER X.

ELEMENTARY ASPECTS OF MOULDING.

The Preparation of a Mould.—Some elementary notions of moulding have been indicated in a previous chapter, but, as indicated, the method of open sand moulding is limited (1) by the rough surface of the top face, and (2) by the fact that this face must be a horizontal one. As a result, only comparatively few of the castings produced may be made in open moulds. Turning to the more legitimate methods of moulding, it will be well, in the first place, to consider a few of the more elementary principles involved in the preparation of a simple mould.

As a first example, we shall take the case of a flat plate 12 inches square by ¼ inch thick, to be moulded in a box 14 inches by 16 inches. The pattern is laid on a flat "turning-over board," and the bottom part of the moulding-box is placed over it, joint side down. This should be so placed as to leave 1 inch space between the pattern and the sides and one end, and a space of 3 inches at the other end. For facing, a slight sprinkling of coal dust is well mixed with a shovelful of floor sand and sieved on the pattern to a depth of ½ an inch. The box is filled with riddled floor sand, and the edges immediately over the joint well rammed with the pegging rammer. The sand overlying the pattern is not touched with the pegging rammer, but more sand is spread on the box, and the whole lightly rammed with the flat rammer or trodden with the feet, the object being to obtain the joint hard, but the rest of the sand firm and compact only. Surplus sand is strickled off level with the box edges, and the box is then ready for turning over. In this class of work bottom parts are not provided with cross-bars, hence a bottom board is bedded on to prevent the sand falling out whilst turning over, and also to permit of the complete mould being carried to a convenient place for casting. After strickling off, a layer of sand is sprinkled on, and the bottom board bedded by rubbing it to and fro until a level bearing is obtained and the board rests on the box edges. The board is removed, and a series of channels made by lightly striking the sand with a rammer shaft. The whole of the sand is then pierced with a vent wire, the board returned, and the whole thing turned over by gripping the two boards together. The turning board is removed, and the joint of sand round the pattern sleeked with a trowel. Any loose sand is removed by brush or bellows, and a sprinkling of parting sand thrown on. After standing a moment, the surplus is blown off and a further light dust of parting sand thrown evenly over the joint. The top half of the moulding-box is fitted on the pins, and held "sun about"[1]; a runner peg is placed in the centre of the widest end of the joint, and floor sand sieved on as before. The box is filled with floor sand, which is tucked under the cross-bars by the fingers and rammed all over with the pegging rammer. More sand is spread on, rammed compactly with the flat rammer, and the surplus strickled off level to the cross-bars. The runner peg is withdrawn, and the top widened by scooping out a shallow head, which serves as a pouring basin. The top part is vented by piercing with a vent wire, and then lifted off, turned over and laid on a flat board. The sharp edge round the runner is filleted, and the sand face forming the top of the casting dusted over with charcoal or plumbago, and the surplus blown off. On the joint of the bottom part a channel is cut parallel with the pattern, and connected with it by means of light runners, as shown in fig. 68. These runners are most conveniently cut by means of the spoon gate cutter. Loose sand is blown off, and the joint round the pattern just touched with a water swab; the pattern is then lightly tapped, to loosen it, and drawn out. Should the pattern be of wood, its removal is effected by a sharp spike; but, if of metal, two holes are previously drilled in it, and the pattern lifted by means of spikes placed in these holes. This drawing should be effected so as not to start the edges of the joint. If a very smooth face is required on the casting, charcoal dust or plumbago is shaken on the sand, and "sleeked" or lightly smoothed with a trowel. The mould is blown out, the top part returned, and the box cottered or weighted; it is then ready for casting.

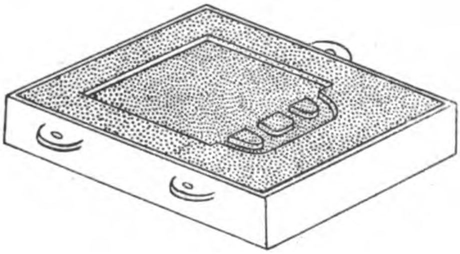

FIG. 68.—Mould for Flat Plate.

As a second example, a pattern of the same size and thickness as the foregoing is selected; but the surface, instead of being plain, is covered with fine detail, such as flowers, fruit, etc. The method of moulding is very similar to that followed for the plain plate, except that strong facing sand is sieved over the pattern, and, after filling with floor sand, the whole of the box is rammed with the pegging rammer. The box is turned over, the joint made, the top part rammed, and runners cut as before. A very fine skin is imparted to the casting by "printing" the pattern, that is, after drawing out the pattern, the surface of the mould is dusted over with plumbago, the pattern returned to exactly its former position and pressed down, thereby pressing the plumbago into the intricate details of the mould, and so securing an effect equivalent to sleeking. Naturally, the pattern must be returned to the exact position from which it was drawn, otherwise the mould will be spoilt. A small pattern of this kind offers no difficulty in "returning"; but larger ones are most con-

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[1] In the case of a flat joint, twisting is not of grave moment, but "sun about" should always be enforced when placing the top half of the box on the bottom half; that is, the right hand side of the box is pressed towards the moulder and the left hand pressed away.

veniently "staked" before the first removal, by fixing spikes at the corners, which serve as guides on returning the pattern. After printing, the mould is blown out and made ready for casting, as in the first case.

As a third example, the pattern of a block 12 inches square by 12 inches deep may be taken. Here, owing to greater depth, the pressure of the liquid metal on the bottom and sides of the mould comes into play, a condition not so marked in the first two examples. The sides and bottom must, therefore, be rammed sufficiently compact to resist this pressure. On plain work of this kind, floor sand, to which coal dust is added, will answer as a facing, and the more open its character the harder should be the ramming. Should the floor sand be too weak, it may be bonded by the addition of from 10 to 25 per cent. of new sand, but the mixture should be essentially open in nature. The sides are rammed in courses of 4 inches, that is, after covering the pattern with facing sand a layer of floor sand 4 inches in depth is spread round the pattern, and evenly rammed with the pegging rammer. In ramming up the sides, the rammer should not approach nearer than an inch and a half to the pattern, and should not on any account strike the pattern. The courses round the sides are repeated until a depth of 4 inches of sand on the bottom of the mould is obtained, which is lightly and evenly rammed with the pegging rammer. A further course is spread on, and the whole rammed harder than the first course. The whole of the bottom of the mould may then be rammed comparatively hard with the flat rammer, strickled off, and well vented. Before venting, a series of channels are scraped by the point of the vent wire from side to side and end to end of the box. After venting, the box is turned over on to a level bed and the joint made. The top part is fitted on the pins, and a runner peg fixed as before; but in this case, owing to the large volume of liquid metal, it is evident that there will be a fair amount of liquid shrinkage. To meet this a "feeder" is placed in the centre of the top of the pattern, and rammed up with the top part. After strickling off the top, the runner peg and feeder are withdrawn, and the top part lifted off. The method of gating differs from that adopted with the thin plates, and a deep runner of  section will be sufficient here. Before drawing out the pattern narrow channels, roughly, ⅛-inch deep × ¼-inch wide, are cut along the joint and connected by branch channels leading to the box edges, as shown in fig. 69. This channel is about 1½ inch from the pattern, and is vented at distances of an inch all round the mould, taking care to force the vent down parallel with the sides of the pattern. The vent wire is also pushed beneath the box and the bed on to which it was turned. The pattern is then drawn out, and the mould finished and made ready for casting. On pouring fluid metal down the gate and through the runner into the mould, it is obvious that the metal will gradually fill the mould and rise in the feeder until it reaches the same height as the runner. This feeding head will therefore act as a reservoir, and, so long as it is fluid, will supply the shrinkage of the casting below it. The position of gate and feeder on the casting as it leaves the sand is shown in fig. 70, the diameter of the feeder being reduced at its junction with the casting in order that it may be more readily broken off.

These three examples of moulding give rise to the following considerations respecting ramming, venting, and gating:—

Ramming is not an easy operation to describe, further than to state generally that it is not mere sand pounding, but demands the exercise of some judgment. Thus, in example one, the flat plate was not rammed with the pegging rammer, but simply consolidated by treading or lightly ramming with the flat rammer. In the second and third examples, the pegging rammer was used on the face of each mould and a fairly compact ramming given.

In making flat work of plain surface, all that is necessary is to get the sand sufficiently compact to resist liquid pressure; provided this requirement is met, the softer the ramming the better the result. If too soft, the casting will swell; therefore, the greater the depth of the casting the more compact must be the ramming. The question naturally arises, if compact ramming is permitted in the case of a heavy block, what harm can it do, further than a waste of physical effort, in the case of the thin plate? An answer is found in the very fact of the plate being thin, for, if a fully run casting is required, the metal must enter the mould quickly; in other words, the air and gases of the mould must escape rapidly. If they do not escape, the casting is "seamed" or marked by more or less worm-like hollows, which are a source of disfigurement. These streaks, due to the non-escape of gas, when present may be traced to the use of too strong a facing sand or to the hard ramming. Compact ramming in the case of the block is required in order that the mould shall not swell. Therefore, an open sand is used and venting assisted by the vent wire, as indicated. Not only is there a greater pressure on the mould, but there is also a greater depth of liquid metal to force the gases downwards through the sand.

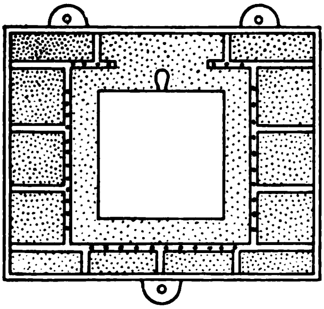

FIG. 69.—Mould for Block.

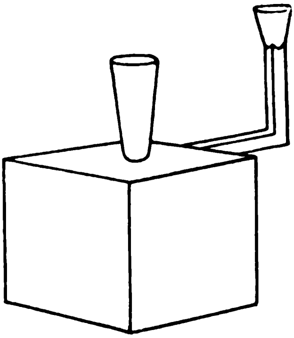

FIG. 70.—Block Casting.

In the second example, strong facing sand was compactly rammed on a figured surface. In this case the sand must be squeezed into the finest intricacies of the pattern if a replica possessing the delicate detail of the original is desired. A limit to hard ramming is, of course, found when the sand is so wedged into the details of the pattern that the latter cannot be drawn out without bringing the sand with it. Rammed within reason, such a casting will seldom "seam," and artificial venting is hardly necessary. In fact, large numbers of panels, canopies, and the like, are moulded, and a vent wire never used.

This gives rise to a feature of moment, in that the tiny projections of sand forming the detail of the mould offer a route for the egress of gases. Molten metal does not lie so kindly on a plain surface as on a figured one, hence the greater precautions necessary in thin flat work. The foregoing refers only to the bottom parts of a mould. Top parts are always rammed comparatively hard, in order to withstand lifting off, turning over, and replacing. Whilst molten metal has to lie *on* the bottom face, it only lies *against* the top face. Comparatively few remarks are necessary here as to the use of the vent wire. As shown in the foregoing account, it is an artificial aid to the porosity of the sand; therefore, in heavy work, where compact ramming is required, venting should be liberally practised. In venting, the wire should not touch the pattern, for, if it does, metal will enter the vent, in which case it cannot serve its intended purpose as a channel for the escape of gases. In thin work the sides of the mould do not enter into consideration; but in deep work, as in the third example, provision should be made for venting the sides of the mould. In all cases the vent should be allowed a free escape, hence the cross channels made on the bottom of the box before turning over. During casting, the gases escaping through these channels are "lit" by applying a red-hot skimmer.

Gates or runners denote channels cut for the passage of metal from the ladle into the mould, formed, as shown, by ramming up a peg with the top part and cutting a channel communicating with the hole left by this peg. A typical form of gate is shown in the block, fig. 70, representing a V-shaped channel, whilst a sprue form of a gate is shown on the plate, fig. 68. In connection with sprue gates it is well to remember that their area should not exceed that of the down gate or runner. The authors have had much difficulty in getting experienced moulders to recognise this, and one often sees a gate cut with a dozen sprues, equal to an area of 2 square inches, supplied by a down gate of an area equal to 1 square inch. Under such conditions, some of the sprues cannot be effective, and it is always well to see that the source of supply is equal to the demand. In fact, the area of the down gate should always exceed that of the sprues. A series of sprue gates are always cut on a thin casting, which must be filled quickly. Owing to its thinness, such a casting must be supplied by several streams of metal from distinct points. A heavy casting can be successfully run by one gate cut of such a size as to take the whole of the metal supplied by the down gate. Here the metal will not chill so rapidly as in the case of thin plates.

Risers, or "whistlers," are placed on portions of a casting which project into a top part in order to ensure these portions being "run up" sharp. In other cases, risers are placed on the opposite side to the runner, in order to tell when the mould is full and to prevent straining. The purpose of a feeder has been shown to be that of a reservoir to supply liquid shrinkage. The size of the feeder will, therefore, vary with that of the casting, and in certain cases it may be necessary to place several on different portions of the casting. An example of the latter is found in the rim of a heavy fly-wheel. In order to make a feeder more effective, it is kept open by churning with an iron rod, the object being to keep a passage between feeder and casting open, so that at intervals further supplies of liquid metal can be poured in, thus ensuring a casting being "fed up," that is, solid to the top.

These notes, in conjunction with those given on open sand moulding, cover the more elementary aspects of moulding. Practically, they may be summed up by regarding a mould as a receptacle for liquid metal, which receptacle must not be injured by the temperature or pressure, and be of such a nature as to permit the removal of gases, and give a casting which in form shall be an exact replica of the pattern.

CHAPTER XI.

GREEN SAND MOULDING.

THE method of turning over has been described, but it is readily apparent that few of the large range of patterns handled by any foundry can be laid on a flat board for the purpose of ramming up the bottom part. Patterns of regular contour, but which do not, in the solid, permit of the use of a flat turning-over board, may be divided through the centre, as, for example, the flanged pipe, fig. 71.

The halves of such a pattern are maintained in true position by pins and dowels, as in the case of core boxes. In moulding, one half is laid on a flat board, and the bottom part and joint formed as before. The second half of the pattern is placed in position on the first half, and the top part rammed up, which, on lifting off, brings with it the embedded half pattern. A light wooden pattern will be readily lifted by the suction of the sand; if there is any danger of the pattern not lifting, a spike is driven into each flange, and these are held by a boy, whilst the top part is being lifted off. On turning the box over, the spikes are drawn downwards. A metal pattern, evidently, will not lift with the top part. Such patterns are therefore drilled and tapped, usually $\frac{3}{8}$-inch thread, and a screw is inserted having an eye projecting through the top part. After ramming, an iron rod is passed through the eye and wedged on the sides of the box, as shown in fig. 72. This device ensures lifting the pattern with the sand; but it may be noted that, after lifting off and turning the box over, the screw will not prevent a side thrust on the sand. Hence, if the pattern is heavy, it must be held by hand during the time of turning the top part over.

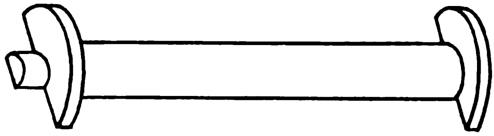

FIG. 71.—Half Pipe Pattern.

Turning to the pipe again, after lifting off the top part, and turning it over, the two half moulds are ready for finishing, that is, the two half patterns are drawn out, gate cut, and any damaged part of the mould mended by tools. Before drawing the pattern from the top half, the sand round both flanges is "sprigged." Sprigs vary from 3 to 6 inches in length, according to the depth of the flange, and are pressed in, as shown at fig. 73, with the object of holding the sand in position after removing the pattern. These sprigs are pressed in about ½-inch from the flange, but at an angle to it. The projecting boss shown on the pattern, fig. 71, is termed the core print; and reference to fig. 73 will show that by placing the core in these prints, a space will be left between it and the mould, as shown by dotted lines. This core is placed in the bottom half, and the top part closed over it. When closing a top part of this character, namely, one from which a pattern has been drawn, it is advisable to turn it over away from the bottom part and note if any sand falls away. Should such be the case, the top part can be turned back again and mended. If turned directly over the bottom part, any sand falling will enter the mould; hence, in addition to patching the top part, the bottom will also require cleaning.

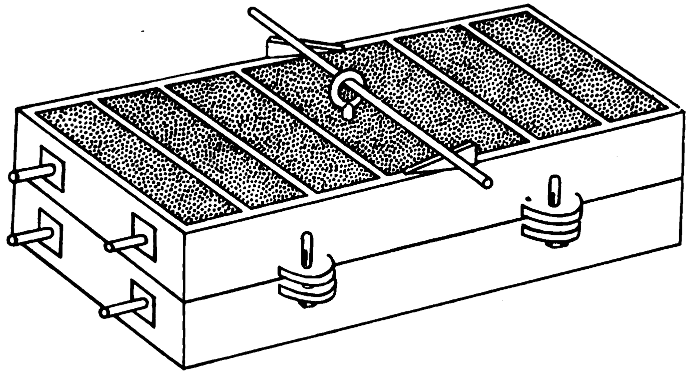

Fig. 72.—Lifting Pattern in Top Part.

Evidently, then, by splitting the pipe pattern, as in fig. 71, its moulding is simplified into, practically, that of a flat object. However, as an illustration, we will assume that the pattern is solid, as in fig. 74. Here a flat turning board cannot possibly be used, and, for turning over, an "odd side" or false top part is required. The top part of the box to be used is laid on the floor, filled and trodden in with floor sand. After strickling off, a rough outline, corresponding to the pattern, is cut out, and the latter sunk to half its depth. The pattern is bedded by tucking in sand under any portions which spring, until the whole lies solid. The bottom part is placed on, rammed-up, the two parts cramped or cottered, and turned over on to a level bed. The top part is lifted off and knocked out. The pattern is jointed down to its centre, which

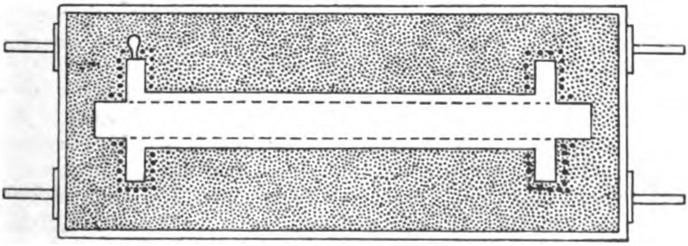

Fig. 73.—Half Pipe Mould.

must be faithfully followed; for if the joint is cut below the centre, the sand of the top part will not lift; on the other hand, if the joint is cut above the centre, the pattern will not give a clean draw, but will start the edges of the joint. Having made the joint, examination will show that the body of the pipe will readily lift, but such conditions will not hold in the case of the flanges which are comparatively square, that is, in the direction of their thickness they possess no taper. Two holes are burnt in the top of each flange, in order to take a ½-inch rapping bar drawn to a point where it enters the holes. The top part is placed on, and over each hole in the flange a small runner peg is placed. A layer of sand, approximately 1 inch in depth, is sieved over the joint in this layer, and, following the contour of the pattern, lifters are bedded. Before bedding, the lifters are dipped in clay-wash, and the top of each lifter given a bearing on one of the cross-bars of the top part. The latter is then rammed up, and the runner peg and the two pegs on the flanges withdrawn. Through the latter a rapping bar is passed into the hole of the flange, and the bar rapped equally in the direction of the length of the pipe; *i.e.* the untapered sides of the flange. This treatment is applied to the other flange, and the two holes may then be filled up with sand, packing by means of the fingers, or left open to serve as risers. The top part must be lifted absolutely level until it clears the flanges, and, if the foregoing details have been followed, a fairly clean lift will result. Any damaged places are mended up, and for the flanges a strip of wood may be used as a guide. In working from a solid pattern, it will be seen that the "odd side" replaces a flat turning board. As another example of moulding the same pipe, we will assume that no bottom part is available, and that only a top part can be procured in which to make the mould. For this example it is immaterial whether the pattern is solid, as in fig. 74, or split, as in fig. 71 [1]; in either case, the method of moulding is the same. A trench is dug in the floor, and filled in with riddled sand, over which a layer of facing sand is sieved. The pattern is laid on and pressed down until level with the floor line. Should the flanges be deep, sand in their vicinity is scraped away by the hand, and the pattern then bedded solid by laying a block of wood on it and tapping it down. When approximately solid and level, the pattern is weighted and sand tucked round and under by the fingers. The pegging rammer is then used until the sand is compact to the joint line. A joint is made as usual, and top part placed on. After ramming the top, and before lifting off, it is staked at the four corners, these stakes taking the place of pins, and serving as a guide on returning the top. The stake may be an iron bar, a flat file, or a piece of wood; but, in any case, it is driven into the joint parallel with and bearing on the sides of the top part. Two such stakes at each corner serve as efficient guides on returning the top. The only other feature calling for note is

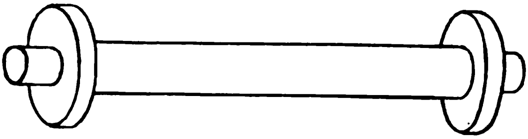

FIG. 74.—Solid Pipe.

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[1] It may be noted that when pipe patterns are solid the flanges are usually split so as to lift with the top part. The example of a solid pipe with fixed flanges is given for purposes of illustration.

that before drawing the pattern from the bottom part, which in this case is the foundry floor, being a "bedded-in" job, it should be vented from the joint by means of a channel scraped round the pattern, and the vent wire pierced under but not catching the pattern, as in the case of fig. 69, noted in Chapter X.

Pipes, such as those shown in fig. 74, are, for various reasons, often required to be cast on end. If a pattern, such as is represented in fig. 71 or in fig. 74, has to be used, and the mould made in green sand, then the method followed is that described in the first or second example, with the exception that the runner is cut so as to drop the metal between the core and the body of the pipe. Instead of turning the bottom half on to a sand bed, it is turned over on a board; after finishing and coring the mould, the top half is closed on and a board bedded on it. The two boards are then either cramped together or fastened by binding screws, and the complete mould turned on end, with the pipe in a vertical position.

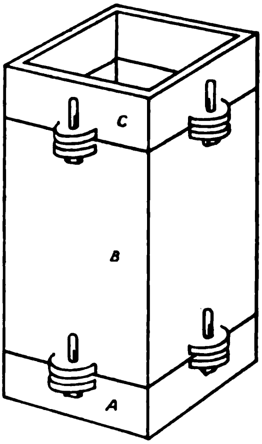

Fig. 75.—Moulding Pipe on End.

However, a slight alteration of the pattern will permit of it being moulded directly in the vertical position. Thus, if the two flanges are loose, so as to permit of their removal in a vertical direction, the pipe may be moulded in a square box by having a joint at each flange. Thus, using a box of the type shown in fig. 75, the method is somewhat as follows:—The bottom flange of the pipe is laid on a flat board, and the box part A placed over it, joint side down. This part is rammed up, turned over, and jointed. The body of the pipe is fitted into the flange, and the box part B fitted on to the part A, and then rammed in courses until level with the top of the pipe. The top flange is then fitted on to the pipe, sand tucked under and round it, and a joint made level with the top of the flange. The box part C is fitted on and rammed. For convenience in centring the core, the print should be carried through this part, and, if not long enough for this purpose, may be cut through later. A wedge-shaped gate is rammed up with this part; the point of the wedge butts against the print, and is so fixed as to deliver a stream of metal directly down the pipe. On lifting off C, the core print is cut through, which destroys part of the gate. The top flange is drawn and then the body of the pipe. The box part B is then lifted off and the bottom flange drawn. The three parts of the mould are finished ready for closing, the part B returned, and the core lowered down into the print in A. It is at once apparent that the core may be fixed in this print before returning the part B. By following this plan the core is easier to centre, and the part B is then lowered over the core. Further, if desired, an intermediate joint may be made by having B in two portions. In such a case the joint is not parted until the pattern is drawn. This further division of the mould offers greater facilities in finishing and in centring the core. The core in position, and the mould closed up to the joint of the top flange, the part C is then fitted on. As the core print of this part has been carried through, it is evident that the core can be guided into its print as the box is being lowered on. Thus, a boy by means of a spike in the vent of the core can move it in the direction required as the box is lowered down. It will be remembered that part of the gate has been destroyed in cutting the print through. The wedge gate is therefore returned to its position, the spike left in the vent of the core, and both gate and print made good by packing sand with the fingers. Before removing the gate a small head is formed, and on removing the pin care is taken to see that no loose sand falls into the mould. On removing the spike which had been inserted in the vent of the core, a passage is left connecting the vent with the atmosphere, and offering a route for the escape of the core gases.

From the foregoing it is evident that any one pattern can be moulded in various styles, and the particular method adopted should, of course, be that most suitable to the appliances at hand. It will be specially noted that three methods, rolling over, bedding in, and casting on end, have been introduced. The last one gives an example of the use of a mid part, and a little imagination will show that by the aid of two or more joints very complicated patterns can be moulded in boxes.

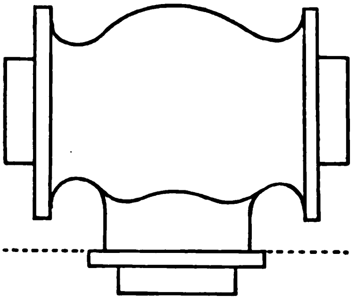
Fig. 76.—Valve Body.

In many cases the floor may be made to serve the purpose of a bottom part in a two-jointed mould, and, as an example, we may take the case of a valve body, the core of which is in two portions, thus necessitating the mould being made in the position shown at fig. 76. Such a pattern would be made in three portions, divided in the centre, and with the bottom flange loose. This flange is bedded in the floor and jointed, and the bottom half of the pattern fixed on the flange. In these patterns the distance between the lower side of the body and the flange is comparatively narrow; hence the sand filling this space must be strengthened, which may be effected by lifters, or, preferably, by wedging in cross-bars. The bottom part, which really serves the purpose of a mid part, is "staked," and the further details of moulding are practically those already indicated. Another method of moulding is found in turning over. Thus, the bottom half of the pattern is laid on a board and rammed up to the flange joint, the flange is bedded on, and the sides of the box rammed. A fairly steep joint is made down to the flange, as in fig. 77. In order to make the parting sand adhere on a steep joint of this character, it is first damped and then smoothed round the joint. If thrown on dry it would all roll to the bottom; hence, when parting, the two surfaces would stick together or "clag." In place of damp parting sand, strips of paper may be laid on the joint, and will effectually isolate the two surfaces. After making the joint, sand is rammed over the flange, level with the rest of the box. A board is then bedded on and the whole turned over. Further details are

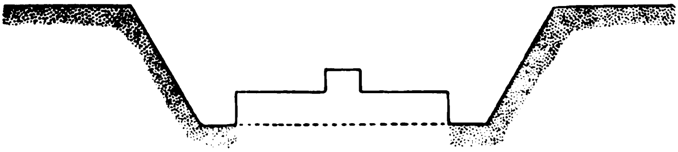
Fig. 77.—Mould Joint.

familiar. It may, however, be noted that the steep joint serves as a guide when returning the mid part.

The joint shown in fig. 77 is the first one introduced which is not of a flat character. It is, however, obvious that the contour of many patterns is such as to demand very irregular partings. Turning again to fig. 77 it will be noted that the joint before tapering off is carried for a short distance level with the flange. Supposing it had been jointed straight down to the flange, then, on turning over, and after removal of the midpart and flange pattern, a feather edge of sand would be left, as shown in fig. 78. A thin body of sand of this character is exceedingly liable to crush; hence the reason for making the joint as shown in fig. 77. Further illustrations are shown in figs. 79 and 80. A semicircular pattern, such as 79, should be jointed as shown at A; the joint shown at B does not give room for lifters, and the thin body of sand will not lift well, hence necessitating patching. Lifters can be readily placed along the joint A, and every particle of sand will come with the top part. Fig. 80 shows a joint which, for a short distance, continues the lines of the pattern; this type of joint will not only lift well, but also give a casting with clean edges, and quite free from "fins."[1]

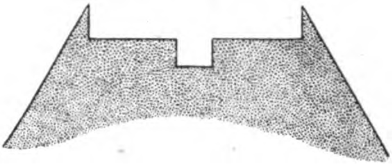

FIG. 78.—Mould Joint.

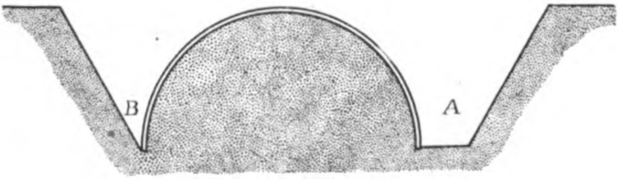

FIG. 79.—Mould Joint.

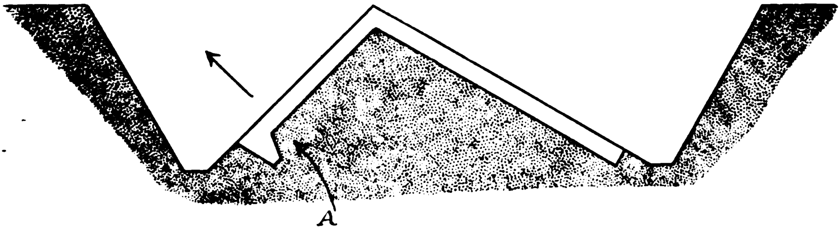

FIG. 80.—Mould Joint.

In drawing patterns from the mould, an absolutely vertical lift is usually necessary. However, this does not apply in all cases. For example, the part shown in fig. 80, drawn vertically, would bring with it the whole of the sand undercutting at A, thus entirely spoiling the mould. If drawn in the direction of the arrow, a clean parting of mould from sand results.

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[1] When two joints are strained by the fluid metal, or when they are not in perfect contact, a fin of metal results along the edges of the casting.

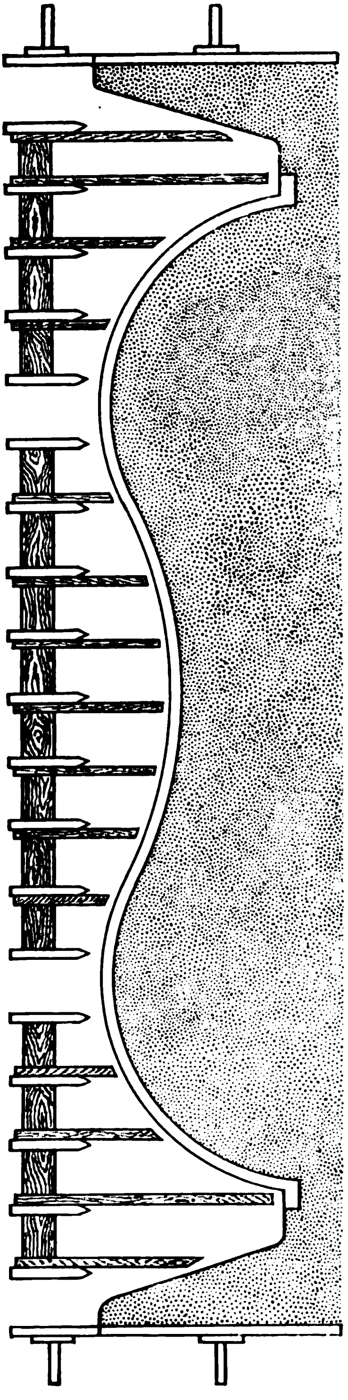

FIG. 81.—Mould for Range.

When speaking of moulding-boxes, Chapter VI., it was shown that in the case of special or repeat castings the cross-bars in the top part are arranged to follow the contour of the pattern, thus dispensing with lifters. But there are many cases in which a flat top part must be used, and such cases involve the exercise of much ingenuity in securing good lifts. In every case in which a deep lift has to be obtained from a flat top part, it must be remembered that the cross-bars carry the weight of the sand, and therefore any artificial support given to the sand must in turn have a direct bearing on these bars. Thus, all lifters must hang from the bars, if their purpose is to be efficiently served. Not only so, but the side of the lifter should bear directly against the side of the bar. Lifters are of various forms, and are made either of cast- or of wrought-iron. They help to deepen the top part, as in the case of fig. 79, along the joint A. In place of lifters, "chocks" may be used. These are simply pieces of wood cut to size, and wedged in between the cross-bars. By this plan very deep lifts may be obtained, and, the wooden chocks being wedged in position, there is no danger of a side slip when turning the top part over. An example of chocking may be taken from an old-fashioned range made in a box having a flat top part, as in fig. 81. After jointing, the chocks are wedged in, as shown, and follow the contour of the joint and pattern.

With certain deep lifts, pans for instance, a grating may be used. Such a grating is made on the open sand bed, and, if necessary, iron rods are cast in, as in the case of a core grid. Eyes or nuts for lifting are also cast in, and by means of these the grating is hung or bolted to the top part. Naturally, a selection of lifters, chocks, or gratings will permit of practically any top part being lifted clean, and the choice will be determined by the most suitable appliances at hand. A kindred subject to lifting is that of strengthening isolated pieces of sand. Such protection is comprised in the use of sprigs and rods of iron which rely for their support on a sand backing. One example of sprigging has been given in fig. 73, the object in this case being to strengthen the joint. The use of sprigs in holding projecting bodies of sand is found in the teeth of spur wheels, and, according to the size, two or more sprigs are bedded in during the ramming. It may be well to note that ramming on the teeth of such wheels is a delicate operation. If too soft, the teeth will swell, and the wheel be useless. On the other hand, if too hard, the chances are that in drawing out the pattern the sand in the teeth will be started, if not actually drawn up with the pattern. Hence the practice is either to press sand into the teeth with the fingers, bedding in sprigs during the process, or to throw sand into the teeth. In the latter case, a handful of sand is thrown, the distance and sharpness of the throw depending on the size of the teeth. Either method is good, but the authors prefer to press in the sand by the fingers, for, in this case, the sense of "touch" guides the moulder, and on the whole ensures more reliable work. When the projecting body of sand is too long to receive adequate support from sprigs, then rods of iron are cut to the desired length and bedded in as the ramming progresses.

CHAPTER XII.

GREEN SAND MOULDING—*continued.*

LOOSE PIECES AND SUBDIVISION OF PATTERNS—FALSE CORES AND DRAWBACKS—MOULDING IN THREE PART BOXES—COKE BEDS—ADDITIONS TO TOP PARTS—STOPPING OFF OR EXTENDING PATTERNS.

UP to the present only the more familiar aspects of moulding have been considered, but essential principles have been introduced, and it has been shown that a given pattern may be moulded by different methods. Thus, in the case of the pipe, the methods applicable were (*a*) turning over, (*b*) bedding in, and (*c*) moulding in a vertical position by means of loose flanges on the pattern and mid parts in the moulding-box. Whilst the majority of patterns have to be drawn vertically from the mould, it has been shown, in the case of fig. 80, that a draw at an inclination to the vertical becomes necessary in order to avoid tearing the sand. This practice is applicable to a large variety of patterns, but it has its limitations. In machine-tool castings, recesses, bosses, and the like are often required, and these may be so situated as to fall below the joint line of a pattern, which, of necessity, has to be drawn vertically from the sand. These requirements involve the provision of core prints carried up to the joint line of the pattern or the attachment of "loose pieces," which, in effect, serve the same purpose as the loose pieces in a core box. The most familiar examples of extended core prints are found in the case of castings requiring small round or square holes in the sides at some distance below the joint. In such cases the bottom part of the print serves as a seat for the core, which, when in position, follows the dotted lines of fig. 82. The upper part of the print is filled in with sand; for this purpose a stopping-off strip, fig. 82, is placed over the core, and held against the sides of the mould. The core may be made to fill its own print, as in fig. 83. Here a recess is required along the side of a casting, and, in order to give a flat joint, the core print is carried to the top of the pattern. On inserting a core, of the section shown, into this print, the recess is formed, and the side of the core also corresponds to the side of the casting.

The core print of fig. 82, instead of being carried to the joint, may be worked as a loose piece. Thus, on ramming up the pattern, immediately a solid bearing of sand has been obtained under the print, the screw holding it in position is removed and the ramming continued. It therefore follows that the print, being loose, remains in position on withdrawing the pattern, and may be removed by drawing directly into the mould. This assumes that the mould is of sufficient width to draw the print and insert the core. In practice, loose prints are only used on patterns leaving sufficient working space for the foregoing operations, and extended prints are used on patterns of narrow cross-section, as, for example, flanges. Fig. 84 shows a type of recess common to slide castings, which obviously, owing to the taper, is such as to prevent a clean parting of solid pattern from sand. The pattern is, therefore, made in three pieces, and the loose pieces are temporarily held in position by wire pins, as shown. The inside is rammed with the strips held in position by means of the pins, the latter are then withdrawn from the outer edge of the pattern, and the ramming completed. The mould is turned over and carried to the stage of withdrawing the main part of the pattern. This will leave the two strips remaining in the sand; but the space provided by the removal of the pattern will permit of the strips being drawn sideways until they safely clear the overhanging sand.

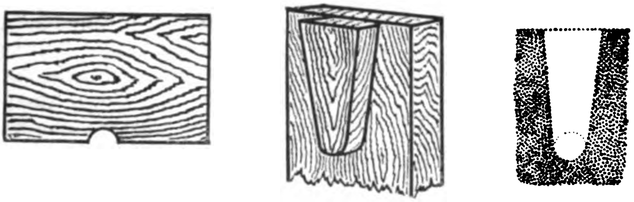

FIG. 82.—Extended Print.

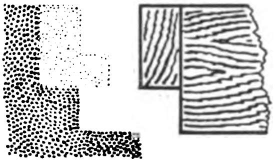

FIG. 83.—Extended Print.

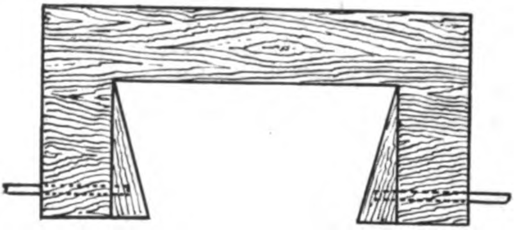

FIG. 84.—Method of Moulding.

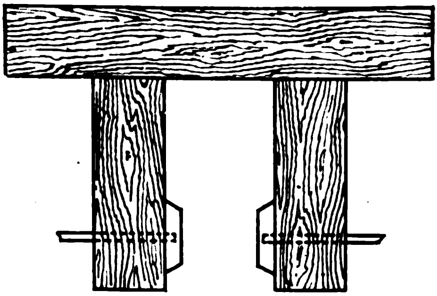

FIG. 85.—Method of Moulding.

Projecting bosses are similarly moulded by means of loose pieces, as in fig. 85. These two examples sufficiently illustrate the applicability of loose pieces as a means of withdrawing projecting parts of a pattern which do not fall on a joint line. When ramming up any pattern filled with loose pieces, care must be taken to see that each piece is maintained in its proper position. Further, all pins or holding screws must be withdrawn as the ramming proceeds, otherwise, when drawing the pattern, the loose piece will belie its name and the mould be spoilt.

In certain cases loose pieces may be avoided by substituting a dry sand core. Thus, if a core print is fixed on to fig. 84 the pattern will, in section, take the form shown in fig. 86. This renders moulding comparatively simple, and the recess is formed by fitting the core into the print. Similarly, fig. 85 may be moulded in the way shown in fig. 87. The substitution of a dry sand core for what, in reality, is a green sand one, may increase pattern-making costs so far as a core box is concerned, but to some extent it simplifies moulding and lessens the risk of waster castings.

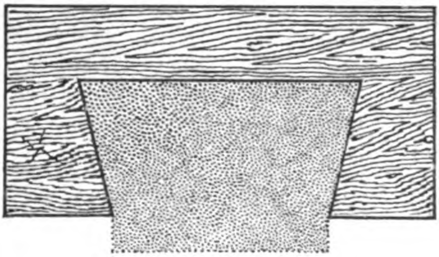

FIG. 86.—Method of Moulding.

Quite apart from the attachment of fitting strips, bosses, etc., as loose pieces, in certain cases it may become necessary to subdivide a whole pattern into many distinct portions. For example, a fluted column, the half pattern of which is shown in fig. 88, is divided into six portions, dovetailing one into the other, in order to facilitate moulding. The column is moulded with one joint across the centre, and after drawing the central part of each half pattern, two side pieces remain in each half mould. These are removed in a direction suitable to the contour of the fluting. This method of division is largely applicable to such work as ornamental columns, gas or electric lamp standards, and palisading. In every case where the character of the ornament is of such a nature as to prevent a vertical draw, that portion of the pattern is dovetailed on to the main body in such a manner as to remain behind on drawing the first part of the pattern. In place of dovetails, the segments of a circular, hexagonal, octagonal, or like form of column may be screwed together. In this case the screw heads must come to the inside of the

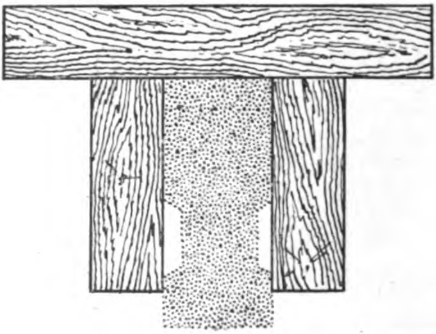

FIG. 87.—Method of Moulding.

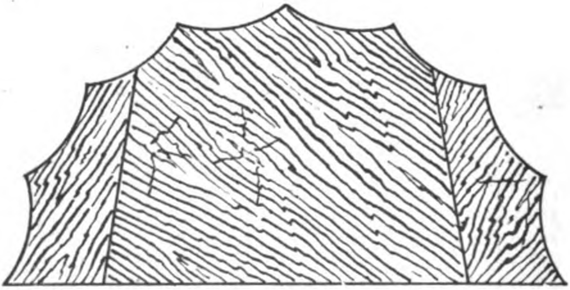

FIG. 88.—Fluted Column.

pattern in order to permit of loosening after the halves of the pattern have been separated. This is after the top part of the moulding-box has been lifted off and before the patterns are drawn. Some patterns met with in engineering work have to be practically taken to pieces before they can be removed from the mould. Hence it is of importance that all holding screws should be accessible to the moulder from the position in which the mould is parted or jointed.

False Cores and Drawbacks.—In certain cases the pattern may be solid, not fitted with core prints, and yet have projecting portions on the side faces below the joint line. In order to draw such a pattern, some portion of the mould must be removed horizontally from the pattern in order to admit of its free removal. In light work these removable parts of a mould are termed "false cores," and in heavy work "drawbacks." Examples of false coring are often met with in iron and brass ornamental work, and intricate details below the joint line of the pattern are successfully reproduced by these means. Thus, in the case of flowers or beading on the side of a pattern, after making the joint and parting the halves of the moulding-box, sand overlying the flowering is cut away, and a false joint formed, which widens as it leaves the pattern. The whole of the projecting flower is thus exposed, and the joint is made in such a fashion that a core may be formed within it, permitting of lateral movement from the pattern. After making the joint, parting sand is applied as usual, and strips of paper laid on the sides, sieved facing sand is tucked into the pattern and round the joint. A small ball of clay is pressed into the centre of the core, and the core completed by tucking in sand to the level of the mould joint already formed. After making the mould ready for the removal of the pattern, the first step is to cut away the sand and the back of the false core. A core pin is then inserted catching into the clay of the core, the pattern is *lightly* loosened, and the core gently drawn away until clear of the pattern, when it may be lifted up and laid on the joint. The pattern is drawn and the core returned to its former position. The back of the core, which had been cut away, is made good by filling in with sand so that there shall be a solid backing to maintain the core in position when the pressure of the fluid metal comes on it. The purpose of the clay will readily be seen to be that of giving body to the core and providing a material into which a lifting pin may be inserted. Naturally, one casting may require many false cores; but the method thus outlined is, irrespective of the number of cores required, applicable to any small casting.

Obviously, clay can only be employed as a lifting medium for false cores of comparatively small size, and, when depth and width each exceed 2 inches, a more solid stiffening becomes necessary. False cores lifted away by means of supports other than clay are more legitimately known as "drawbacks." These supports may take the form of a piece of coke, a wooden chock, a cast-iron frame, grid or plate, or a piece of sheet-iron. An example of the use of a sheet-iron drawback plate is shown in fig. 89. These plates are cut to the required contour, and bedded on the joint, the upper face being clay-washed. The core is made up on the plate, and the mould carried to the stage of drawing the pattern. The back of the drawback is cut away to allow of its lateral movement. It will be noted that the operations are precisely the same as in the making up of a false core, except that the central ball of clay in the latter is replaced by a foundation plate of sheet-iron to carry the sand of the drawback. Exceeding 8 inches in length, sheet-iron becomes too springy for use as a drawback plate, and it is replaced by plates of cast-iron. These plates are made to the required size on the open sand bed, suitable lifting eyes and strengthening rods being cast in.

Fig. 89 represents one of the smallest drawbacks. It is manipulated entirely by means of the fingers, and removed from and into position by means of the sheet-iron plate. Fig. 90 shows another type of drawback which practically forms a complete side of the mould, and is treated as though it were a box part and handled by means of a crane. The particular casting is a gun-port door cast in gun-metal, but the actual casting is of less moment than the features introduced in making the mould which are applicable to various types of castings. The pattern is bedded in the floor and jointed, as shown, the horizontal portion being levelled by the aid of a spirit level, and the inclined portion formed in a small pit about 4 feet deep by 6 feet wide. The joints down the side of this pit follow the inclination of the pattern, which is such that the lowest part projects some 6 inches beyond the highest part. Obviously, a flat drawback plate would not carry such a depth of overhanging sand; hence, two rows of strengthening rods are cast in, the back row being perpendicular and the front row inclined from the perpendicular to follow the joint of the pattern. Fig. 91 shows the arrangement of these rods and the two lifting eyes for attaching the plate to the slings of a crane. Two snugs are also shown at the back of the plate, each one being cored out. This drawback, when completed, will form a fairly heavy mass of sand and metal; therefore, in order to ensure that it shall not sink, the bottom joint of the pit must be very firmly rammed. As a further precaution, two flat weights are bedded in with their upper faces level with the joint, thus giving a secure and unyielding support to the drawback plate. It has already been noted that dry parting sand does not readily adhere on

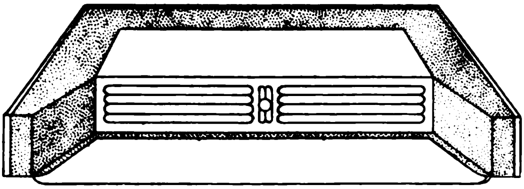

FIG. 89.—Small Type of Drawback.

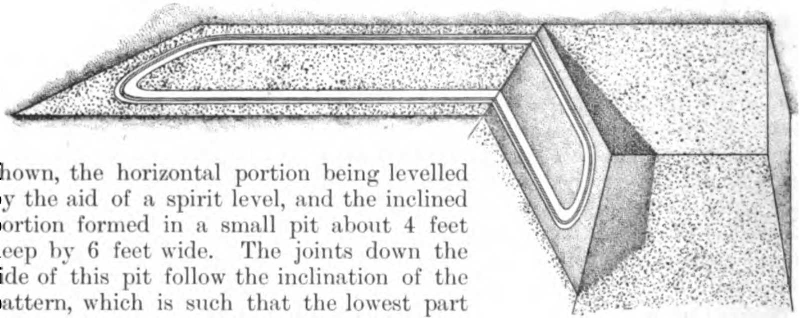

FIG. 90.—Large Type of Drawback.

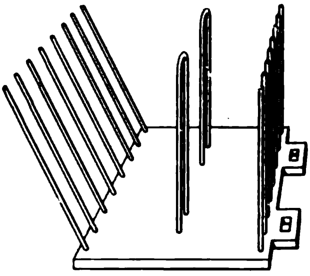

FIG. 91.—Drawback Plate.

a sloping joint; hence the joints of the side of the pit are "papered," the paper being held in position by small tacks pressed into the joint. The drawback plate is clay-washed, placed in position, and rammed up as though it were a loose part. Here two features require notice. The strengthening rods should show no tendency to spring; but if they do, they may be tied together by wire and wedged by jamming small chocks of wood between each bar. Frequently such a pattern has a recess which, to obtain a good parting, will require nailing, that is, sprigs are bedded in the recess as the ramming proceeds upwards. To give a solid backing for ramming, boards are wedged against the sides and back of the drawback. Ramming in courses is continued until the horizontal joint is reached, and the top of the drawback is levelled off to form a continuous and level joint. A top part covering the exposed part of the pattern and the top of the drawback is then laid in position, runner pegs inserted, lifters, if required, and the whole rammed up. Before removing the top part, it is staked, in order to give guides for its return. After removing the top part the pit is cleared, and the plate is staked by driving in iron bars at each end, which serve as guides for the lower portion of the drawback, and V-grooves are cut at its junction with the flat joint. These serve as guides for the upper part of the drawback. The sand overlying the lifting eyes is cut out, and the crane brought into position for lifting. However, before removing the drawback, two points have to be considered: (1) if the aforementioned recess is present, this will prevent a vertical lift; and (2) the overhanging part of the drawback will throw it out of balance. These involve that the drawback shall not be lifted vertically until it has been removed sufficiently far in a horizontal direction to clear the recess. In order to balance the drawback, the toe of a cramp is passed through the hole in each snug, two bars are laid across these cramps and a weight placed on them. A trial by just taking the weight of the drawback in the crane will at once tell how the balance is, and the weight may be moved either in or out as required to effect a perfect balance. This obtained, the full weight of the drawback is taken by the crane, *but no more*, and the whole is drawn forward until the recess is cleared.

The drawback may be then hoisted out of the pit and rested on battens for finishing. The removal of the drawback permits the removal of the pattern, as also the finishing of the bottom part of the mould. When the mould is ready for closing, the drawback is returned in a similar manner to that followed for effecting its removal, that is, it is lowered vertically downwards at some distance from the lower part of the mould and returned to its position in a horizontal direction. The two stakes at the bottom and the notches at the top act as guides in returning the drawback. Evidently, when casting this mould, there will be considerable pressure at the bottom of the drawback, and the least possible movement will result in a casting thicker than the pattern. Comparatively little movement will result in a waster casting. It has been shown that in the case of false cores, or small drawbacks, the sand cut away to allow of removal of the core must be made good in order to give a solid backing to the core or drawback. So, in the present case, the drawback must be firmly secured in order to resist movement due to the pressure generated by filling the mould with liquid metal. However, owing to the depth of the drawback and its inclination, the conditions are more severe than in the comparatively simple cases already outlined, and a backing of sand only will be insufficient. Therefore, an iron plate is solidly bedded against the side at the back of the pit, and from this plate the bottom plate of the drawback is securely wedged by means of bars and wedges. A course of sand is compactly rammed over these bars, and a plate then bedded on the drawback corresponding to that at the back of the pit, and the two plates wedged as before. The whole pit is then compactly rammed with sand, level to the top of the drawback. The top part is returned to position, weighted down, and the mould made ready for casting.

The procedure advocated for binding the drawback in position may seem elaborate. As a matter of fact, it takes comparatively little time and avoids a considerable amount of risk. It must be remembered that a drawback on a bedded-in job receives no support from the sides of the bottom part. When a bottom part is employed, a drawback can undoubtedly be maintained in position by a solid backing of sand between the drawback and the side of the box. Where a bottom part is not used, as in the case of a deep drawback, the outward pressure must be resisted by supporting the drawback from a solid and unyielding support. Rammed sand alone is insufficient for this; hence the reason for solidifying the back of the pit by bedding a plate up against it and wedging the drawback from it.

Sufficient has been given to show the applicability of drawbacks; they are used on many forms of engineering castings, and more especially in machine-tool work. For instance, the sides of a mould forming a lathe bed are often made as drawbacks, which provides for any projecting portions and at the same time allows easy access to the mould for finishing. The latter aspect is of some moment, and certain castings of deep and narrow section are often made with drawbacks simply to give access in finishing the mould and fixing cores.

A further aspect of drawbacks is found in substituting them for deep lifts in the top part. Thus fig. 81 may, alternatively, be made by means of two drawbacks instead of the two deep lifts as shown. For drawbacks of this character a long piece of cupola coke, roughly broken to the required form and clay-washed, forms an admirable stiffening support and lifting medium. In other cases, in order to avoid a deep lift, a cast-iron frame or pocket may be used. These frames are usually tapered, and the side coming against the pattern is open. A good example of the use of such a frame is found in fig. 92, representing a rectangular casting with an outlet pipe placed some distance below the joint. If this mould, jointed as shown, were lifted in the top part, owing to the square sides of the pattern a bad lift would inevitably follow. But if that portion of the mould overlying the top half of the outlet pipe is made as a drawback, a clean parting is readily obtained. To effect this the joint is made as shown, and a cast-iron pocket fitted in, with the open side to the pattern. This is rammed and treated as a drawback. As the flange on the pipe is loose and in halves, when the drawback is lifted it may be eased by drawing it slightly away from the pattern. This gives a clean parting, because, as the drawback moves from the pattern, the square sides of the latter do not adversely affect the character of the lift.

Moulding in Three-part Boxes.—The use of a mid part was indicated when describing the moulding of a pipe on end. Where a mid part is employed, a divided pattern is necessarily required. As an example, the two flanges of the pipe were loose and the pattern therefore in three pieces. The most familiar example of three-part moulding is found in sheave wheels or similar castings having the diameter of the rim less at the centre than at the outer edges. These patterns are divided through the centre, as in fig. 93, the halves being dowelled together in order to ensure a true fit. When moulding, the bottom half of the pattern is bedded on an oddside, rammed up, and turned over. The flat joint is made down to the outer edge of the rim of the pattern, the top half of which is then placed in position and weighted down. The mid part to carry the groove of the sheave is clay-washed and placed on the bottom part. As this mid part has to carry a certain amount of sand, and has no central support, it should be free from spring, and its stability may be increased by wedging in four bars parallel with the sides, but as near to the pattern as possible. Sieved sand is tucked into the groove of the pattern, the weights on which prevent the top half from being forced upwards. In the centre of the groove a row of clay-washed sprigs or pieces of nail rod are bedded, receiving support from the bars fixed into the mid part. Tucking is continued until the upper edge of the sheave is reached, and the outer portion of the mid part is rammed and jointed. The arms of the sheave are then jointed and made ready for ramming the top part. After removing the top part, the upper half of the pattern is drawn, which leaves the mid part free for removal. After lifting the mid part, the lower half of the pattern is drawn, the mould finished and closed by returning the mid part and the top part. Sheaves are usually gated by means of a plump gate on the boss at the side of the central core.

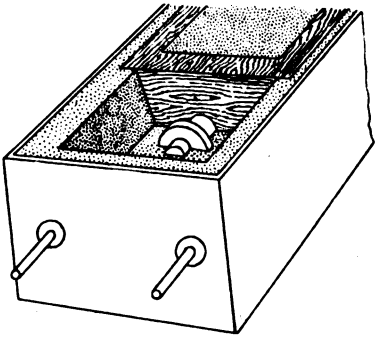
FIG. 92.—Pocket Drawback.

In jobbing foundries, patterns are not always available, and moulds have at times to be made from old castings. Thus, if a mould has to be made from an undivided sheave, it may be moulded in a two-part box, the groove being cored out by a series of drawbacks, each of which forms the segment of a complete core or drawback, or, instead of this, the groove may be filled in by a wooden core print and dry sand cores made in segments to fill the print. This involves making a core box. This method is often applied to legitimate patterns; but as the cores for sheaves of large diameter have necessarily to be made and placed in the mould in segments, the groove is liable to be out of truth, and, at the best, a joint will show at each division of the core. Only comparatively small sheaves may be cored out by means of a complete circular core, and the larger the diameter of the sheave the greater the division into segments.

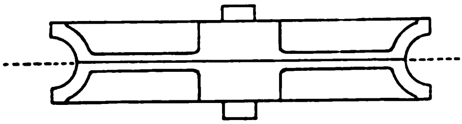
FIG. 93.—Divided Sheave Pattern.

In moulding a sheave by the method first given, the purpose of the mid part is to lift away the sand overlying the bottom half of the pattern, in order to permit of its removal from the mould. If the halves of the pattern can be drawn away from each other, then the necessity for a mid part vanishes. In practice, this is achieved by moulding in a two-part box and regarding each half as a top part for the time being. In other words, by means of a "double turnover," the mid part may be dispensed with. As before, the lower half of the pattern is bedded on an oddside, and the bottom half of a moulding-box placed over it. This part is temporarily converted into a top part by wedging in cross-bars, in order that it will permit of its being lifted directly off the pattern. A runner peg is placed on the boss of the pattern, and the part rammed up and turned over. The joint is carried down to the bottom of the groove, the upper part of the pattern placed in position, and the groove tucked in with sand and stayed by means of sprigs. The second joint is carried to the box edge, and the arms of the sheave jointed and made ready for the top part. This part is rammed without a gate peg, lifted off, turned over, and finished. The upper part of the pattern is drawn, and the exposed parts of the mould finished. The top part is then returned, the two boxes cramped together and turned over, thus bringing the part with the gate uppermost. The gate is cleared from the loose sand, and this part lifted off, thus giving access to the remaining half of the pattern. This half is then drawn, care being taken to prevent any loose sand falling into the lower part of the mould, the latter finished and closed ready for casting.

This method, known as a double turnover, or a tumbling core, is applicable to many split patterns in which the outside diameter is smallest in the middle. A limitation is only found when the weight of the half pattern is such as to crush the sand when turning over for the second time. This at once negatives the use of heavy metal patterns, but comparatively large wooden patterns may be used in this manner. The halves of the box being in perfect contact when being turned over, the core forming the groove cannot move, and it is thus maintained in its true position.

Other methods of eliminating the mid part, or at any rate lessening the labour connected with it, are worth noting. Fig. 95 represents a type of small castings often met with; in dividing the pattern, the upper part and stem should be in one piece. The lower part is jointed level with the joint of the bottom part of the box, the bulk of the pattern thus coming into the top part. Sand is then tucked in between the two parts, and a second joint formed, as shown in fig. 95. The top part is rammed and lifted off, leaving the whole of the pattern in the bottom part. The upper part and stem are drawn, taking care not to disturb the sand core. The joint of this core is then clay-washed, and the top part returned and lightly pressed. On again lifting the top part, the whole of the core will come with it, thus allowing for the removal of the bottom part of the pattern. This particular method is only applicable to comparatively light iron or brass castings, but it is largely followed in moulding ornamental fruit dishes, stands, card and ash trays, and similar articles.

Fig. 96 shows a type of pattern which, if moulded with the small flange uppermost, may have a comparatively small top part, the mid part in reality becoming the top part. Such a pattern would ordinarily be moulded in a two-part box, the upper part taking the whole of the upper portion of the pattern, and being of such a depth as to reach the top of the small flange. This flange is jointed and covered by a small box some two or three inches larger than the flange. This box practically takes the place of a removable core, and, although it does not avoid having a joint, it does save a certain amount of ramming. Before removing it, marks are made to serve as guides for its return, or whitening may be shaken on the four corners, which will serve the same purpose.

After removing the loose flange, the remainder of the pattern should be lifted with the top part, as, owing to the straight boss, a good lift from the pattern would be sufficient. On turning this part over, the pattern is readily drawn from it. When closing the mould for casting, the lower boxes are cramped together, and the small top part must be weighted down with loose weights or cramped by passing two bars over it and cramping from the ends of these bars on to the main box.

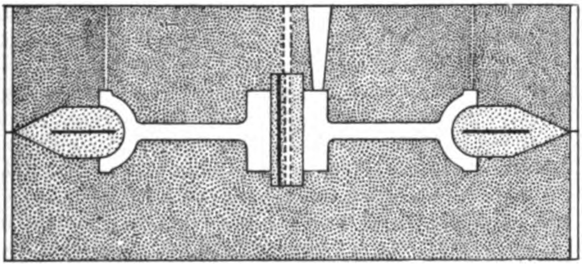

FIG. 94.—Sheave Mould.

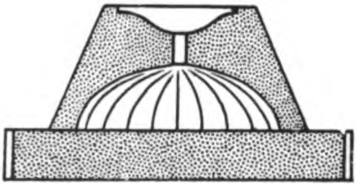

FIG. 95.—Two-joint Casting in Two-joint Box.

Assuming that fig. 96 is moulded with the small flange down, then a bottom part deeper than the pattern and a shallow top part are required. After bedding the pattern on the top part as an oddside, the bottom part is rammed up until level with the small flange, around which a joint is made. Two flat pieces of dry sand core or loam cake are then fitted to cover the flange and have a good bearing on the sand joint. Each of these cores must be recessed to take half the core print; and when the two are in position, they should exactly fit the print. After fitting the cores, the flange is drawn, leaving the print in position. The covering cores are returned, care being exercised to avoid the entrance of loose sand into the flange. Ramming is continued over the cores until the bottom part is ready for turning over; the further treatment is the same as that of a single-jointed casting. Other examples of covering cores, so as to avoid mid parts, are afforded by patterns having L or T-shaped brackets. As a simple

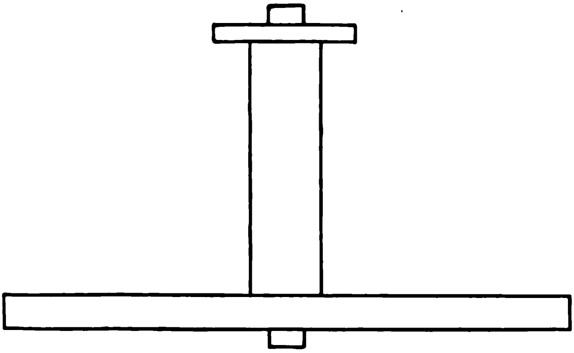

FIG. 96.—Small Covering Top Part.

case, a bracket on a flat plate is selected, and an examination of fig. 97 will show the method of moulding. It may be noted that the sand pocket forming the bracket will require stiffening with nail rod. The covering core is applied precisely as in the former case, that is, the flat part of the bracket is drawn when ramming up the bottom part, and covered with a core, ramming completed and the part turned over. It will also be remembered that covering cores were used in the case of moulding a box part to form the snugs.

In examining figs. 95 and 96, the thought will naturally suggest itself—why not divide the patterns along the length of the stem or the boss, and mould them as single-jointed patterns? This, of course, could be readily done with fig. 95, assuming the lower face to be plain; but, as noted, the method given is chiefly applied to ornamental work which demands a vertical draw. Castings of the type shown in fig. 96 often have ribs connecting the lower plate with the boss, and, further, the plate itself may have to be cored. in several places.

Coke Beds.—Some reference to the practice of bedding-in has been made, and it has been stated that such a job is vented from the joint. However, when the size of the pattern is too large for effective venting from the joint, recourse must be had to a coke bed. To some extent this is simply an extension of the ash vent of a core, and the object is to provide a porous bed some distance below the mould into which the mould gases may be drawn. Vent pipes leading from several points of the bed into the atmosphere offer a means of igniting these gases, thereby drawing them from the bed under the mould. Fig. 98 gives a section through a coke bed, showing vent pipes at each end. In making the bed, a trench is dug out some 16 or 20 inches deeper than the pattern. The bottom of this trench must be rammed hard with the flat rammer, in fact, it cannot be too solid. Over this a layer of roughly broken coke is spread to a depth of 6 inches, and the flat rammer passed over it. This is then roughly levelled off with smaller pieces of coke, and the vent pipes (ordinary wrought-iron tubing of 2 inches internal diameter) inserted in such a position that they will readily clear the top part and yet draw the gases from the coke bed. On the smaller coke a thin layer of straw is spread, and the bed is then ready for ramming with sand. This is effected in courses, the lower ones being compactly rammed so as to give a resisting backing of sand to meet the pressure of casting. It may be here noted that a covered bed will admit of harder ramming than an open one; and in a way this is fortunate, since liquid pressure is greater with a covered mould than would be the case if the mould were open. The actual depth of sand over the coke bed varies according to the contour of the pattern, but is usually such as to leave about 12 inches between the straw covering

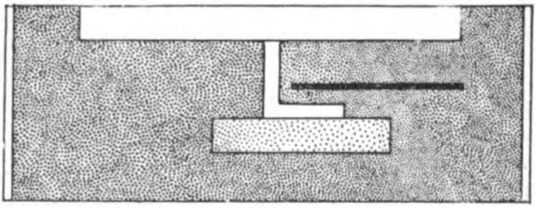

FIG. 97.—Use of Covering Core on Bracket.

and the lowest portion of the pattern. When a depth of 9 inches has been reached, straight edges are bedded in, levelled, and set to give the requisite depth of sand. Sand is rammed along the edges of these strips to maintain them in position, and ramming is continued between them until a height of about half an inch from the top has been reached. The whole surface of the bed is then pierced with $\frac{1}{4}$-inch vent wire, each vent reaching well into the coke bed. This venting must be thorough, because the sand has been rammed comparatively hard, and thereby rendered more or less impervious, and must therefore be artificially opened by the vent wire. After venting, a layer of facing sand is spread over the surface of the bed and solidified by as light a ramming as the weight of the casting will admit. When strickled off level with the straight edges, the bed is ready for setting the pattern in position.

Instead of venting in the way described, ramming may be carried up to the top of the straight edges, the bed strickled off and then vented. Each vent is carefully closed by means of the fingers, a light layer of sand thrown on again and strickled. The object in both cases is to close up the head of the vent so as to prevent the entrance of metal into it. Just as in venting a turned-over job the vent wire should not jab into the pattern, so, here, each vent should serve as a channel for the escape of gases. It cannot be too strongly asserted that this purpose is most effectually destroyed the moment any fluid metal enters the vent. Hence, the ideal is to have a series of passages, separated by a thin stratum of sand from the fluid metal, leading down to the porous coke bed in which the gases may be collected and drawn off by means of the vent pipe. To prevent loose sand falling down these pipes and thereby choking the bottom, their tops are loosely plugged with tow or shavings, which, on casting, may be ignited by a red-hot skimmer, and serve in turn to light the escaping gases.

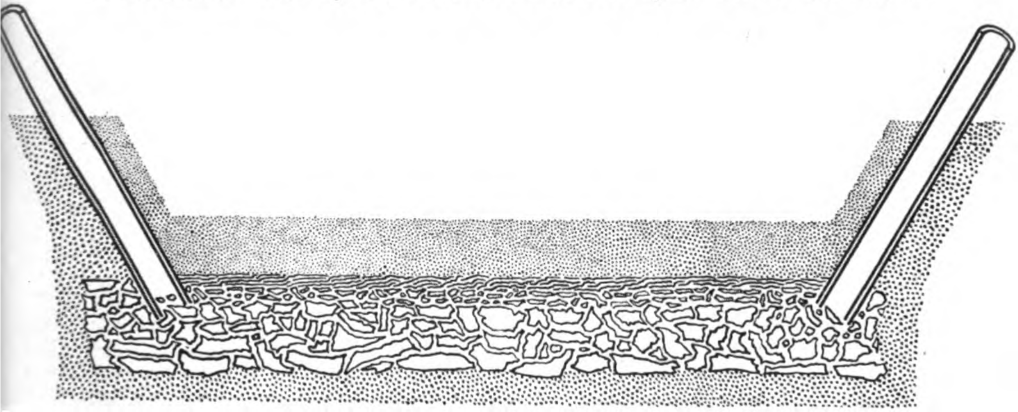

FIG. 98.—Coke Bed.

Whilst the coke bed provides a most effective means of venting the lower surface of the mould, it does not directly affect the sides, and these, if of any depth, are usually vented by sending the vent wire parallel with the pattern at a distance from it of an inch or thereabouts. These vents are led off from the joint by means of channels, as illustrated in fig. 69.

One coke bed will serve a series of similar castings but it is false economy to make one bed serve for dissimilar castings; and it is always advisable, on completing an order, to take up the bed, riddle out the whole of the coke, and fill in the pit again.

Naturally, the coke bed must be laid on an unyielding foundation of sand; hence the reason for hard ramming the bottom of the dug-out trench. With very heavy castings and a doubtful floor, it is always safer to bed a heavy loam plate as a foundation on which to lay the coke bed. Such plates also offer facilities in binding the moulds for casting. It is also obvious that a deep pit must not act as a well for the accumulation of water, an important point in foundries situated near the surface water level, since it must be remembered that fluid metal and water never take kindly to each other.

Additions to Top Parts.—In green sand work by means of bedding in, drawbacks, or covering cores, intricate castings can be made irrespective of the boxes available. However, the top surface of these moulds must be covered by means of a top part, and it may be that in one direction or the other the parts available are too short for the length or width of the pattern. Two or more top parts may be employed to cover a bedded-in pattern. In this case the parts butt against each other, if possible; but it may be that lifting handles, snugs, or even fitting strips prevent this. If so, the space between the two boxes may, if the pattern has a flat upper surface, be covered with a flat core after the two boxes are in position, rammed over with sand, and weighted or wedged down from the ends of the boxes. In the event of the pattern not being flat, a drawback is made between the two parts to take the place of the covering core. When the boxes butt together, there will almost certainly be a space of greater or less magnitude through which molten metal would leak, on casting. This space is first of all filled in with tow, pressing it down with a cleaner, but not into the mould. Sand may then be firmly tucked between the boxes, the tow preventing its entrance into the mould. It may be noted that when two or more boxes are used to cover a mould, the junction of the boxes should not give a metal bearing on the pattern. This is readily prevented by raising the joint so that the boxes clear the pattern. Should snugs fall between the junction, they should be arranged to lie over the joint, and not on the pattern. There will necessarily be more or less fin between these junctions, but with care this may be kept within narrow limits. Heavy fins are dangerous, as they retard contraction, and, by binding against the top part, prevent freedom of movement in the casting. This, of course, may be obviated by removing the top parts soon after the solidification of the casting.

Complete moulding-boxes may be temporarily extended by cramping on pockets of wood or cast-iron. For example, in stove-grate moulding the legs of a register front may be carried through the box, and wooden frames of sufficient size to cover this projection cramped on to top and bottom parts. This involves breaking away some portion of the box joint in order to let the pattern come through.

Stopping Off or Extending Patterns.—In work of a non-repeat character alterations to existing patterns are frequently necessary, and these have in many cases to be effected in the sand by the moulder. Taking the simplest aspect of the case, if a 12-inch square plate is wanted, and only a 14-inch square pattern is available, then, after completing the mould, by stopping off 2 inches from two sides the requisite size is obtained. Stopping off simply implies carrying the joint forward to the required extent, and is effected by laying in a straight edge and filling the intervening space with sand to the height of the joint. On the other hand, a 14-inch plate may be required from a 12-inch pattern, and this is effected by laying 2-inch strips on two sides of the pattern. . These strips should have the same thickness as the pattern. In the case of plain work, but of irregular contour, strips of lead are bent to the same form as the pattern, and serve for either extending it or making up strips for stopping off. If a straight edge or bent strip cannot be laid on the face of the mould, as on ornamental surfaces, a thin stopping-off plate, practically a knife edge, is used. This will not disturb or disfigure the details of the ornament.

In many cases a sheet-iron frame may be used to give the outer edges of a pattern, as in fig. 99, which represents the sweep for a fire grate. These grates, when of an irregular size, are made from a large standard grating. On completing the actual moulding of this grate, the position of the sweep is marked, and it is then set back to a distance corresponding with the thickness of metal required on the front edge. The curved part of the sweep is then lightly marked on the cores forming the bars, the ends of which are cut away to these marks. The sweep is then returned to the position marked and sunk down to the bottom of the grating, the cores are cut away parallel with the sides and back to give the requisite thickness, which has been already obtained for the front, and the mould is cleared of loose sand. The outer edges of the sweep are made up to the level of the joint, the sweep drawn, and a gate cut. The top part is tried on with the object of noting if the thickness of the joint is correct, and also of noting the cores which have been cut away. This is facilitated by shaking rosin or whitening on the bottom part before trying on; after lifting off the top part, distinct marks will be shown where contact has been made. Thus, if the joint is correct, its outline will be shown on the top part; if too thick, the bottom part will be crushed; and, if too thin, no outline will show. Where the cores have been removed from the bottom part will also be indicated on the top part, and this portion should be smoothed over so as to take away sand marks on the plain surface of the grate.

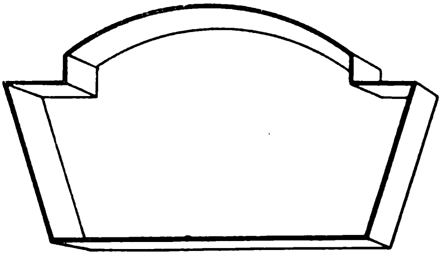

FIG. 99.—Template.

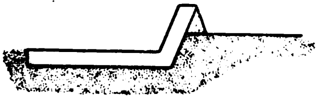

FIG. 100.—Stopping Off a Flange.

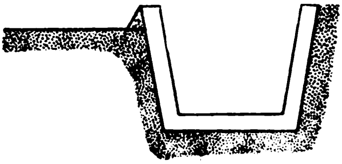

FIG. 101.—Stopping Off One Side of a Casting.

Fig. 100 shows a method of stopping off a part of the flange on a flat casting. In jointing, a strickle is cut so that when slid on the top of the flange a joint is struck giving the height required in the flange. The tapered side of the flange is then filled in, as shown, in order to obtain a good lift. After lifting off the top part, the flat joint serves as a guide for filling in the flange to the required depth. Fig. 101 is another illustration of the same principle applied to stopping off a portion of the side of a casting, as, for instance, the inside of a fender curb, in order to fit over a tile hearth. This is jointed, as before, down to the depth required to be cut off, and the flat joint is used as a guide in filling up the top part.

When bosses, or cylindrical castings moulded on end, have to be cut in the sand, a good plan is to mould the pattern as a three-part job, sinking it in the lowest part to the depth required to be stopped off. This is facilitated by marking the circumference of the pattern and using this mark as a guide for jointing. In fig. 102 the portion of the pattern bedded in sand has to be stopped off; on completing the mould, this is effected by filling in to the level joint there shown. Before filling in, the core should be set in its print. Circular castings moulded on the flat, when required of shorter length than the pattern, need a filling-in piece in order to obtain a new print for the core. These pieces, as in fig. 103, may be either flanged or not, and are made exactly to fit the pipe. When set in position, a new flange and core print are readily formed in both halves of the moulding-box.

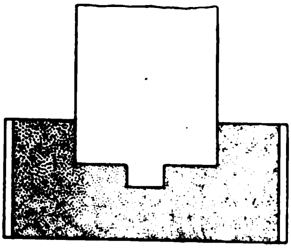

FIG. 102.—Stopping Off Part of Boss.

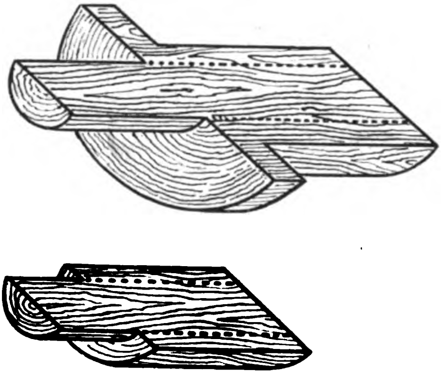

FIG. 103.—Filling-in Pieces.

CHAPTER XIII.

SECURING CORES IN MOULDS.

THE irons and vents in a core, as has been indicated in Chapter IX., give stability in the one case and in the other act as a channel for the escape of the gases contained in the core. It will also be remembered that when discussing moulding sands in Chapter III. it was stated that molten metal would not remain in an impervious mould, because the gases would find a path to freedom by ejecting the metal through any available outlet, as, for instance, through runner or riser. It has also been shown that the gases generated in a mould on casting must be drawn through the sand, and that the natural porosity of the sand must, in certain cases, be intensified by artificial venting. Such conditions also hold good for cores, *i.e.* the porosity of the sand must be further increased by vents or channels to draw away the gases generated within the core. Practically, all cores are dried before use; they therefore contain no added or hygroscopic water which will generate steam, as is the case with a green sand mould. The authors, however, have met certain moulders who contend that a dry core will not, when heated, give off any gas, and who further state that the reason for venting a core lies in the fact that gases given off by the molten metal are drawn *through* the core; but in justice it must be stated that these views are held by a few only.

In examining facts, the first feature of note is the almost complete surrounding of the majority of cores by fluid metal. As a consequence, the core is heated to a very high temperature; thus, in the case of yellow brass, the temperature reached will vary from 950° C. to 1100° C.; with gun-metal or bronze it will vary from 1000° C. to 1200° C.; with normal cast-iron the temperature will range from 1300° C. to 1400° C.; and in the case of steel from 1550° C. to 1650° C. The point, however, is not one of mere degrees of heat, so much as the fact that the temperature is sufficient to burn the sand of the core. It has been shown that burning, in the case of sands and clays, is accompanied by an evolution of combined water, and at these temperatures this evolved water is necessarily in the form of steam, which forms one source of gas generation. Another source is the organic and carbonaceous matter present in all sands, for example, horse dung, core gum, coal or coke dust, etc. To the carbonaceous materials must be added the facing on the exterior of the core, which, whether it be plumbago or a blacking of charcoal dust or coal dust, will inevitably generate carbonaceous gases.

Dry cores must, therefore, be regarded as capable of generating gases at temperatures exceeding a red heat; further, if this gas is not drawn through the core it will pass through the fluid metal. In this respect it must be remembered that the generation of gas in the interior of a mould offering no free passage for its escape is equivalent to an explosion, the intensity of which varies according to the amount or volume of gas generated and to the rapidity with which it is formed. Thus, in a mild case, the metal in runner or feeding heads gives a slight "kick" and settles down. In an extreme case the whole of the fluid metal above the source of gas generation is ejected. Such an ejectment is the result of one discharge of gas, which, however, in ejecting the metal, breaks it up into shot, thus extending the danger area, and, in certain cases, giving the appearance of a series of explosions. In many cases this ejectment of molten metal has been attended by fatal results, and, apart from the loss of castings, the risk of personal injury, or loss of life, is such as to demand the utmost care in providing for a free escape of all gases generated within the mould and its cores.

Turning to the second point, that fluid metal gives off gas, just sufficient truth lies in this contention to make it dangerous when used as an argument. However, the moulder need not trouble or try to eliminate any gases evolved by fluid metal, for nothing he can do to the mould will achieve this end. Gases contained in fluid metal, that is, occluded gases, cannot be drawn away by core or mould vents. Further, properly melted, deoxidised, and well-killed metal will not be fiery or evolve gases. It need hardly be added that, after taking the trouble to make a mould, only suitably melted metal should enter it. In every case within the authors' personal experience, the discharge of molten metal from a sand or loam mould could be definitely traced to a fault in the mould or its cores. The word "fault" is used advisedly, for it is always due to the generation of gas (a term including steam) for which no escape has been provided, or the easy escape of which is prevented by the usual outlet having become choked.

Fortunately for the moulder's longevity, violent ejections are comparatively rare; the milder forms, however, are not so rare, and, if nothing more, they tend to risk the loss of a casting. The kick previously described indicates the passage of gas in the wrong direction, that is, into the metal instead of through the mould or core. It may be thought that the gas having, by means of the kick, found freedom, that the metal will settle quietly down again. This, however, only occurs in a few fortunate cases. Generally a casting which has kicked will contain a few or many blow-holes along the path followed by the gas. Blow-holes not due to the nature of the metal are simply trapped bubbles of gas or air, which may, or may not, be detected on machining the casting. If undetected, it constitutes a source of weakness, and, to some extent, is always an element of danger to the working life of the casting.

Evidently, then, as cores give off gas when heated, and as, in the majority of cases, all but the extremities of the cores are surrounded by fluid metal, it follows that not only must the core be vented, but also that the gases generated in the core and collected in the vent must be drawn away through the mould. This practice is summed up in the term "leading off the vent"; in other words, leading the core vent through the moulding-box, so that, on casting, the gases evolved by the core may be lit outside the box. With cores run up on barrels, the latter often project through the box, thus communicating directly with the atmosphere; hence, no leading off is required. In such a case, the end of the barrel is lightly packed with shavings, which are lit on casting, and serve to ignite the gases evolved. In the case of sand cores set in a vertical position, the vent is most conveniently brought through the top part of the moulding-box, as illustrated in fig. 94. To lead off a vent in this way usually means that, in moulding, the core print is carried through the top part, as indicated when describing the moulding of a pipe on end. With an open print of this character, a rod may be inserted in the vent of the core, the edges of the core packed with tow, and the print filled in. On removing the rod there is a clear communication between the core and the atmosphere. Sand cores set horizontally in the mould have their vents led away through the joint. Thus, assuming perfect contact between core and print, all that is necessary is to scrape a channel along the joint, and to lead the vent of the core to the box edges. Such an assumption is, as a rule, perfectly safe in repetition work, in which patterns and core boxes correspond exactly to each other. In jobbing work this correspondence does not always occur, and it is quite possible that cores may be slightly smaller or fuller than the prints. If small, metal will get between core and print, possibly entering the vent, thereby destroying its purpose as a channel for the escape of gases. A choked vent is worse than no vent at all, and a blown casting will certainly be the result. Not only so, but the metal will pass along the channel cut for leading off the vent, and so cause a run out, which, of all foundry mishaps, is the most vexing and the least excusable. On the other hand, if the core is full, the moulder will have to card it down to fit the print, and the chances are that he will card it slightly smaller than the print, in order to prevent a crush. Therefore, in doubtful cases, the safest plan is, after fixing the core and cutting a channel, to place a string in the core vent, leading it along the channel and over the box edge. The channel is filled in level with the joint, and the string drawn after closing the top part. If this plan is followed, even if meta does get between the core and print, it cannot enter the vent. With cores having ash vents, a larger channel is cut in the joint, loosely filled with small coke, and the joint made good as before, thus continuing the vent of the core right to the edge of the box. In this respect, it may be noted that the joint between two parts of a moulding-box is neither air- nor gas-tight, and the gases evolved by a core will readily escape through the joint.

In certain cases it is necessary to lead the vent through the bottom part, which, if level with the foundry floor, may be managed by means of the vent wire. A series of vertical vents are made in the print before placing the core; and these are in turn connected with a series of horizontal vents pierced between the bottom of the box and its bed. When the casting is bedded in the floor, such vent should be led down to a coke bed. Bottom venting of cores should always be a last resort, as, wherever possible, all core vents should be led through the top part, or, failing that, through the joint.

In a composite core, vents may have to be led from one core to another; therefore, in fitting them in position, every care should be taken to see that the vents are clear, and that contact between the two cores is such that no metal can get between them so as to destroy the vent. If the separate cores fit into one another by means of prints, a safe and continuous vent is easily achieved. When two cores butt one against the other, it is safer to have separate vents, the vent holes at the point of contact being closed, or filled in with a mixture of plumbago and oil.

In all cases in which moulds are rammed in a pit before casting, care must be taken to see that all core vents are brought to the surface by means of tubes. Finally, although many examples cannot be considered in detail, it will be seen that the whole secret of core venting lies in having a clear passage right through the core to the atmosphere, and that precautions must be taken to avoid choking this passage during casting. Whatever method will most readily secure this end must be adopted; but the method will, of necessity, vary according to the character of core and mould. When casting, all core vents are lit by applying a red-hot skimmer at the place where the vent issues from the mould.

Quite apart from venting, important points with cores are that when fixed in the mould they must be true to position and perfectly rigid. Perfect truth is readily obtained when prints and cores exactly correspond, and, in such a case, all that is necessary is to maintain the core in position during casting. Where such truth is not found, the cores must be centred in the mould; this can often be effected by means of calipers.

Practically, all cores set in a vertical position may be centred from the sides of the mould; but when calipers cannot be used, as in cores set in a horizontal position, the thickness of metal must be tested by means of small balls of clay. Thus, balls of clay are placed in the bottom part of the mould at all points of which the thickness of metal is desired, and the core placed in position. Similar balls of soft clay are placed on the upper part of the core, and the top part fitted on. On removing the top part, the thickness to which the balls of clay have been squeezed will give an index as to the thickness of metal, similar information being gained on removing the core from the bottom part. Any locally thin parts are remedied by carding the core with a card wire, or thickening the mould according to circumstances. If the prints are too easy, the core must be raised in them by just half the amount of difference between the print and the core. This naturally involves packing, and the material so employed may be plumbago and oil mixed into a paste, a thin layer of sand, or thicknesses of brown paper. If the print is smaller than the core, the latter must be carded down to size, or a crush will follow. These remarks apply to cores sitting in horizontal prints; vertical cores are tested by calipers, and directly centred from the mould. It may be noted that clay balls may be made to adhere on the sloping sides of a core by small tacks, or, in certain cases, tacks may be used alone, the thickness being taken from the length of tack projecting after fitting on.

Having attained the right thickness, or centred the core, the next point lies in maintaining it in that position during casting. In other words, the core must be so stayed as to resist flotation and the washing action of a stream of fluid metal. Short cores in a vertical or horizontal position are sufficiently stayed by top and bottom prints. A point worth noting is that horizontal prints of green sand moulds must be of sufficient strength to carry the weight of the core on one hand; and, on the other, of sufficient stability to resist any upward movement of the core when casting.

Hence, it is often advisable to strengthen a short print by bedding an iron across it when ramming-up bottom and top parts. Some types of valve and cock cores may be made with ball prints, thus giving a good bearing in the print and a heavy body of sand to balance that in the mould.

Long cores carried by two opposite prints, when cast in a horizontal position, tend to lift in the centre. This will occur in cores of length, no matter how firmly the prints are secured; hence, the metal on the top of the casting will be thinner and that on the bottom thicker than desired. In an extreme case all the thickness will be on the bottom, and the top at the centre of the casting entirely cut through. This introduces the use of chaplets, studs, and pipe nails. The last are simply iron nails, with large flat heads, and tinned in order to prevent rusting. They are used in steel and iron moulding, whilst flat-headed copper nails are used in brass and bronze moulding. Chaplets are formed from sheet-iron, brass, or copper, according to the class of casting. They are formed of two plates, rivetted together by a pin, the distance apart of the plates being varied to suit the thickness of metal between core and mould. Pipe chaplets are circular discs of sheet-iron into which a long stem is rivetted. Types of chaplets, etc., are shown in fig. 104, and their use will be indicated in a moment. Studs are chiefly used in brass moulding. They may be either turned from rod, or cast in the form of sprays. Before use, they should be thoroughly cleaned from adhering sand. Sheet-iron chaplets of various sizes are stocked by all foundry supply houses, but the authors have always had to make their own copper chaplets. Such a one is shown with the pin carried through the plate, in order that the chaplet may be nailed on to a sloping core or mould. Studs, when used on sloping surfaces, are tacked in position by means of small tacks.

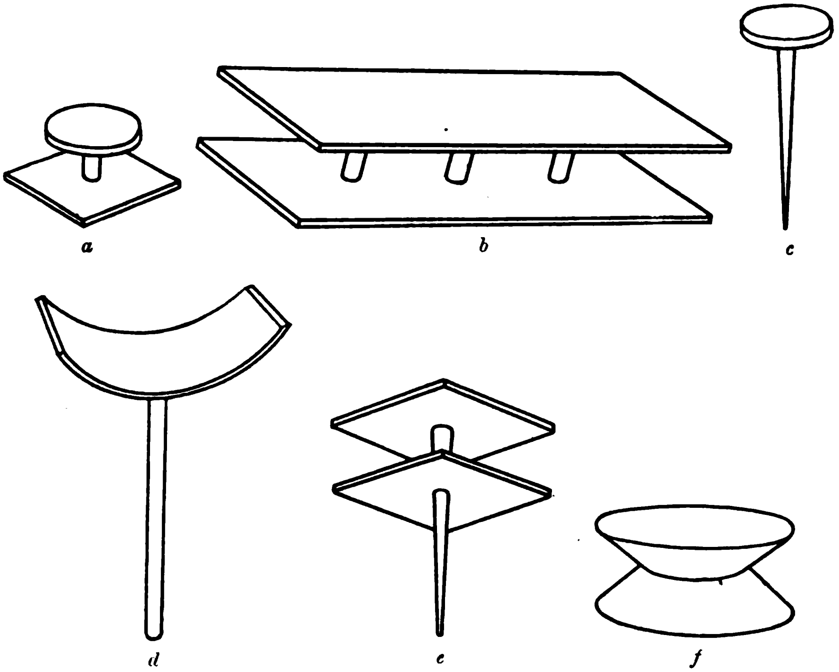

FIG. 104.—Chaplets.

The purpose of a stud, chaplet, or flat-headed nail is to maintain the core in position during casting, but, obviously, the insertion of a chaplet between a dry core and a green mould will not achieve this end; for, when pressure is applied to the core, it will lift and force the chaplet into the yielding sand. For similar reasons, a chaplet cannot be used alone on a green core. The chaplet, to tulfil its function, must have direct contact with an unyielding substance; and, whilst a dried core may be regarded as firm, a green mould cannot be so viewed. Herein lies a matter of great importance, second only to that of venting. The authors find that, as a rule, far too much time is given to placing chaplets in a mould and far too little to securing an adequate support for them. As an axiom, it can be taken that the fewer the chaplets, the better the result, provided each one is effective, and that an ineffective chaplet should never be placed. To secure effectiveness, the golden rule is metal to metal, that is, the chaplet is continued by metal to the top of the box, where it may be either weighted or wedged into an immovable position. In the case of bottom parts, a solid bearing is obtained by ramming-up or bedding-in metallic packing in places where chaplets have to be placed. A similar end is attained by bedding a block of wood in the bottom part into which a pipe nail may be driven. This nail may be driven flush with the face of the mould, and a chaplet laid on it, or it may be left projecting to the extent of the thickness of the metal required. With cores cast in a horizontal position, the greatest lifting pressure is below the core; hence, the top of the core requires the most attention in securing. The position of studs or chaplets placed on a core is noted by means of whitening and trying on the top part of the box. On removing the top part, the position of each stud is shown by the whitening, and a hole is pierced through the centre of each mark. When the top part is returned, a rod is passed down the hole previously made and bedded on the chaplet. The top of this rod is packed with metal packing, small plates, etc., to the same level as the top of the box, and a flat weight bedded on. With metallic contact throughout, any pressure below the core can only lift it when that pressure exceeds the weight placed on for holding down.

Two important conditions must be observed here: (1) the lower side of the core must be so stayed as not to yield when its upper side is chapletted down; and (2) the skin of the core must not be broken, and the chaplet must not penetrate the core. These two conditions demand recognition when applying weights to the uppermost chaplets. Hence, the weight must be bedded on the top surface of the box; in other words, the load must be carried by the box and not by the core; but from the lower side of the weight right down to the core there must be a rigid support for the top of the core. Also, for the same reason, green sand cores must have a metallic projection from the core barrel to the surface of the core in all parts on which a chaplet has to be placed.

Weighting down in the manner indicated is effective with the majority of small and medium-sized cores, but in many cases wedging is preferable. This is effected by wedging a cramp firmly across the top of the box. Between the top of the iron leading from the chaplet and the underside of the cramp a wedge is inserted and tightened. The latter requires care, for, if the wedge is driven too tight, either the core is depressed or its skin broken. Weighting and wedging are applicable in all cases in which cores are placed in a horizontal or an inclined mould. It may be noted that the contour of the chaplet should be bent to follow that of the core; that, in every case, the chaplet should be dry; and that, in green sand moulds especially, chaplets should not lie too long before casting. Rusty chaplets are dangerous, chiefly because the rust indicates the presence of water. Iron chaplets should always be tinned. When an untinned chaplet has to be used, it should be heated to a red heat, and allowed to cool before placing it in the mould. Such a chaplet is also better for a coat of oil previous to use, or chalk rubbed over the surface will answer the same purpose as oil, namely, to retard to some extent the deposition of water on the chaplet. However, notwithstanding precautions, chaplets are often a source of blowholes or unsoundness, especially in the case of high-pressure steam or water castings. They are, however, a very necessary evil; therefore, all possible care must be exercised when using them. A chaplet may be replaced by a solid stud coated with loam, which is removed from the casting, and the hole tapped gas thread and plugged. Similarly, brass castings may be chapletted down by passing an iron rod on to a brass plate bedded on the core. The iron is removed from the casting, and the hole plugged.

With moulds in which the cores are vertical, the necessity for side chaplets vanishes. Castings, such as long liners, plungers, and cylinders in which the main cores are vertical, require no chaplets, except on branch cores, such as, for instance, those of the steam ways of a cylinder. However, other considerations arise, of which the buoyancy of the core and the necessity of maintaining it in a central position are of chief moment. A built-up cylinder core, when cast in a vertical position, is held down by the top plate; and as both mould and core rest on one foundation plate, the two plates, when tied together, effectually secure mould and core against vertical pressure. A liner core in a sand mould differs in that its security must be obtained by means of top and bottom prints. The bottom prints must, therefore, give an unyielding bearing to the core, which is afforded by metallic packing or distance pieces from the bottom of the box. If the liner is of equal section throughout, that is, a simple pipe, then there will be no upward lift on the core, further than that induced by its buoyancy. The latter depends on the weight of core and barrel and the thickness of surrounding metal. Thus a 4-inch core, placed vertically in a mould 5 inches in diameter, has less severe conditions to meet than a core of the same diameter placed in a mould 36 inches in diameter. In one case the core is surrounded by ½ inch of fluid metal, which quickly solidifies; and, in the other, by 16 inches of metal, which keeps fluid for a considerable time. Considerations of this kind show that in all foundry operations judgment must be exercised; and in this particular case, whilst the risk of movement in a vertical core surrounded by half an inch of metal can be provided against by prints, these factors become less safe as the thickness of surrounding metal increases. A long core having a solid bearing in the bottom print may be weighted from the top print somewhat after the style of weighting down a chaplet. If the core barrel does not continue through the top part, it is lengthened by hollow distance pieces and weighted down. In weighting, the vent must not be closed. If the barrel projects above the top part, weights are laid on the edges of the box for packing, and two bars laid across them bearing on the core barrel, but not closing the hole for the vent. Weights are laid across the bars for holding down. Assuming the weights to be effective, it will be noted that such a core is practically immovable between the metal packing of the bottom print and the holding down weights on the top, which naturally should be the case for the purpose of casting. After casting, the temperature of the core increases, with the result that the barrel expands in accordance with the rise in temperature. Therefore, the weights holding the barrel down should be removed on solidification of the casting, in order that the core barrel may expand in the direction of its length. If the weights are not removed, the barrel will buckle as it expands; further, as the casting is contracting and the barrel bending outward, at one part two opposing forces meet each other, and such meetings are not good for castings. The point, however, is that, on cooling, the barrel will not straighten itself, and will therefore be troublesome for future cores.

A better method than weighting is found in wedging bars across the top of the box, and packing the core barrel to the under side of these bars, again keeping the vent open. This packing is released on solidification of the casting.

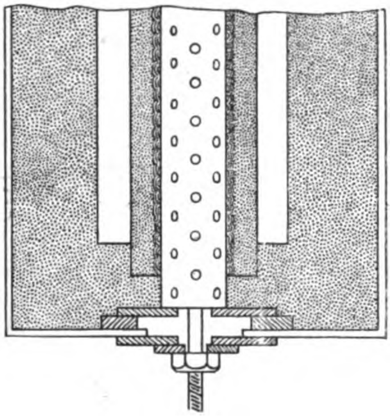

FIG. 105.—Method of Binding Core.

The best method of all, and a perfectly safe one for any class of vertical core, is shown in fig. 105. The lower end of the core barrel is reduced in diameter, and threaded to take a nut. A rigid support for the core is obtained by using a flat washer, which is packed by distance pieces from the bottom of the box. This also prevents the core from being drawn downwards when the lower nut is tightened. On tightening this nut from below the box, the core becomes rigid; it can neither fall nor rise; but, at the same time, the barrel is free to expand in one direction of its length. The method is elastic, and it can be applied to any type of green sand, dry sand, or loam mould cast on end, and it becomes of enhanced value in cores having inner recesses which give rise to an upward lifting pressure distinct from flotation. A simple expedient of this kind would, in many cases familiar to the authors, have saved castings, and, in at least one case, human lives.

CHAPTER XIV.

MOULDING FROM GUIDES.

MOULDING, as considered up to the present, involves a complete pattern as a prime essential; and, whilst it has been shown that these patterns will admit of cutting or extension in the sand, such alterations have not eliminated the actual pattern. Practically speaking, sand moulding cannot be followed without a pattern of some kind, and in makeshift work the moulder makes his own pattern by using guides. The latter may take the form of strickles, templates, or frames, giving an outline of the required casting.

Skeleton or frame patterns are largely used in many classes of heavy work. These patterns, instead of being built from the solid, are made up as frames; before moulding, the spaces of such a frame are filled in with sand, and sleeked over to the pattern outline. Parting sand is spread over the sand face, and the pattern then treated as a solid. As a rule, skeleton patterns are more common in dry sand and loam moulding, though, to some extent, they are used in green sand work.

Swept cores serve as good patterns for liners and similar cylindrical castings. After sweeping the core to "core size," an additional thickness is swept on, corresponding to the thickness of metal required in the casting. The dry core is then treated as a pattern, for the time being; and, if flanges or other projections are required, these are made of wood and treated as "loose pieces." On removing the "pattern" from the mould, its thickness is stripped, and it is subsequently returned to the mould as a core. Strickled cores are usually made and finished to core size; such cores, when used as patterns, are thicknessed by means of clay thickness strips. The latter are made up in open core boxes of the required thickness, and then fitted over the core. Flanges or bosses are temporarily placed in position as loose pieces. After completing the mould and removing the core pattern, removal of the thickness strips leaves the necessary space between core and mould. A little thought will show that these methods admit of very considerable extension; and that a combination of strips of varying thickness, with the necessary loose pieces, will enable an intricate casting to be moulded from its own core. A swept core rotating in a trestle may be regarded as a solid object in a lathe, and therefore may be turned to any required form. These two methods admit of the moulding of various types of castings, and, although the skill required from the moulder is high, pattern costs are correspondingly low.

In certain cases a mould may be built up by cores which are set in position on a level bed, and covered by means of a flat top part or by covering cores. As an example, a lathe bed may be selected, the sides, ends, and centre of which are formed entirely of cores. These cores are made from frame core boxes, and suitable grids provided with lifting eyes are placed in the cores, thus permitting of ready handling after the cores are dried. A level bed is struck off in a floor pit, and vented down into a coke bed. The cores for end and sides are partly shown in fig. 106; these cores are set in position, as shown in fig. 107, and backed with sand. Fig. 108 shows one of the covering cores, which also form the interior of the bed, giving cross brackets and internal lugs. The requisite number of these cores to cover the mould are placed in position, and flat plates bedded on their upper surfaces to provide a bearing for the holding-down weights. Moulds of this type may be gated through the covering cores, or, preferably, from the bottom of one of the ends. In the latter case, ingates are provided in the end cores, and connected with vertical runner pegs, which are rammed up in the sand backing. Obviously, this sand backing must be of sufficient stability to resist outward pressure when the mould is cast. The most effective manner of securing this is by the use of a curbing or a cast-iron frame larger than the mould. As this frame surrounds the cores, a solid ramming of sand between it and the cores is readily obtained. Naturally, no matter how solid the sand at the back of the core is rammed, unless this backing has an unyielding support, it will fail when the liquid pressure in the mould reaches its maximum. Hence, in this class of work, in which the comparatively deep sides of a mould are formed of cores only, the use of surrounding frames is most advisable. Such a frame is readily set in position, dispenses with a considerable amount of ramming, and renders the mould safe.

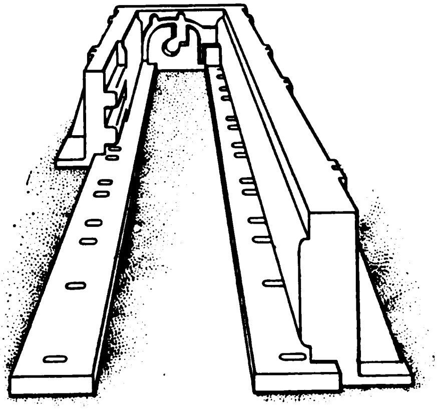
FIG. 106.—Side and End Cores for Lathe Bed.

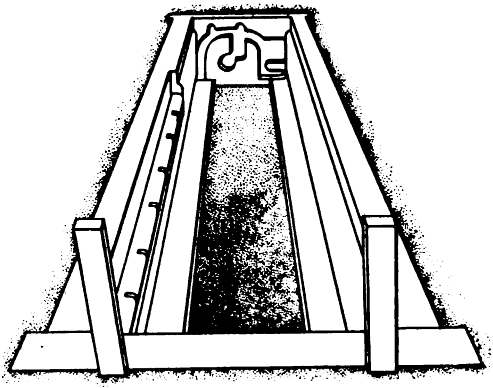
FIG. 107.—Lathe Bed Cores in Position.

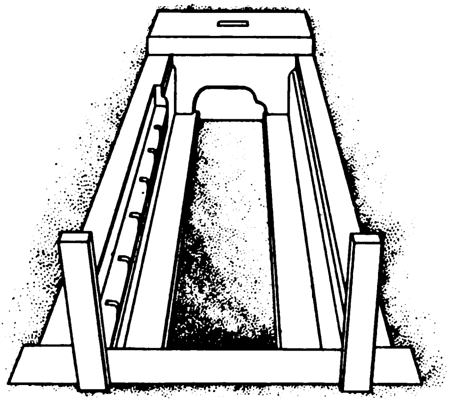
FIG. 108.—Lathe Bed, showing one Covering Core.

Although only one example of the use of cores to form a mould can be given, others will readily occur to the reader; and it will be seen that this method, as in the case in which cores are used as patterns, will admit of much extension. Circular castings may be made by scribing the diameter required on a level bed, and setting cores, made as a segment of the circle, to the line so scribed. A flat top part would complete such a mould. However, with circular castings the more usual plan is to form the mould by sweeping or strickling. So far as moulds are concerned, sweeping is simply an extension of the methods already given for circular cores, the only difference lying in the fact that the mould is stationary and the strickle movable. Thus, a level bed may be struck from a strickle attached to an upright spindle working in a central socket. Assuming a horizontal straight edge attached to a vertical spindle, then rotation of the straight edge over a bed of rammed sand will sweep a level surface precisely in the same manner as by means of a strickle working on two previously levelled straight edges. The tackle required when sweeping a green sand mould comprises strickles cut to the required shape, spindle and socket. The last two are illustrated in fig. 109, and, with the top of the socket in a horizontal position, the spindle should be truly vertical. In fitting up, the socket is first set at some distance below the face of the required bed, and levelled by means of a spirit level. This socket remains in position until the mould is cast. Strickles are bolted to a wrought-iron arm having a boss which fits the spindle and is secured to it by means of a set screw. The end of a strickle corresponds to the circumference and the lower edge to the bottom surface of a mould. In setting the strickle, the distance from its end to the centre of the spindle should be carefully adjusted to give the diameter of the mould. This is regulated when bolting the strickle on to the arm of the spindle, and at the same time the upper edge of the strickle is levelled by means of a spirit level, in order to set it horizontally. Fig. 110 shows a mould swept up by means of a strickle, the latter being so cut as to give the bottom, sides, and joint of the mould. Whilst it is comparatively easy to sweep flat surfaces, as, for example, the bottom and joint of fig. 110, it is not so easy to sweep the straight sides of a mould. The usual plan is to pack the sand firmly by hand into a rough outline of the required form, working the strickle repeatedly round until the finished form is obtained. With very deep moulds the sides may be rammed against a guide temporarily placed in position, and finished off with the strickle.

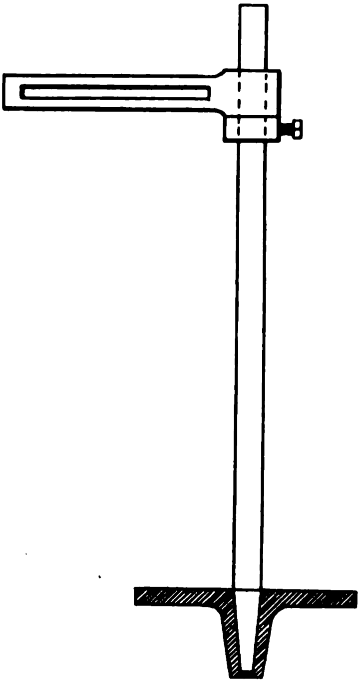

Fig. 109.—Spindle and Socket.

Fig. 110 shows the method of obtaining the bottom, sides, and joint only of a circular mould. Assuming this mould to be for a fly-wheel, then, after removing the arm and strickle, a print with a central hole fitting the spindle is passed over the latter and bedded in the bottom. This ensures a central print for the boss core, and, after obtaining it, the spindle is removed. The arms of the wheel are formed by means of dry sand cores, which also give the inner walls of the rim and the outer walls of the boss. These cores are readily set in position by means of distance pieces cut to give the rim and arm thicknesses. The boss core is set into the central print already formed, which completes the bottom part of the mould; and a flat covering part completes the whole mould.

A similar end may be gained by sweeping a flat bed, scribing on it from the central spindle the circumference of the wheel, and, by means of a segment, ramming up the sides in stages. Dry sand cores are again employed to form the central part of the mould. If flat top parts are employed, these may be rammed up by placing them on a hard and level bed; if the joints are not flat, the top part must be rammed up from a reverse mould swept from the same centre as the bottom part. So far as wheels are concerned, the boss is often deeper than the face of the wheel, and note will be taken of this in the following example. As an example of green sand sweeping in conjunction with the use of dry sand cores, the case of a spur wheel may be selected. The spindle socket is set and levelled, the spindle placed in position, and the reverse strickle levelled and bolted on the arm. A depth of sand is rammed and swept into shape by the strickle, as shown in fig. 111. The spindle is removed and the hole plugged with tow, a top part is placed over the bed and staked for guidance in returning. Runner pegs are placed over the sand projection which forms the boss, and risers are placed at intervals where the rim of the wheel will finally come. The top part is then rammed up, lifted off, and, after finishing, set on one side until the bottom part is completed.

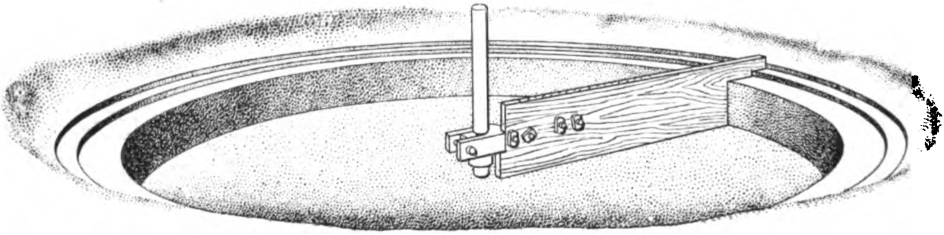

FIG. 110.—Sweeping.

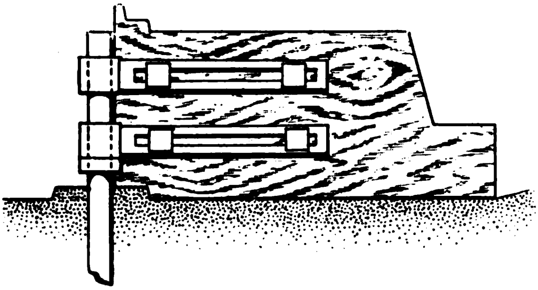

FIG. 111.—Sweeping Reverse Mould.

The tow filling the hole occupied by the spindle is removed, and the spindle returned to its socket. The sand forming the reverse mould is cut away, and a new bed swept at a depth equal to the width of the wheel face. Fig. 112 shows this bed, and it will be noted that the depth is obtained by setting the projecting part of the strickle level with the previous bed.

This strickle gives a level bed for setting the outer and inner cores, and also forms a print for the boss core. After sweeping the bed, a circle is scribed from the spindle corresponding to the circumference of the wheel at the bottom of the teeth. The cores forming the teeth are made in a core box, each core forming a segment of the complete circle. These cores are dried and blackwashed on the tooth faces. They are set in position to the line already scribed, and, if the core box is a correct segment, a true circle is obtained. The truth of the circle is readily tested from the spindle; if correct, the latter is removed, and the hole left filled in with sand to the bottom of the print. The outer cores are backed with sand, which should be compactly rammed in order to prevent outward movement. The arm cores are set in position by the aid of distance pieces, which are cut to give the width of rim and arm respectively. The boss core is set in the print struck when sweeping the bottom, which completes the bottom part. The appearance at this stage is shown in fig. 113, and all that now remains is to try on the top part in order to test its bearing on the bottom part. If the sweeping has been true, there should be perfect contact without crushing. On lifting off the top part, the position of the vents in the arm cores will be shown, and holes are pierced through in order to lead the vent through the top part.

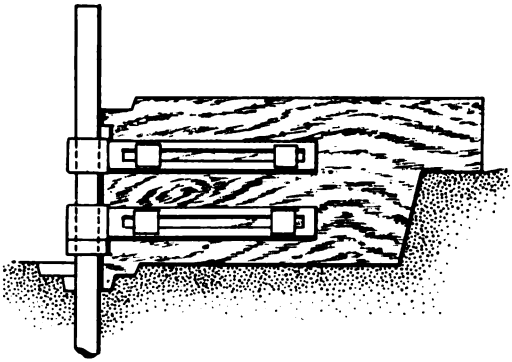

FIG. 112.—Sweeping Bottom Part.

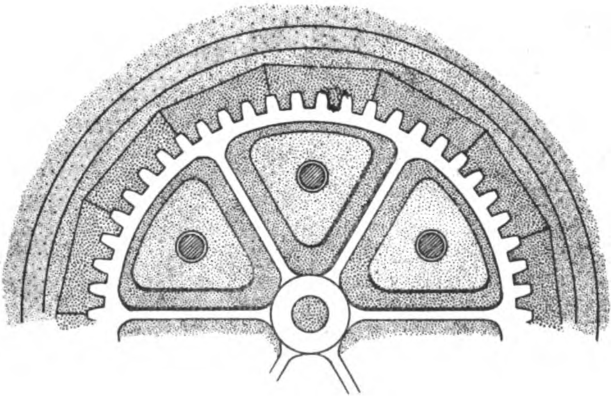

FIG. 113.—Spur Wheel Cores in Position.

This method of sweeping gives very true wheels at comparatively low pattern cost. As regards moulding costs, swept wheels may, in certain cases, be produced at a lower labour cost than when working from full patterns; this, however, is a question solely determined by the foundry equipment and the skill of its personnel.

As regards the applicability of sweeping, practically any object, the outer form of which may be struck from a central spindle, can be made. Although few examples are given, the applicability of the method will be readily seen, the only disadvantage is the non-coherence of green sand, a feature chiefly shown on vertical surfaces. Hence, in the case of castings having deep sides, sweeping up in loam becomes a more profitable occupation. For flat work, and where the sides may be formed by means of cores, green sand sweeping is certainly a decided advantage in cutting down pattern costs.

The limits of space preclude more than a passing reference to many methods of moulding, which, though interesting in themselves, to some extent lack interest to the general foundry worker. Of these methods we note first "reverse moulding," which is practically confined to foundries engaged in ornamental work. When introducing a new design for a canopy, stove front, or similar article, a solid plaster block, which gives the face of what is required in the casting, is modelled by the designer. This block is set on a turning board, and maintained in position by guide strips. A suitable box is selected, and the bottom part laid on the turning board, centred to the block, and maintained in position by means of blocks nailed to the turning board. This half of the box is raised from the face of the board by "thickness strips," which are of the same thickness as that required in the casting, usually about ¼ inch. The box is rammed up, and turned over on to a level bed. The plaster block is drawn, and the mould is carefully jointed. The joint is carried down to the face of the ornament, and all square corners are tapered a little to allow clearance. Parting sand is thrown over the surface, the excess blown off, and a dust of resin shaken on. The top part of the box is placed in position, and rammed up with the necessary lifters. The top part is lifted off, finished as usual, and set on one side. The plaster block is again placed on the turning board in exactly the same position as before. The bottom part of the box, from which the top part has been rammed, is knocked out and returned to its former position on the turning board. This time the bottom part is placed flush on the board, and is *not* raised by thickness strips as before. The part is rammed up, turned over again, and the block drawn. A joint is made and raised from the face of the mould to the extent of the thickness strips previously used. The rest of the joint is made to correspond to the top part. All loose sand is removed, and a dust of resin given to one part and a dust of blacking to the other, which, when the two parts are fitted together, will readily show how the joints correspond. After fitting on, any thick parts of the joint are sleeked down, and thin parts are made good. Gates are cut in the bottom part, and runners to suit cut through the top part, and the mould made ready for casting. It will be seen that the thickness of the casting is that of the strips which were placed between the bottom part and turning board on first ramming up, and also that the contour of the back of the casting will exactly follow that of the face; in other words, no matter how intricate the ornament, the thickness throughout will be equal. The first castings are intended for permanent patterns, and are finished up accordingly. In the case of a very intricate casting, it is modelled in sections, moulds of each section being made by reversing, and cast in lead. These lead sections are then worked up into form, and soldered together for the complete pattern.

In other branches of ornamental work, castings may be made from "destructible" patterns, methods in this case relying for their success on destroying and removing the pattern by means of heat. For example, if a dead insect, say a large beetle, be taken, and surrounded by a pasty material which, whilst entering into all the fine interstices of the insect, will withstand a high temperature, then on baking such a mould the insect will be charred and a space left corresponding to the form of the beetle. Plaster of Paris may be used as the plastic material; the only difficulty in this type of moulding lies in removing the charred ashes from the mould, as the latter is not accessible. Should any reader desire to experiment in this direction, he may, by placing small round sticks (lead pencils) on the object when forming the mould, provide channels through which the ashes may to some extent be blown out after the mould has been baked. One of these channels will then serve as a runner. Generally the material selected as a pattern medium is one which can be melted out of the mould, as, for example, wax. This has given rise to the "lost wax" process common in statuary founding. In a sense, this is beyond the scope of ordinary foundry practice, but a few words may be given to the leading principles. Methods vary with different designers, but, as a rule, the core is built up by hand to the outline required. This core is built up in much the same fashion as a loam core, that is, vented as usual, and strengthened by suitable irons; but the core material is a mixture of plaster of Paris, loam, and cow hair, and pieces of wire-netting may be interspersed for strengthening. On acquiring a rough outline, the core is stiffened by drying, and a coat of wax evenly distributed over its surface. This wax is modelled into final form by the designer of the figure, and, when completed, the outer mould is made. The wax model is covered by a stout frame of iron, and the whole filled in by spreading the plaster over the surface. To maintain the plaster in position, cross-bars are placed in the frame, which also increase its stability. The requisite runners, risers, and openings for draining the wax from the mould are made as the work progresses. After the plaster has "set," the mould is fired by building fires around it and keeping them going until all the wax has been melted out and the mould itself has been thoroughly baked. This baking gives the necessary porosity for venting. The draining holes are then filled in, the mould surrounded by an iron curbing, and firmly rammed by a backing of sand, heads made on runners and risers and casting effected from a ladle or by means of a basin built on the top of the mould. In the latter case, the runners are closed by plugs, and the basin connected by means of a channel to an air furnace and filled with molten bronze before lifting the plugs. This, of course, implies that the top of the mould is below the furnace level. Should a waster result, the whole of the work on the wax model is lost. As an alternative, the figure may be modelled in clay, and a master mould made from this clay pattern. This is effected by using the clay figure as a pattern, and building around a plaster mould constructed in a series of drawbacks. After setting, these drawbacks are removed and assembled, sheet wax may be then pressed into the mould and a wax pattern obtained, which may be laid directly on the core in suitable sections. The joints at the sections are touched up by the designer, and the whole prepared for the outer mould, as before.

This is possibly one of the most ancient methods of moulding, since it was evidently known in early historic, if not in prehistoric, times. Another historic method of moulding is that of bell-founding, which, though practised to-day, is of little interest to the average founder, as bells are now generally moulded in loam by methods similar to those indicated in a later chapter.

CHAPTER XV.

BENCH, ODDSIDE, AND PLATE MOULDING.

MOULDS for small castings are most conveniently made on benches or in tubs, otherwise termed troughs. A good type of bench is shown in fig. 114, the shelf at the back being used for holding tools, patterns, and parting sand box. Benches of this type are chiefly used in light steel and iron foundries, whilst the tub is common in brass-foundry practice. A suitable tub to accommodate two moulders is shown in fig. 115. The bottom of this tub will hold sufficient sand for one heat. Movable skids rest on the ledges shown, and on these the box is worked. The arrangement of benches or tubs will naturally vary with the class of work and the character of the foundry. If placed along a wall, they should, if possible, be under a window; and if in the centre of a floor, are best back to back. Ample floor space on which to place the boxes for casting must be allowed. This problem is less acute in a brass-foundry where several heats are taken off during the day than in an iron-foundry casting only once a day. In the latter case, a large floor space is required, and the boxes made towards the end of the day have to be carried some distance in order to place them ready for casting. To economise the floor space, it is often an advantage to have a tier arrangement, so that each moulder can put his boxes one upon the other, leaving the runners accessible to shank or ladle. Another arrangement, which only pays in the case of highly specialised work, is to have a narrow gauge track running from the fixed benches to a casting floor. The track is well supplied with trucks holding three or four boxes each. These trucks are run out to the casting floor, and the boxes poured; then the trucks pass on to

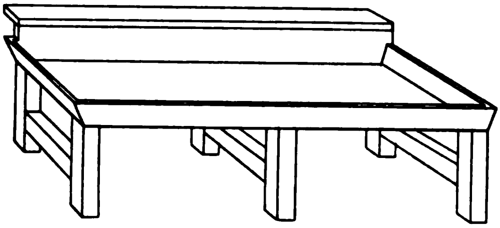

FIG. 114.—Moulding Bench.

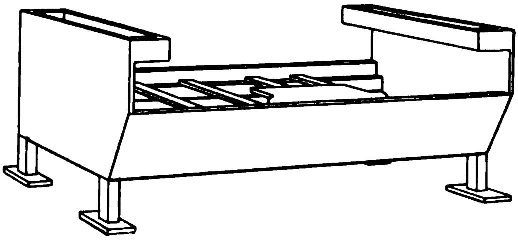

FIG. 115.—Moulding Tub.

a sand mixing shop, the boxes are emptied and returned to the moulders with sand ready for use again. In other cases, a light movable bench may be used, which is made to travel with the work. Such a bench is worked the length of a sand heap in the day, working back in the opposite direction on the following day.

Turning to the methods of moulding adopted in this class of work, these are in principle exactly the same as those already described in green sand moulding. Either moulding boxes or snap-flasks may be used, and the former should be accurately fitted and interchangeable. In using snap-flasks for deep work, trouble has arisen in many foundries through the moulds bursting. This may be entirely avoided by the use of sheet- or cast-iron binders and flat weights. Well-fitting boxes or flasks lend themselves to large outputs, provided the patterns are also equally suitable. To this end, patterns, if of wood, should be made from a hard variety, and suitably divided along the centre. To save tool work on the mould, all fillets, etc., should be on the pattern. Should the patterns not be filleted, temporary fillets of clay, beeswax, or red lead may be put on, which will serve until the order is completed, and will save much cutting and sleeking of the moulds. All patterns, whether of wood or metal, should, whilst in use by the moulder, be kept in good order, an end attained by brushing them over, after each day's work, with a stiff brush and beeswax, or washing with naphtha. In the case of finely-toothed wheels, a wash over with naphtha before each mould is made will materially assist in obtaining a clean draw.

Flat or divided patterns are worked on a turning-over board, which is laid on the bench or across the skids of the tub. When the quantity required from one set of patterns will warrant it, a pattern of the runner and gate should be made. Thus, in setting the patterns on the board the runner is first placed in position, and the various patterns placed in contact with each gate. After ramming up and turning over, the joint should only require sleeking. A runner peg is placed on the pattern gate, and, after ramming up and lifting off the top part, the patterns are drawn. Assuming these patterns to be in good condition, the mould should require no further work, as it is already gated. In this class of work, when a bad draw is obtained, it is always quicker to knock out the box and ram up again than to attempt mending or patching. A plan often adopted with light brass castings, such as plumbers' work, cock and valve mountings, etc., is to attach as many metal patterns as the box will hold to a cast gate, the whole forming one pattern, and involving only one draw. Twenty or thirty separate pieces may be thus moulded as one pattern, and, if the latter is well finished, a large output will result.

More intricate forms of moulding are practically those already described, though practised on a smaller scale. Thus, intricate patterns are sub-divided in order to admit of drawing without tearing the mould, loose pieces are attached by dovetails or pins, and, in the case of solid patterns, small drawbacks or false cores are employed. A two-jointed casting may, in many cases, be made in a two-part box by means of a "double turnover."

The more specialised forms of moulding followed in the production of small repeat castings may be summed up in the two terms, oddside and plate moulding. An oddside is, of course, necessary for any irregularly shaped pattern moulded by turning over, but in repeat work an effort is made to give the oddside a permanent character. Thus, the flat turning-over board may be replaced by a built-up one constructed to follow the joint lines of the patterns. However, such boards are somewhat costly and difficult to make.

The more usual plan is for the moulder to make his own oddside, which, according to the number of castings required, may be of sand or plaster. A green sand oddside is formed by ramming up a top part, sinking in the patterns to the required depth, and cutting the joint to suit. Such an oddside will give fairly good joints for several sets of boxes; and it is used in precisely the same manner as the turning-over board which it replaces. An oddside rammed up in dry sand, carefully jointed, blackwashed, and dried, will give a longer working life than a green sand one. The best type of sand oddside is that known as the oil-side, and the authors have found this to be of a fairly permanent character. To make this, one part of litharge is added to twenty parts of fairly dry new sand, and the two are thoroughly mixed and passed through a fine sieve. The mixture is brought to the consistency of moulding sand by means of linseed oil, and in this condition is rammed up to form the oddside. After jointing, the side is allowed to harden in air for a period varying from twelve to twenty hours. These oddsides keep in good condition for a long time, and give true joints in the moulds. Should the edges become damaged, they may be made good by means of beeswax.

As permanent oddsides, those of plaster are the most extensively used. In making these oddsides the pattern is first bedded face downwards in the exact position required, and the joint carefully made. As the oddside will be an exact reverse of this joint, every care must be taken to see that it is accurately made, that is, the joint must neither be full nor yet undercutting. To prevent the plaster adhering, the pattern is greased or oiled. A second box part is placed on the one containing the jointed pattern, and, if necessary, strengthened by cross-bars. The joint between the two boxes is seamed up with slurry, a mixture of black sand and water, which is rubbed well into the joint to prevent leakage. The requisite amount of plaster of Paris is mixed with water to a cream-like consistency, and then poured over the pattern until the box is filled. This is allowed to harden, then turned over, the sand part lifted off, any adhering sand removed, and the pattern drawn. The face of the plaster side may be varnished over, and, when dry, the side is ready for use.

The necessity of making a true joint in the first instance is at once shown by the fact that any inequality on the oddside is necessarily reflected on the mould, thus involving tool work to make the mould joint good. The most essential property of any oddside is that of giving a sharp clear joint without the use of tools, and, unless the original joint lines of the pattern are followed, this essential is not realised. At the same time, if, during use, the joint edges of the oddside become chipped or broken, the good qualities are destroyed to the extent of the breakage. In this respect it may be noted that isolated portions may be strengthened by inserting sprigs previous to pouring in the plaster in much the same way that isolated pockets are strengthened in a sand mould.

Naturally, the most that can be effected with a permanent oddside is the elimination of joint-making, as patterns have to be drawn and the mould finished as usual. None the less, the method is capable of yielding good results, and is largely followed in cast-iron, malleable cast-iron, steel, and brass foundries. The next advance on oddside moulding is that of plate moulding. A plate may be of metal or wood, having mounted on it the patterns and gates necessary to form a complete mould. If for hand moulding, snugs project from the plate, and holes are drilled in them corresponding to the pins of the moulding-boxes. In this way the box pins act as a guide in drawing the plate and its attached patterns. The method is capable of quick and accurate results, and may be carried out by strong boys or trained labourers.

In mounting plate patterns various methods are adopted, the exact procedure being determined by the number of castings required. Wooden plates have been mentioned, and, though these are not usual in British practice, the authors have found them of high service in quickly executing small repeat orders. The plates are of seasoned wood, about ¾-inch thick, but, provided the thickness throughout is uniform and sufficient for stability, the actual thickness is immaterial. Both faces of the plate are planed, snugs corresponding to the boxes are provided and drilled with holes to fit the box pins. To minimise wear, these holes are lined with metal, for which purpose brass or iron tubing will be found convenient. If the patterns are flat, they are attached to one face of the plate by means of wood screws from the other face. The heads of these screws are driven flush with the face, and smoothed over with red lead in order that no marks shall be left on the casting. Wooden patterns forming runner and gates are attached to the plate and connected with the patterns. On the plain face of the plate which corresponds to the top part of the mould, a small boss is fixed in the position where the runner peg should come, which serves as a guide for placing the peg when ramming the top part.

In moulding, the plate is placed between two box parts, with the pattern side of the plate and the bottom part of box uppermost. The bottom part is rammed, and the whole turned over; a runner tube is placed over the boss indicating its position, and the top part rammed up and lifted off. The plate is tapped round its edges and drawn, the pins of the box serving as a guide. It will be seen that, whilst ramming up, the two parts of the box are separated to the extent of the plate thickness, but, after removing the plate and closing the box for casting, the parts come together. Hence, whilst the actual thickness of the plate is immaterial, it is essential that the thickness throughout be uniform.

Patterns not having a flat upper surface, but permitting of division along their centres, are mounted in halves, one on either side of the plate. Here again, for small orders, wooden plates are effective. In mounting such patterns the halves must exactly correspond with each other, so that when the half moulds finally come together no overlapping occurs. This is most readily effected by means of dowel pins in the pattern, which, if lengthened to allow for the thickness of the plate, offer an accurate and simple method of adjusting the halves to each other with the plate intervening. A pair of divided patterns, as in fig. 116, are quickly mounted on a plate by a patternmaker, and on completion of the order they may be removed and replaced by others. This method of fixing wooden patterns on plates is only adopted when the order is not likely to be repeated at some future time. The authors have found this plan economical in cases where only thirty sets of castings were required. As in any case the patterns should be divided, there is very little further trouble in mounting them on a plate. If a stock of suitable plates is kept in the pattern shop, comparatively little pattern expense is involved in mounting, and the gain to the foundry consists in reducing intricate moulding to straightforward simple work, which may be readily executed by plate moulders.

The chief difficulty with wooden plates arises from their tendency to warp, which may be partly overcome by forming the plate of two boards with the grain of one crossing that of the other. Another method consists in roughing the boards down to within an eighth of an inch of the finished size, and then soaking them for a period of 10 or 12 hours in molten crude paraffin. A convenient apparatus for this purpose consists of two tanks, one within the other, provided with steam pipes in the space between the two. However, where treatment is involved, the process becomes relatively costly, and, in this country at any rate, wood cannot compete with cast-iron under these conditions. Wooden plates are only recommended under the conditions indicated, that is, when the pattern-maker can readily mount a series of patterns and thereby assist the foundry in the rapid production of good work when required in comparatively small quantities only. When the number of castings required is larger, or when the patterns are of a standard character, then both plates and patterns should be of metal.

Metal pattern plates may be fitted up in a somewhat similar fashion to those of wood, or they may be cast with patterns attached in one piece. As a first example, the case of a flat plate cast with pattern on may be selected. Assuming the pattern to be a standard 12-inch hand-wheel, the first essential to note is that the pattern should be provided with a double contraction allowance; and the second that the pattern should be divided across its centre. A 12-inch wheel would be worked in a 14-inch box; the pattern plate will therefore require to be 14½ inches square. One half of the pattern is laid on a flat turning board, and a bottom part, about 18 inches square, placed in position with the pattern exactly in the centre. This part is rammed, turned over, and jointed. The joint should be level with the top of the pattern and the box edges, as this joint will form the lower surface of the plate. The upper half of the pattern is placed in position, and the top part rammed up and lifted off. A frame is laid over the joint of the bottom part and centred by the pattern. The thickness of the frame should be that desired in the plate, and its outer form should correspond in size and contour to the boxes in which the plate will be worked. Therefore, snugs for the box pins and for lifting are provided. Having centred the frame, the joint surrounding it is packed with sand and strickled off level with the top. Loose sand is removed, and the frame drawn. Patterns are drawn from the top and bottom parts and the mould finished.

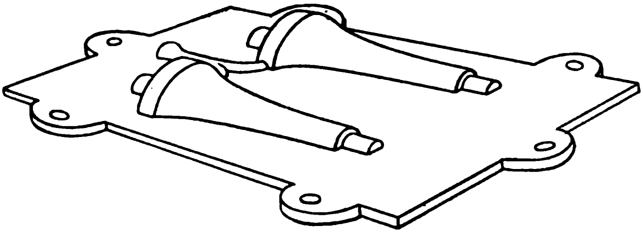

FIG. 116.—Plate with Patterns.

A wheel of this character would be run by a plump gate on the boss, but, for illustration, it will be gated from the rim. A gate is cut, as shown in 117, neatly tapered, and finished to serve as a pattern gate. The plate itself is gated, as shown in fig. 117, and a runner to correspond is cut through the top part. Before closing, iron packing of the same thickness as the frame used for making the joint is placed at the four corners of the box in order to prevent the raised joint crushing when the box is cramped or weighted.

Fig. 117 shows an alternative method in which the mould joint is kept level with the box edges by sinking the half pattern below the level of the box to an amount equal to the desired thickness of the plate. In the former method, which in the opinion of the authors is decidedly the better, the joint is raised above the box edges to a similar extent.

Practically, then, the feature involved in making a pattern plate lies in separating the half moulds by a distance equivalent to the thickness desired in the plate. It need not be added that this involves careful moulding, for, unless the resulting plate is perfectly true as regards thickness and coincidence of patterns on each side, it will be useless.

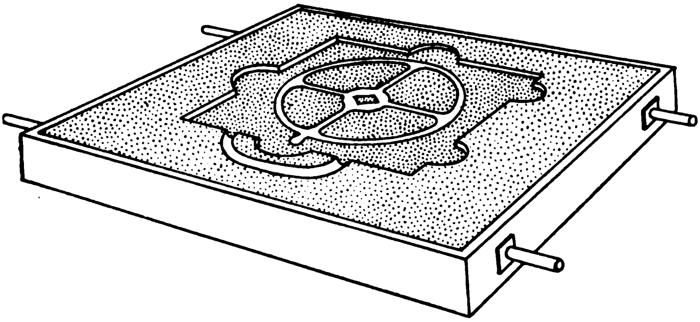

FIG. 117.—Mould for Pattern Plate.

A solid pattern may be used instead of the divided one described, but such a course increases the difficulty of making a true joint. With a divided pattern, the face of the plate is formed by the turning-over board; with a solid pattern this face must be made by hand, using the box edges as a guide. Therefore, if a solid pattern is used, it must be sunk in the top part, employed as an oddside, exactly down to its centre line. Further, the pattern should lie perfectly level. This may be reached by setting the top part with a spirit level, and levelling the pattern by the same means. After setting the pattern, the bottom part is rammed and turned over. The joint is strickled level with the box edges, and this will obviously correspond with the centre of the pattern.

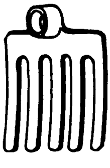

FIG. 118.—Rake Head.

As a second example, a plate having an irregular joint may be selected; such plates are practically always moulded and cast with patterns attached. The rake head, fig. 118, represents a type of steel casting which may be profitably put on a plate, and it will be noted that the contour of the prongs demands a sloping joint, which must be repeated on the plate. The pattern is bedded on the top part, using it as an oddside; the bottom part rammed up, and the whole turned over. The joint is made to suit the plate and not the box in which it is moulded; hence, it is given the requisite slope down to the prongs, but ample allowance is made for a flat surrounding portion on which the plate thickness is subsequently placed. After removing the top part, a frame is placed on the flat part of the joint, and the thickness made up, as in the first case. The completed plate is shown in fig. 119, the only projecting portion on the upper side being that of the core print, whilst the centre of this side is dished to follow the slope of the prongs. The method of making is identical with that of the first plate; but the joint, instead of being on one plane, has to follow the contour of the pattern. Thus the centre of a plate may be dished out to any required extent, but the edges must be horizontal in order that the plate may lie evenly between the two parts of a moulding-box, separating them to an equal extent in all directions.

Cast plates cannot, as a rule, be finished by machining; they have, therefore, to be filed and scraped by hand. Any slight defects are filled in with solder, and finished off level with the surface. Holes are drilled in the snugs to a jig or template corresponding with the pins in the boxes used, and the plate, before use, is varnished over. Although tersely described, it will be seen that hand-finishing involves considerable labour; hence, when possible, it is advisable to cast the patterns in halves, temporarily fix them together, and finish in a lathe, subsequently mounting the halves one on either side of a planed iron plate. For instance, the hand wheel, fig. 117, if in halves may be readily matched on either side of the plate. In this case, there being only one pattern, mounting is resolved into a question of centre lines on either side of the plate; but if twenty or thirty patterns have to be mounted on one plate, their adjustment in perfect truth is not so easy. A usual method is to arrange the half patterns on a plate in the order required, marking their outlines, and scribing the dowel holes of the patterns. The latter are drilled through, and, as the patterns have been fitted, pins passed through the holes in patterns and plate ensure the halves matching. An extension of this principle lies in the use of a master plate or jig. This is a plate marked in squares, each square being drilled by several holes. Half patterns are arranged on the master plate, and the required holes noted, and these are used as guides in drilling the pattern plates. Patterns are attached by passing pins through the plate and matching the half patterns as before. Runners and gates connecting each pattern are pinned on, and the plate is ready for trial.

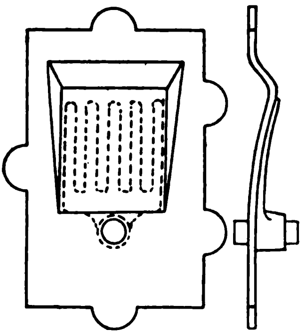

FIG. 119.—Plate for Rake Head.

So far, plates have been considered as containing the whole of the pattern, that is, both halves fastened together with the plate intervening. If we imagine such a plate split into two portions by division through its centre, then, obviously, one half may be used for ramming bottom parts and the other for top parts. In other words, the patterns for one half of a mould may be attached to one plate, whilst those for the second half are attached to another plate, thus permitting two operators to work on one mould. One man will thus ram up bottom parts and another top parts only. This plan has certain good features, and, whilst not usual for hand moulding, may be necessary for machine moulding.

In other cases a set of half patterns mounted on one side of a plate only may be made to serve for the production of a complete mould. Thus, if a series of divided valve bodies are mounted on either side of a central runner, it is evident that opposite half patterns can be arranged to match each other so as to give a complete casting. This may be illustrated by means of the diagram, fig. 120, which is assumed to represent a plate with lines scribed as shown. If A B is maintained in a constant position, and the plate turned completely over, then C will occupy precisely the same position as D; whilst D will take up the position of C. Therefore, if along the lines D and C corresponding half patterns are mounted equidistant from the centre line A B, a complete mould can be produced by ramming up two half moulds; for, on ramming up the bottom parts, and lifting them off the plate, they have necessarily to be turned over, but, while following the same course, the top parts are not turned over; hence, the patterns being equidistant from a centre line, and relative to each other, the necessary rotation of one half mould, to complete a full mould, is obtained. This aspect of plates, as with the last one, is more familiar in machine than in hand moulding.

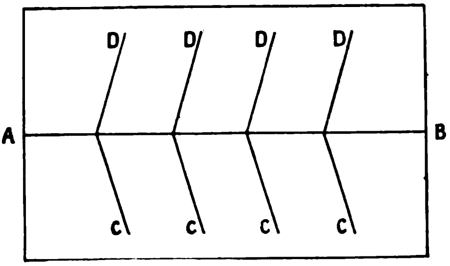

Fig. 120.—Diagram to Illustrate Turning.

Oil tanks for boiling stoves are good examples of specialised plate-moulding. These castings are practically square boxes enclosed on all sides, except the print shown in fig. 121. Two patterns are provided on each plate, which is fitted with snugs corresponding to the square pins of a moulding-box. These castings are extremely thin, and, after placing the core in its print, the proper top thickness is assured by pressing down the thickness plate shown in fig. 122, until it bears on the box edges. A round disc of tinned iron is placed on the top of each core, on to which a nail is passed through the top part and weighted down to serve as a chaplet. In one foundry familiar to the authors the daily output per man by this method is 25 boxes, that is, 50 castings; each man makes his own cores, casts, and knocks out his own work.

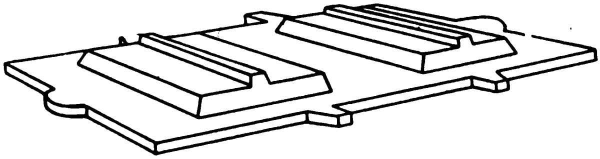

Fig. 121.—Plate for Oil Tanks.

The Possibilities of Plate Moulding.—Plate moulding is practised in the majority of foundries, but in only a few of the more specialised shops is it worked to full advantage. The authors are strongly of the opinion that machine moulding only pays when the possibilities of plate moulding have been exhausted. As a matter of fact, they have, on certain classes of castings, obtained far more economical results from plate than from machine work.

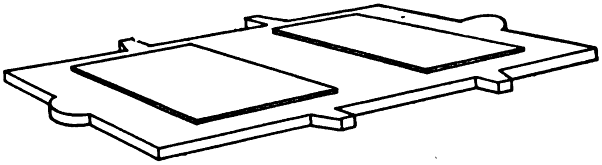

Fig. 122.—Thickness Plate.

It has been shown that, in the case of comparatively small orders, plate moulding can be readily adopted; and, in work of a standard character, permanent plates can be constructed which practically only involve ramming to produce a mould.

CHAPTER XVI.

MACHINE MOULDING.

THE term "machine moulding" should be interpreted with tolerance, for comparatively few moulding machines are, in the full sense of the word, mechanical. As illustrations, a hand press, which simply squeezes sand in a box, is often termed a machine; similarly an apparatus which, by means of a lever, draws a pattern plate from a box rammed by hand is also termed a machine.

Many ingenious mechanical ideas have been developed in order to facilitate one or more of the stages followed in moulding, and the sum total of these constitute machine moulding. A combination of these ideas has resulted in the development of an automatic ramming machine, which also draws the patterns, and, in at least one case, closes the mould ready for casting. Whilst on one of these machines a complete mould can be produced in something under a minute, the end is by no means yet in sight, and, notwithstanding the number of years that moulding machines of one type or another have been in use, machine practice is still in an experimental stage. One or two establishments have travelled beyond this stage, but these represent exceptional cases. This has resulted in various accusations against foundrymen for their conservatism and tardiness in not taking fuller advantage of mechanical methods. Whilst these accusations contain a certain amount of truth, it must also be remembered that the utility of mechanical aids in moulding cannot, on any account, be judged from the usual mechanical standpoint. Primarily, foundries are established to produce good castings at a profit; therefore, the utility of any mechanical aid lies in the extent to which these conditions are realised. It is well within the range of possibility that mechanical aids, whilst actually increasing the cost of production, may, by an improvement in the quality of the product, render their adoption desirable and advisable. In other cases, these aids may, whilst lessening labour cost, actually increase total cost of production, and the quality may, or may not, be adversely affected. The whole question is therefore one requiring unbiassed judgment founded on actual foundry experience. The authors have endeavoured to reach this plane; and in the following notes, whilst certain machines are necessarily referred to by name, such reference is drawn from actual experience and not from the maker's catalogue.

From a foundry point of view, no one type of machine is, or can be, universal; each machine must be regarded as a tool specially adapted to produce a particular class of work in which alone its full possibilities will be realised. The variety of designs actually in use, each one giving satisfaction in a particular field, illustrate this. Each moulding machine, no matter how perfect its mechanism, requires a certain amount of skill from the operator. The statement so often made that any unskilled labourer can successfully handle a machine is by no means true. Some skill on the operator's part is essential, and a very considerable demand in this direction is made on the management, if full results are to be obtained. Machines are sometimes advocated in that they save floor room, and contribute to neatness and cleanliness in the foundry. Now, if a machine is to be a profit-earner, considerably more floor space for setting down boxes will be required than for hand moulding; not only so, but a greater demand will be made on the casting facilities. A foundry in active operation cannot be neat and clean, but it should always be orderly; and we have not found any special value in machines arising from their cleanliness.

Once a machine has been installed, it should be given a full and fair trial. This might seem an unnecessary statement, were it not for the fact that we have known many cases in which machines have been bought, fixed, and condemned after a very half-hearted trial. As a rule, we have found that whilst the initial cost of a machine is not considered, the after-cost of accessories is cut down to the narrowest possible margin. This is short-sighted, for, if mechanical aids are adopted, there must be no half-measures, or failure will inevitably follow. It cannot be too strongly urged that the cost of a machine represents only the beginning of expenditure. Quite apart from accessories which facilitate moulding, good core-making facilities are required. For example, a power machine operated by two men will turn out, say, 200 complete moulds per day. If each mould contains 10 castings, each of which requires a core, then 2000 cores are required per day. Should these cores be intricate, then the capacity of that machine is entirely determined by the output of cores. This example is on the safe side. As another, we may quote a case recently brought under our notice, in which a power machine was employed on a plate fitted with 20 1-inch valve bodies. This particular machine, when worked at full capacity, will turn out 300 moulds per day. Hence, 6000 cores of a fairly intricate character are required per day, if the full capacity of the machine is to be obtained. Yet, in this particular case, the costly pattern plates were provided with only one core box, and the output of this one box determined the output of the machine. This is a telling example of the vice of thrift, for the greatest possible output under the conditions was 100 dried and blackwashed cores per day, and 100 castings would be readily moulded by hand without any expensive accessories.

Turning from the general to the particular, the first points demanding notice are mechanical aids to core-making. The most simple form is found in a plunger forcing a previously rammed core from a die. The core moulds may be round or square internally; each one is fitted with a ram, which may be set to any depth in the core mould, and thus determine the length of the core. Ramming and venting are done by hand; on completion of which, the ram being forced upwards ejects the cores. Fig. 123 illustrates a machine built on this principle by J. W. and C. J. Phillips. In operating it, a mould of the required size is placed on the table of the machine, and a ram of the same size fixed to the end of the plunger. The sand is rammed and the core vented and then ejected by pulling the hand lever forward and depressing the treadle. The rack is brought down again for a new core by turning the pivoted handle of the hand lever inwards, thus allowing it to pass beyond the stop, and releasing the pawl from the ratchet wheel. At the same time, a brake device for checking the return of the rack also comes into operation. The rack is balanced by means of a chain and balance weights.

These machines, operated by boys or girls in the case of cores of small diameter, yield a large output of good cores. Wherever large quantities of straight cores are desired, such a machine will prove a good investment.

It will be noted that the foregoing machine is limited to straight cores, a remark also applicable to the various types of machines which admit of grouping under the general heading of sausage machines. Fig. 124 illustrates one of these machines, the principle being that of compressing sand through a die of the required size by means of a differential screw. At the same time, a central vent hole is provided, and the cores produced in continuous lengths, which are afterwards cut into desired sections. In the plunger type of machine, a core iron can be rammed up with the core, hence ordinary core sand is available; with the sausage-machine type, core irons are not applicable, hence special mixtures of sand are required. These mixtures take the form of ordinary sands mixed up with linseed oil.

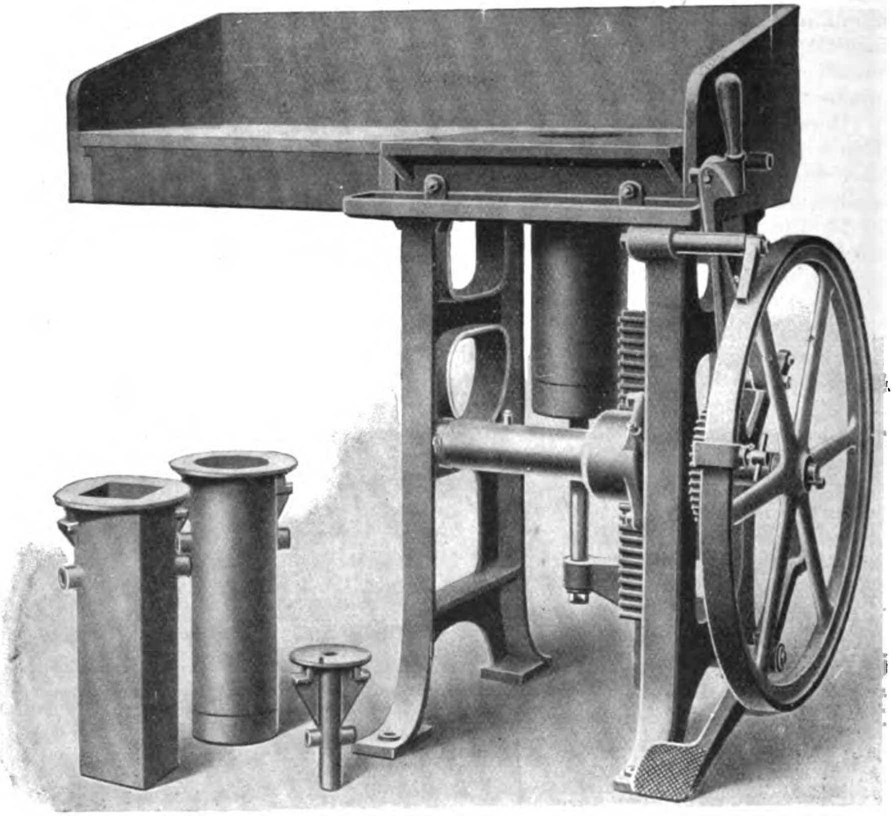

FIG. 123.—Phillips' Core Making Machine.

In considering swept cores, the most apparent mechanical aid lies in the introduction of power for rotating the core barrel. This is largely adopted where long cylindrical cores are required, as, for example, in pipe foundries. A machine for running up circular cores in sand is shown in fig. 125. The cores are struck up on an ordinary barrel by means of a reciprocating steel bar which presses the sand on the revolving barrel. The reciprocating bar also acts as a strickle, and is therefore cut out to suit the type of core desired.

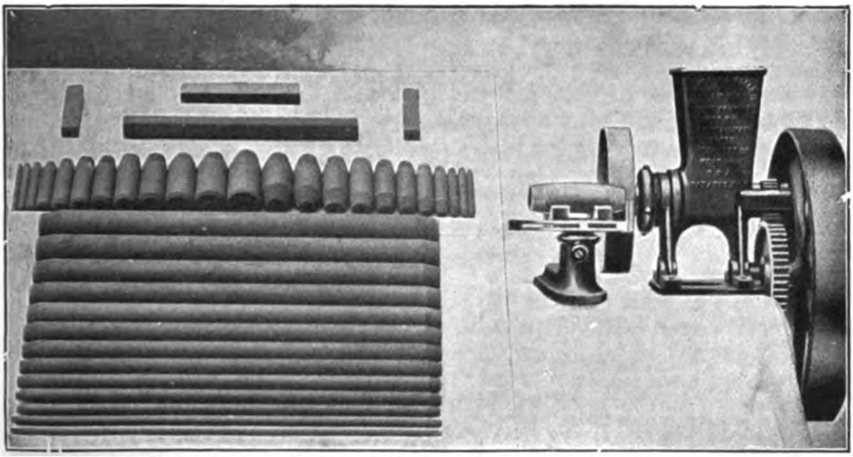

FIG. 124.—Wadsworth Core Making Machine.

The cores may be green or dried, according to requirements. No special mixtures of sand are necessary, so that, in certain classes of work, this machine will prove of high value

Each of the three machines illustrated has a good field in its own particular direction; the only criticism is that none of them admit of irregularly-shaped cores. Here the real difficulty of mechanical core-making is most evident, and the more intricate the core the less the chance of success. One or two British and German inventors have tackled the matter, and in general the principles adopted are as follows :—

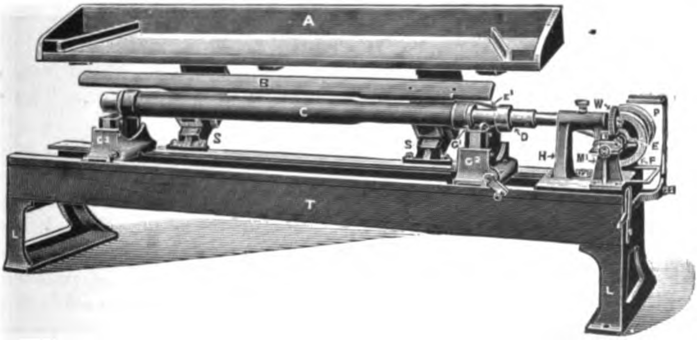

FIG. 125.—W. Jones' Pipe Core Making Machine.

The machine employed may be actuated by hand or by hydraulic power, the core being formed by squeezing sand between two half dies corresponding in form to the halves of the required core box. These dies may, of course, contain several cores, the actual number being determined by the size of the cores and the capacity of the machine. The lower die is set horizontally in the machine, and a filling frame laid over it, which serves as a guide for the amount of sand required. This frame is filled with sand, strickled off, and removed, leaving a cone-shaped heap of sand lying above the lower half of the core die. The top half of the core die is placed in position, and the halves pressed together by the machine. Surplus sand is squeezed into grooves cut at the side of the cores in both top and bottom dies. The top die is removed, a frame laid on and filled with sand, over which a plate is bedded. The whole is turned over, and the bottom die lifted off, leaving the cores lying in a bed of sand and ready for the drying stove. Fig. 126 gives the details of this method: *a* shows the lower die and filling frame, *b* the lower die filled with sand and ready for pressing. After pressing, the surplus sand is forced into the side channels, as shown in *c*; *d* represents the core ready for turning over, an operation completed in *e*.

Just as a metallic form may be pressed into shape by passing it through a series of dies, each one bringing it nearer to the final shape, so a mass of sand may be pressed in stages, the first of which gives a rough outline of the required form and the final stage the exact shape required. Machines have been designed on this principle, and are stated to produce good results.

The authors' experience is that, whilst cores of regular section can be produced by any one of the three machines first described, a departure from a regular section leaves hand core-making in possession of the field. Probably the future will see an improvement in this direction; but at the time of writing it must be admitted that the general run of irregularly-shaped cores are most cheaply and efficiently produced by hand.

Passing from the core to the mould, innumerable mechanical aids are to be found, and selection becomes a task of no little difficulty. Generally speaking, these aids may be divided into two main groups:—

(*a*) As an aid to moulding rather than output; and
(*b*) As an aid to output.

The first group is typified by gear-moulding machines, which are chiefly valuable for producing true wheels without using a pattern. The second group includes any mechanical aid to general moulding.

Gear-moulding machines are most extensively adopted in iron and steel foundries; they have been in use for many years, and are possibly more fully understood and appreciated than any other of the mechanical adjuncts of foundry work. In describing the sweeping of a spur wheel, it will be remembered that the teeth were formed by segmental cores set to a circle described from the spindle. Assuming that an arm carrying a pattern tooth block could be attached to the spindle, and a device affixed to the latter for withdrawing the block from the sand, then, obviously, the teeth of the wheel could be rammed up in stages. The authors have seen many makeshifts rigged up, based upon this crude idea, but its full development is realised in the gear-moulding machine. Several types of this machine are sold, and one or other of them is in common use in foundries. Generally, they may be divided into table and floor machines, although certain of the table machines may be employed in the dual capacity. In the table machines, which are employed for wheels moulded in boxes, the table carrying the box is revolved as the ramming progresses, the pillar of the machine remaining stationary. In the floor-moulding type, employed for wheels of large diameter, the pillar of the machine fits into a bed plate in the floor, and the arm carrying the tooth block pattern is rotated as the ramming progresses.

This type represents the earlier form of machine. It required a number of bases to be set in the floor, so that, on completing the teeth of one mould, the machine could be lifted into another base and a second one made. A further disadvantage lay in the fact that wheels of small diameter could not be made. With the table machine, in which the box is rotated, comparatively small wheels may be made, and on completing the teeth of the mould the box is lifted away and the machine left free for another mould. The arms and boss are formed by dry sand cores, as in the case of a swept gear wheel. Gears for casting in steel are of compo, and dried before fixing in the cores; if for cast-iron, they may be cast green or dried, according to the weight of the wheel.

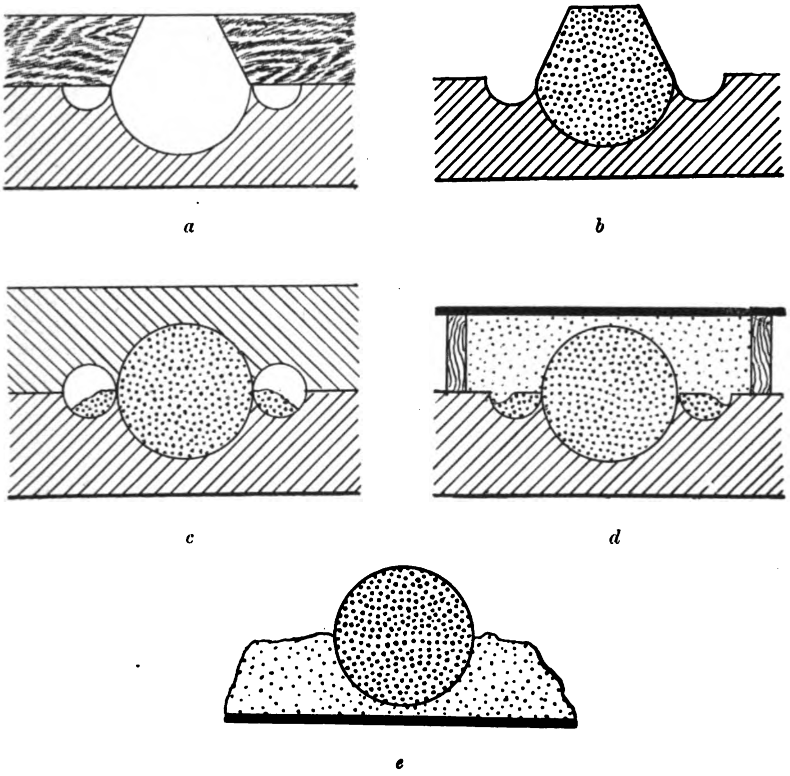

FIG. 126.—Mechanical Method of Making Cores.

The essentially mechanical parts of these machines are the dividing mechanism and the method of withdrawing the tooth blocks. Withdrawal may be effected, according to the type of machine and the character of the teeth, vertically, horizontally, or at an angle. The dividing mechanism is comparable to that of the screw-cutting lathe, and almost any number of proportional relationships may be established between the number of teeth in the dividing wheel of the machine and the wheel to be moulded. Instructions for this division are either attached to, or supplied with, each machine; but, as a general rule, the following may be given:—

"As the number of teeth in the dividing wheel is to the number of teeth in the wheel to be moulded, so is the number of teeth in the wheel on the handle shaft to the number of teeth in the wheel required on the worm shaft."

Having set the dividing apparatus for the requisite number of teeth, the moulding of the wheel is comparatively simple. A bed is strickled at a depth equal to the wheel face, and the teeth are then rammed up. The pattern tooth block has usually two teeth, and the space between the teeth is rammed, that is, one tooth is rammed at a time. Sprigs for strengthening, venting, and other arrangements, according to the character of the teeth, are carried out in the usual manner. In the case of spur wheels, the tooth block is drawn vertically, and, to prevent a tear, a strip of sheet-iron cut out to the form of the intermediate tooth space is held and lightly pressed over the sand by the left hand, whilst the right hand actuates the hand wheel for drawing the block. The tooth block may, by means of universal joints, be set at any desired angle on the slide, and adjusted to enter and leave the mould in any direction. This is of special moment in the case of helical and bevel wheels.

Machine Moulding as an Aid to Output.—Quality of the product is assumed to be equal or superior to hand moulding, and the distinction is that mechanical aids are directed to an increased output at a decreased production cost. Various forms of subdivision are permissible, the one most consistent with our purpose is as follows:—

Hand-moulding Machines.

(*a*) Presses, actuated by a lever with the sole object of ramming or compressing the sand. Patterns are withdrawn by hand.

(*b*) Machines which, by means of a falling platform or lever, draw the patterns from the mould. The moulds are hand rammed as usual.

Power-moulding Machines.

The various types of these machines are designed to ram the mould and separate it from the patterns. They may be actuated by means of steam, hydraulic power, or compressed air.

Hand presses or "squeezers" represent the most simple and adaptable of any of the mechanical aids. Loose patterns bedded in a plaster or oil oddside, or fixed patterns mounted on a plate, may be moulded in either boxes or snap-flasks. The squeezer may be profitably employed on changing patterns, and there is hardly a brass, iron or steel foundry in which one or more of these presses may not be put to good use. Fig. 127 shows the "Farwell Press," made by The Adams Company, Dubuque. This press will squeeze the sand in any box or snap up to 24 inches by 18 inches and up to a depth of 10 inches. Larger sizes are obtainable, but that illustrated represents one of the most useful sizes. The action of the press is as follows:—

A bottom board and oddside are placed on the two cross-bars, forming a table and bottom part of box or snap placed in position. Facing sand is spread over the patterns, and tucked into any pockets; floor sand is filled in and piled to about 2 inches above the bottom part. A stout flat board is then laid over the sand, the lever of the press pulled forward, which brings the plate of the press over the box, and a further depression of the lever compresses the plate, thereby squeezing the sand in the mould. A return of the lever throws the plate clear of the box, which is then strickled, vented, and turned over on to a board, and made ready for the top part. The latter is rammed in the same way as the bottom part. A runner peg, the exact depth of the top part, may be used, or the runner may be subsequently cut through by means of a tube, the latter plan being the more convenient. The box is parted, patterns drawn, and the mould finished as usual.

It will be seen that one movement of the lever rams one part of the box, and even in a comparatively small box, say 12 inches by 12 inches, this means a considerable saving of muscular effort. Various types of presses are made. The one illustrated is stationary, and the moulds are carried away from it on completion. Other types are mounted on wheels, and are, therefore, portable; but we have never found any special advantage due to this feature. Another type of press, known as the Economic, is permanently bolted to a pillar, and is actuated by means of a geared eccentric in direct connection with a toggle working a plunger over the top of the mould.

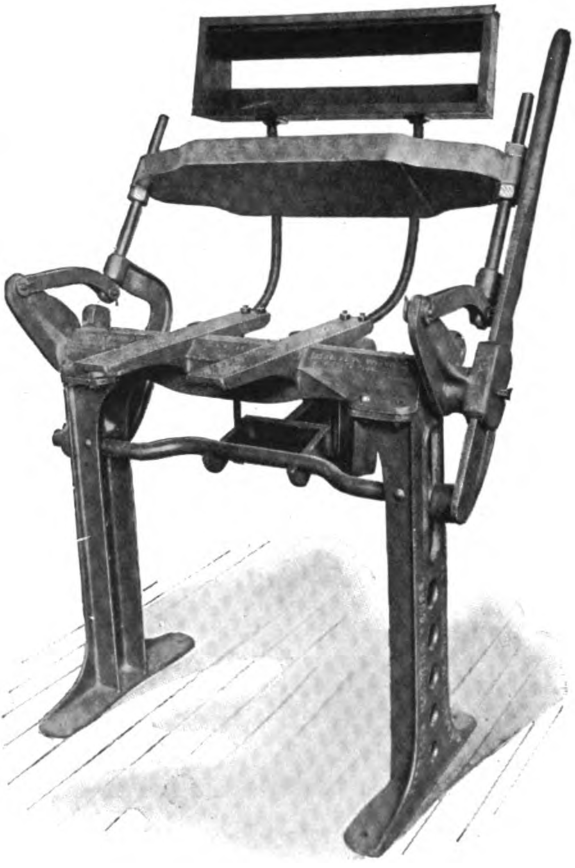

FIG. 127.—Farwell Press.

With any type of press, boards may be cut to follow the outlines of the patterns; and these, when placed between the plates and sand, to some extent secure equal compression in all parts of the mould. In other cases, flat boards may be cut to fit inside the box, which is then only filled to the top, so that, after compression, the sand will be of less depth than the box. Personally, we find the best and least troublesome plan to lie in tucking in any pockets or irregular parts by means of the fingers, and in piling the sand to a depth which, after compression, will allow of strickling level with the box edges.

The next class of machine, in which the object is to effect a mechanical parting of patterns from box, is a large one. We can only select the most typical examples, and these are confined to machines we have actually used. Here the falling platform type is by virtue of longer use the most familiar. Briefly, the principle is that of fixing the patterns on a table which may be turned completely over. On this table, with patterns uppermost, a half-box is cramped and rammed up by hand as usual. The table is reversed, the platform raised until it bears entirely on the box, cramps of which are then released, and the platform gradually lowered, bringing with it the half mould and leaving the patterns attached to the turnover table. On reaching its lowest position, the platform can be drawn forward by sliding on two rails, and ready access is thus given to the mould. Fig. 128 illustrates one of these machines by Darling & Sellers of Keighley. Various types are made by this firm, the one illustrated has a 30-inch turnover table, and will take boxes up to, and including, 24 inches by 18 inches. The distance between the table and platform can be varied from 4 to 28 inches. The falling gear is controlled by the hand wheel shown on the left of the illustration, which is spur geared to racks on the platform, and, as the latter is balanced with adjustable weights, raising or lowering is performed with a minimum effort. In another type of machine, made by the same firm, the falling platform is controlled by means of a lever, but otherwise the general principle is the same.

The method of working has been roughly indicated. Patterns may be attached to the tables in various ways, but in our experience the best results are obtained by working from oddsides or plates, preferably the latter. Interchangeable boxes are an essential, and, in the case of plate moulding, a master box for the plate is desirable. This box is fitted as usual, but, in addition, is provided with fitting strips inside and just below the joint face. These strips are machined out to such a depth that the pattern plate may be sunk in the box, with its upper face dead level with the box edges. Plate and box are then fixed to the table, and the requisite number of half moulds rammed up, parted, and set in position on the floor. The plate is then reversed, and a second set of half moulds to complete the first set, rammed and parted as before. An ordinary plate lying between the two half boxes may be used, but the method of sinking the plate into a half box until it is flush with the joint is the best plan. Should the patterns all be on one side of the plate, requiring only a flat top part, this may be rammed up directly on the platform of the machine.

Hand machines which draw patterns directly from the sand introduce a new feature, namely, the stripping plate, the function of which is to prevent a tear when parting the pattern from the mould. The patterns are mounted on a flat plate, and raised from the surface by a thickness equivalent to that of the stripping plate. The centre of the stripping plate is cut out to correspond with the outline of the patterns, so that when the pattern plate is drawn downwards the stripping plate holds the sand in position. It will be seen that this method involves, in cases where a flat top part cannot be employed, two pattern and two stripping plates, that is, one each for the top and the bottom part of the mould. The respective half moulds are made separately, and assembled for casting. In the case of small orders, both pattern and stripping plates may be of wood; but when large quantities are required, metal plates are more effective. Stripping plates are cast with holes corresponding to the outline of the patterns, but larger in all directions. Sprigs are cast in the body of the plate, with heads projecting into the cored-out spaces. Both pattern and stripping plates are planed level, and, after mounting the patterns, the stripping plate is laid over the pattern plate, its position accurately adjusted, and the space remaining between the roughly-cored holes and patterns is filled in with a fusible white metal. Any type of low melting alloy will answer, and the following is given as a guide :—

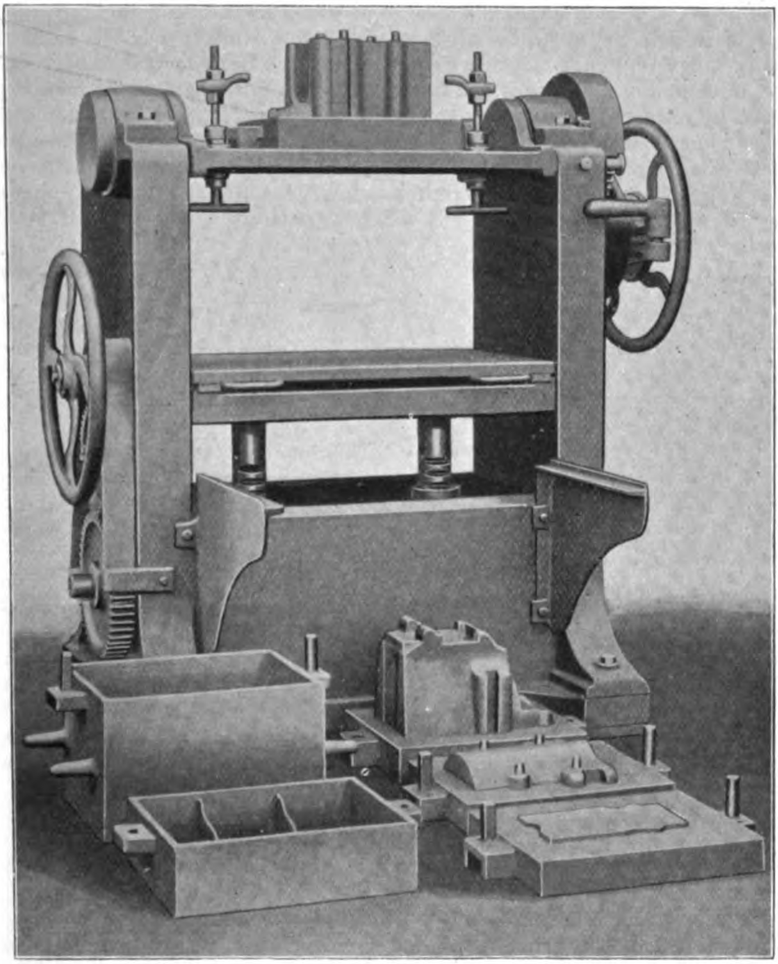

Fig. 128.—Darling and Sellers' Moulding Machine.

Tin, 62 per cent. Lead, 31 per cent. Bismuth, 7 per cent.

After filling in, the upper face is levelled with that of the plate, and the lower edges are bevelled a little in order to lessen the friction when drawing the pattern. Evidently, a stripping plate may be, and is, used with ordinary hand moulding. When used in hand-machine moulding, the sole mechanical device consists in an attachment for lowering the patterns through the stripping plate. An exceedingly good device for this purpose is the Pridmore machine, which is largely used in British and American foundries. In effect the general principle of these machines is as follows:—

The machine consists of a stiff, but, in some cases, portable frame standing on the floor. Adjustable guide ways are provided in and near the top of the frame on which the stripping plate is supported, whilst in the base of the machine there is a single centrally located guide. The construction gives, in effect, a long rigid guide, in which the yoke carrying the patterns is raised and lowered by means of a depending pitman, crank shaft, and lever. The crank shaft is journalled in a brass bushed box, secured to the bottom of the upper frame. The yoke is held in its highest position by the crank pin passing slightly beyond the centre and striking a stop. Means are provided for regulating the amount of draw to suit different patterns. Adjustment is also provided for taking up wear on the guides and crank pins. The machines are built in various styles and sizes, and a choice is thus offered for moulding practically any type of casting on them. Fig. 129 shows a square stand machine; such machines may be worked either singly or in pairs, that is, one machine may be employed on bottom parts and the other on top parts. A plan of working advised by the makers is that of drawing the smaller machines forward along the length of a working floor. By this plan the boxes are set down in position for casting without having to be carried any distance, and, at the same time, the machine follows the sand supply. So far as our experience goes, we have not found very much advantage due to this plan, and, in comparative tests, we have obtained practically the same results with the machine in a stationary position. This, however, is a matter that will vary with individual cases.

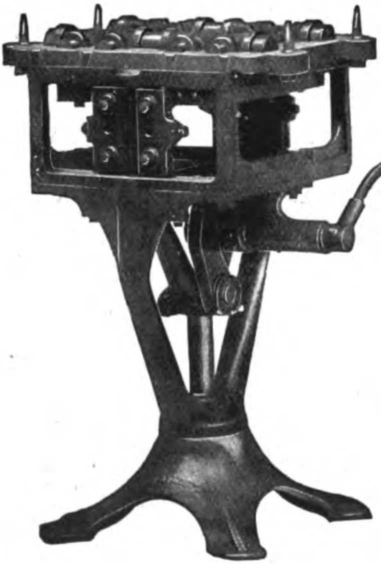

FIG. 129.—Pridmore Single Stand Moulding Machine.

As already noted, orders may be executed by mounting the patterns on wooden plates, and providing wooden stripping plates; for large orders, metal patterns and plates are essential to a full output. In addition, the requisite number of interchangeable boxes fitting the size of machine are required. With the larger sizes of machines, cross-bars in the boxes may be dispensed with by making the sides of each half box in the form of < which adds considerably to the rigidity of the rammed sand.

A combination of press and pattern drawer is found in the Farwell universal moulding machine. This machine, illustrated in fig. 130, is practically a press provided with lifting mechanism located below the stationary press table, and operated by means of the lever shown. The elasticity of this machine is shown in the fact that it may be worked with a stripping plate, or as a lifting machine, in which the mould is lifted off the patterns, the latter being mechanically rapped whilst the box is being lifted.

When used with a stripping plate the pattern rests firmly on the stationary press table, with the stripping plate lying over it. Studs from the lower side of the stripping plate pass down and rest on the lifter table. These studs engage with guides on the pattern plate, and guide the stripping plate in its upward movement. On raising the lifter lever, stripping plate and mould are lifted off the pattern plate.

When the machine is used as a lifting machine only, patterns are mounted on one side of a wooden or metal plate, provided with holes near the front and back edges, through which loose studs are passed down on to the lifting table. When the lifter lever is raised, these studs engage with the edges of the box, and so lift the mould clear of the pattern plate. At the same time a rapping bar is vibrated, thus ensuring a clean lift. It will be seen from this brief description that the Farwell is an exceedingly adaptable machine; this, added to the fact that all operations are conducted by hand, enhances its value for the ordinary iron or brass foundry.

Fig. 130.—Farwell Moulding Machine.

Power Machines.—Various types of power machines are on the market: the majority are founded on one or other of the principles applied in hand machines. Whilst power machines may be employed simply to compress a mould, such a course is unusual and also unprofitable. The majority of machines will compress and draw the pattern from a half mould: a few of them will conduct these operations on a complete mould. Stripping plates may be employed, or, in their absence, a vibrator is attached, which automatically raps the pattern plate as the mould is being lifted off. Moulding-boxes or snap-flasks may be used, according to the type of machine and character of patterns. Operation may be by the aid of compressed air, hydraulic power, or steam. This arrangement also gives the order of merit of the respective sources of power. Whilst steam is usually available, it is not by any means an ideal source of power for operating moulding machines; at any rate, this is our experience. Hydraulic power and compressed air are equally applicable, but, unless water under pressure is available, it will be found more convenient to instal an air compressor.

Fig. 131 gives a type of hydraulic machine, the action of which is as follows:—One half of a moulding-box F is placed on the pattern plate T and the other half F_1 on the trolley W. Both half boxes are clamped to the pattern plate by means of the clamps *h* and *h'*. The top half box is filled with sand, the plunger K raised, and the whole pressed against the stationary head G. On returning, the plate is arrested by ferrules S, is then turned over, and the process repeated on the half box F_1, which is now uppermost. The method of parting mould and pattern is shown in the illustration; and it will be noted that, on lowering the plunger, the trolley will engage the rails and so permit of a forward withdrawal of the mould.

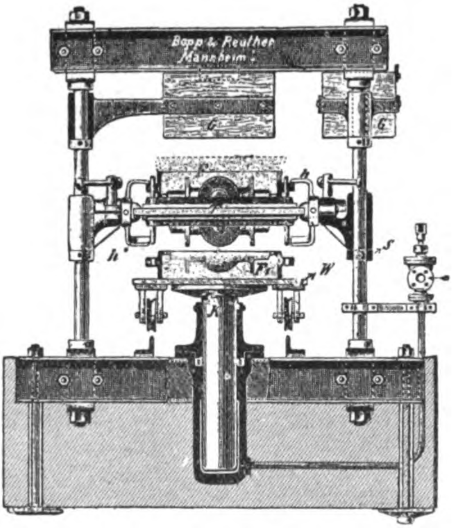

Fig. 131.—Hydraulic Moulding Machine.

Many types of hydraulic machines are made, and an examination of fig. 131 will suggest to the moulder directions in which modifications are made to suit special classes of work. For example, in the case of shallow work such a machine can be made to ram top and bottom parts at one operation. Thus, if the bottom box is filled with sand at the same time as the top box, then, on raising the plunger and compressing the mould, the pattern will be forced into the bottom box. In particular, one type of machine, patented by Leader, will simultaneously ram top and bottom parts, withdraw the pattern, and close the mould ready for casting. This is effected by having the patterns mounted on both sides of a plate swinging to and from the machine, and at the same time capable of vertical movement. Two circular frames, which serve the purpose of boxes, and a plunger for ramming, constitute the machine. An auxiliary plunger is constituted within the ramming plunger, and its purpose will be indicated in the following explanation:—A flat cast-iron plate is laid in the lower frame, which is then filled with sand and strickled off. The pattern plate is swung into position, the upper frame lowered on to it and filled with sand. The plunger is then raised, and the whole pressed against the stationary head of the machine. On reversing the valves and lowering the whole, the top part is arrested first, the plate and bottom part descend a little, and then the plate is arrested, the bottom part descending the full length of the return. The pattern plate may then be swung clear of the machine, leaving access to the bottom part for setting any cores that may be required. The top part is lowered by hand on to the bottom part, thus closing the mould, and the latter is then raised by means of the auxiliary plunger until clear of the two frames. By means of the bottom plate it can then be lifted away from the machine and set down for casting. Practically, a mould so produced is really a complete core; the only tackle required, so far as the moulds are concerned, being the bottom plates. This machine represents the nearest approach to a mechanical moulder we have yet seen, and on shallow work is capable of an extremely large output.

One of the most familiar examples of a machine operated by compressed air is the Tabor pneumatic machine, which is made in various styles to suit special requirements. With the type in which patterns are mechanically drawn, fig. 132, pattern plates containing half patterns on one side only are mounted as usual and filled with sand, the ramming head is then drawn forward, and air at a pressure of about 70 lbs. per square inch admitted to the cylinder. This lifts the upper portion of the machine forcibly against the ramming head, and, according to the depth of the mould, one or more blows are given. On exhausting the cylinder, the machine returns to its original position, and is then ready for the withdrawal of the plate. This is effected by means of a lever worked by the right hand, whilst the left hand presses a valve admitting air to a pneumatic vibrator. In one sense the action of this vibrator is comparable to hand rapping, but with the distinction that no actual movement occurs in the pattern plate, which is more nearly akin to a condition of shivering. A half mould is produced in an extremely short time, so that these machines will turn out a large output per day. If the patterns are such as admit of horizontal division along a centre line, then a series may be mounted on one side of a plate, two moulds from which will give a set of complete castings. Thus, on lifting a bottom part from the machine, it has to be turned over in order to be set down for casting. A top part is lifted straight off the machine, and in this position is ready for setting on the bottom part (see fig. 120).

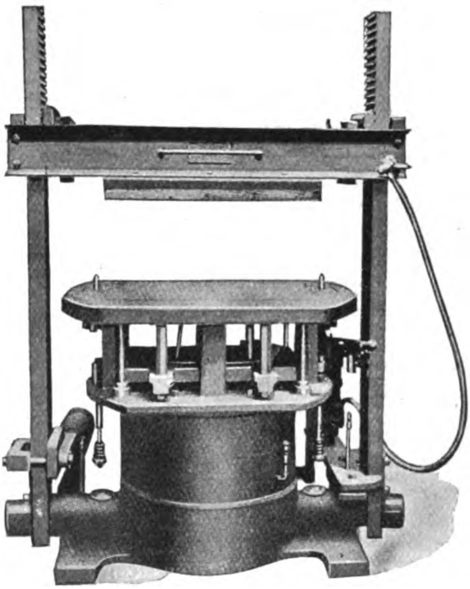

FIG. 132.—Tabor Pneumatic Moulding Machine.

The Choice of a Moulding Machine.—Whilst it is quite out of the question in a work of ordinary dimensions to refer to each individual machine at present in use, it is even more difficult to give any cut and dried philosophy on the choice of a machine. Whilst that choice is largely determined by the amount of repetition work on hand, other determining conditions peculiar to each individual foundry come into play, and naturally the limiting nature of these conditions can only be determined by the individuals most directly concerned. Apart from these we offer the following generalities, which may be useful if supplemented by a perusal of manufacturers' catalogues.

It has been shown that cheap, but efficient, pattern plates can be readily constructed by mounting divided patterns on a board. Such a board worked in conjunction with a hand press will, under good supervision, leave very little to be desired in the way of low production costs. This plan will admit of small quantities being produced in competition with repetition work. Loose patterns on oddsides may also be worked on the hand press.

With ordinary small work, such as is usually included in boxes up to 14 inches by 16 inches, the greatest time consumers are (1) ramming, (2) jointing, and (3) setting cores. Jointing is largely obviated with a good oddside, and altogether so with a plate. Ramming by the aid of a press reduces the time occupied to that required for the pulling forward of a lever. Obviously, then, the greatest time consumers, with one exception, may be very considerably reduced by the simple and inexpensive aid offered by plate moulding and the hand press. The exception referred to is that of setting cores, and, whatever form of mechanical moulding may be adopted, this exception will be found to hold good.

Pattern drawing does not take up so much time as is usually supposed, and a moulder who cannot draw a small pattern without damaging the mould is not worthy of the name of moulder. The advantage of hand-rammed pattern-drawing machines is that the fully qualified man can be replaced by one of less experience. With these machines, jointing and pattern drawing are eliminated, and, in certain cases, the initial outlay is comparatively small. On standard, but changing work, our best results in machine practice have been obtained from the hand press supplemented, in the case of deep patterns, such as flanged valve bodies, etc., by the hand-rammed pattern-drawing machine. Accessories, in either case, are not costly, the output is high, and the quality good. Our best results on standard work, in which one plate could be run for at least 300 moulds, have been obtained from a pneumatic vibrator machine. If the same plate could be run over a period of four or five days without changing, then production costs fall very considerably, but such conditions only hold good in foundries producing large quantities of repetition work.

Whatever may be said to the contrary, stripping-plate machines involve costly accessories; but this outlay is warranted, if the patterns are of a sufficiently standard character. These machines are specially good on intricate patterns, such as small spur wheels or others having little or no taper on the sides.

Whilst hand machines of any type represent a low first cost, the cost of subsequent accessories must not be forgotten. Power machines represent a higher initial and maintenance cost; but, if they can be maintained in constant operation, they give a low production cost. Finally, the chief drawback to the further development of machine moulding of any type occurs in core-making and core-setting. An improvement in the mechanical production of irregular cores will result in a very considerable advance in machine practice.

CHAPTER XVII.

DRY SAND MOULDING.

So far as actual moulding is concerned, the methods employed in dry sand are practically those practised in green sand work. The only essential difference is that the mould, after completion, is dried before being cast; hence, it follows that the sand forming the mould must be of such a nature that it will dry into a porous, but not friable, mould. This demands a strong sand of a similar nature to a core sand, and such that, if the skin of the dry mould is started, the sand below will not crumble away. Ordinary green sand can be dried, but, should the face of the mould be broken, the sand is so friable that it crumbles and washes before the metal. Practically every foundry centre has a natural sand available for dry work, and the rotten rock of the Clyde valley is an example of one of the best of these sands. In the event of a natural sand not being available, an artificial one can be compounded by bonding a weak sand with clay. Thus, a passably good dry sand is obtained by adding clay to old floor sand and milling the mixture. The clay addition is solely to bind an open and incoherent sand, and, for obvious reasons, an excess must not be used. Mixtures of dry loam and green sand are also used, the loam being added in sufficient quantity to give the requisite grip.

Sand mixtures are applicable to brass, bronze, and steel castings, and, whilst the greater bulk of steel castings are made in dry moulds, the facing used is an artificial "compo," made up for the most part of a mixture of burnt refractories, such as old steel-melting crucibles, fire-bricks, and fire sand. All heavy brass castings are made in dry sand, and the sand used is rock, Mansfield, Staffordshire, or Erith, and similar kinds, bonded, if necessary, by clay and opened by horse-dung. Should none of these sands be available, a mixture is made up as indicated. Iron castings of considerable weight may be made in green sand, but, if the casting is at all intricate, as, for example, a steam cylinder, a dry mould will give a better result.

The amount of drying given depends on the character of the mould and the metal entering it. Thus, all moulds for steel castings should be bone dry, and, owing to the high casting temperature, faced with refractory compo. However, exceptions are met with, and the authors in several cases have found a skin-dry sand mould preferable. As would be expected, a bone-dry mould of compo which sets very hard is a comparatively unyielding thing, and, as such, will retard the free contraction of a casting made in it. This obstacle is readily removed in the case of a massive casting by releasing those parts of the mould which bind, as, for example, by digging out the arm cores of a large wheel. With a large intricate casting of light section, parts of the mould which bind cannot be loosened in sufficient time to allow face contraction; hence, in certain cases, a yielding mould is preferable. This is accomplished by making the mould from a good red sand, and drying the skin to a depth of half an inch or thereabouts. Skin drying may be effected by laying fire-baskets over the mould, and burning in them either coke or charcoal; or the moulds may be dried by means of red-hot ingots or plates. The most convenient plan is to cover the mould with naphtha, by means of a small watering-can, and to apply a lighted match. In storing and handling naphtha, its dangerously inflammable character should be remembered. When lighting a mould covered with naphtha, a match should be applied to the edge, and the face held away, as the flame, instantaneously formed, shoots straight up.

Whilst skin-drying is only applicable to steel castings in the limited sense indicated, it is very largely applicable to all types of iron and brass castings. The whole, or a portion only, of the face of an ordinary green mould may be readily dried by a hot plate or a little naphtha. This is of special advantage in the case of projecting pockets of sand which may be readily stiffened to resist the washing action of a stream of metal. Apart from this, any part of a mould which has had to be patched and unduly swabbed may have the surplus moisture readily driven off. In the case of large brass castings, such as large step or tread plates, name plates, and the like, which are notoriously thin, skin-drying is a considerable assistance in obtaining a fully-run casting. It should be remembered that a skin-dry mould, after drying, cannot be touched on the face; it should not be dried until nearly ready for casting, or the damp will strike back, and it should not be closed until the last moment.

A bone-dry mould presents very different conditions to a skin-dry one; in the first place, the whole of the added or hygroscopic water has been expelled, and this fact allows considerable latitude in making the mould. Thus, a comparatively close sand may be used with harder ramming and less venting than in the case of a green mould. The expulsion of water by drying is a most efficient substitute for the vent wire, and a compact sand in the green state will dry comparatively open and porous. By the same token the risk of scabs, buckles, cold shots, etc., is considerably lessened; therefore, a dry mould is always safer than a similar green one; and wasters in dry sand are less excusable than in green sand. This lessened risk is a good off-set against the cost of drying; and, further, the actual moulding operations are often more quickly performed in dry sand than in green sand; hence, in certain cases, total costs compare very favourably with green sand. This is, however, a matter determined solely by the character of the patterns; for example, a mould having several cores which require chapletting down would, if made green, occupy a fair time in making the chaplets rigid; whereas, if made in dry sand, the surface of the mould offers, in the majority of cases, sufficient support for the chaplets. Hence, in the case of an externally plain casting, which could be readily made in green sand, internal cores may actually make a dry sand mould the less costly of the two. As another example, ship's bollards of 30 cwts. or thereabouts may be made either green or dry, but experience shows that comparatively little advantage is gained by drying, and that actually green sand will produce the same quality of casting at less cost. On the other hand, small steam-engine cylinders of 5 cwts. or so, which may be made green or dry, will, in the latter case, not only give a better casting, but also a less costly one.

The choice of method, therefore, depends largely on the type of casting, and, in iron at any rate, not so much on its actual weight. As a rule, hydraulic and steam castings give better results in dry sand; castings poured in a vertical position, cylinders, liners, water-pipes, and so forth, are made in dry moulds, because of the pressure exerted on the bottom of the moulds by the depth of metal. Similar castings in green moulds would swell at the bottom, and, if rammed hard enough to resist swelling, would very likely scab.

As a general rule, all brass castings exceeding 1 cwt. should be made in dry sand, owing to the fact that masses of brass or bronze have a very searching effect on a green mould. Whilst heavy brass castings can be made in green sand, the extra trouble involved in providing against both searching and scabbing renders the method more costly than that of drying. As already noted, practically all steel castings are made in dry moulds, the chief reason lying in the high temperature of fluid steel and its tendency to unsoundness.

As stated in the opening sentence, methods of moulding are the same; thus, complete or skeleton patterns are used, moulds may be swept up and the sides formed by means of cores, etc., by any of the methods already noted for green sand. With some sands it may be necessary to sleek the joint down a little before drying, in order to prevent a crush when closing the dry mould, a plan always adopted in the case of moulds faced with compo. The facing for a dry mould is always applied wet, and not shaken on as in the case of a green mould. With skin-dry moulds either wet or dry facings may be used: but, in the case of a bone-dry mould, the facing is always painted on wet. Types of facings or blackings have been dealt with in Chapter IV.; it may, however, again be noted that pure plumbago in the majority of cases is decidedly the best; and though more costly than "mineral blacking," that is, very fine coal dust, the better skin of the castings is good warranty for its use. Further, it may again be noted that although plumbago and blacking destroy the true brass colour of a brass casting made in a green mould, such is not the case when these facings are applied wet to a dry sand mould.

According to the character of the mould, it may be painted before drying, or after drying, so long as the mould has sufficient initial heat to dry the facing. Plain moulds, such as propeller blades, are painted green and stoved. After drying, if any cracks are present on the face, they are touched up with oil and plumbago, and on all dry moulds oil is used in the same way that the water swab is used on a green mould. Pipe moulds are coated whilst green, and, as hand painting is out of court, various devices have been applied for distributing the liquid facing evenly over the surface of the mould. Thus, the mould may be plugged at the bottom, filled with blackwash, and then drained from the bottom. With large pipes a leather disc mounted on a long rod is placed a short distance in the mould, and two or three buckets of blackwash poured over the top, an up and down movement of the disc serving to distribute the blackwash evenly over the surface of the mould.

Examples of moulds painted after drying are found in toothed wheels and kindred moulds of uneven surface. Finally, it must be noted that, whatever type of blackwash is used, the coating must be evenly applied and the sharpness of any angles must not be obliterated. Many moulders sleek a plain mould, and, when this plan is followed, a good skin is obtained by painting the mould with mineral blacking, shaking a dust of dry plumbago over the wet surface, and sleeking down with tools. Personally, we have not found sleeking of very great advantage on dry sand work, and an initial coating of unsleeked plumbago will give as good a skin as can be desired. This remark is applicable to dry sand castings in almost any metal or alloy.

Methods of drying the moulds vary, but a strong tendency is exhibited towards obtaining better value from the fuel consumption and shortening the time of drying. A mould made in the floor must, of course, be dried in position, but its top parts and drawbacks may be dried in a stove. Similarly, all complete moulds made in boxes may be stoved.

When dried in the floor, fire-devils or fire-baskets are hung in the mould; but in the case of a large mould, fires are built directly over or surrounding the mould. Thus, bearer bars are laid across the mould and covered with perforated plates on which fires are laid. In the absence of a stove, the top part may be suspended over the fire, care being taken that the flame shall not catch the sand and so burn it. Open firing of this kind is done during the night or whilst the foundry is at rest. Obviously, the method is not economical, for, apart from the setting of the fire, considerable time is occupied in removing the ashes, plates, etc., and in cleaning the mould preparatory to closing.

The ordinary drying stove is a brick chamber, supplied with fire grates according to its size, and furnished with a set of rails and carriages on which the boxes for drying may be loaded. The rails from the stove are continued into the foundry in order to bring the carriages within reach of the cranes. The grates may be fired with coal or coke, the latter being preferable, as it does not leave a sooty deposit on the moulds, and the foundry atmosphere is clearer should the stoves be at work through the day. The grates may be fed from the inside, in which case they generally consist of large baskets which are filled up before the carriages enter the stove. In other cases, they may be externally fired, thus giving the advantage of continuous firing without opening the stove doors. The latter are constructed of plate and angle iron, and, as a rule, slide up and down in guides, being assisted in this movement by means of counter weights. Where space in front of the stoves will permit, doors divided in halves and opening outwards are more convenient. The principle of all drying stoves is that of slow combustion, and the moulds are dried by means of heated air, therefore the chambers should be built so as to give the least loss by radiation. Not only so, but the current through the stove should be such that whilst the watery vapour is carried off a minimum of sensible heat is lost. This is attained by having flues at or near the floor level and at the opposite ends to the grates. These flues may be connected to a short stack, but will be found to be as effective if simply led into the open. In any case, a brisk current through the stove should be avoided.

The usual method of getting the carriages into the stoves is by means of a long bar used as a lever between the wheels and the rails; and, in the case of a carriage fully loaded with green moulds, this operation is sometimes heavier than it need be. Assistance in this direction can be obtained by giving the track a slight inclination towards the stoves; for withdrawing the carriage a chain is hooked on to the end, passed through a block imbedded at the end of the track, and connected with a crane.

Many types of drying stoves could be given, but the simple view of a heated chamber, as outlined, practically covers all the more ordinary types of stoves. A stove introduced by Mr J. B. Thomas[1] possesses many special features. Practically, the stove consists of two chambers, both heated from one grate. The temperature aimed at is 475° F., and a pyrometer is used for indicating and thereby regulating the working temperature. Reference to figs.

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[1] *The Foundry*, vol. xiii., No. 73.

133 and 134 will at once show the construction and method of distributing the products of combustion. The latter are drawn from the grate A over the arch B, where they unite with cold air drawn through the opening C, the idea being to pass a large volume of air through the ovens in order to carry away the moisture from the moulds. From thence the gases pass along the flue D and into the distributing box E, built into the partition wall between the two compartments. Openings are placed on either side of this box, about three feet below the roof, through which the hot gases are distributed into the stoves. If desired, a damper can be fitted, so that all the gases may be passed into one stove in the event of the two not being required. The current through the stove is regulated by means of flues J. J., and the hot gases are drawn downwards through the openings shown and into the stack. By this arrangement the hot gases are compelled to pass downwards, and contact with the green moulds will exchange heat for watery vapour which is drawn away. Thus an efficient current can be maintained and the moulds quickly dried without burning.

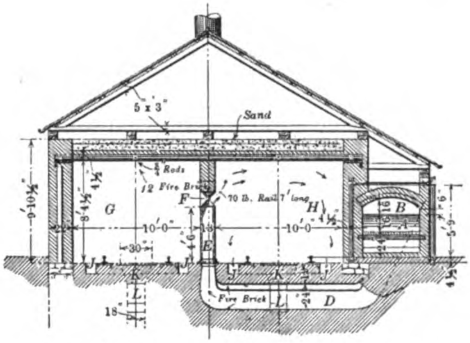

FIG. 133.—Drying Stove (Cross Section).

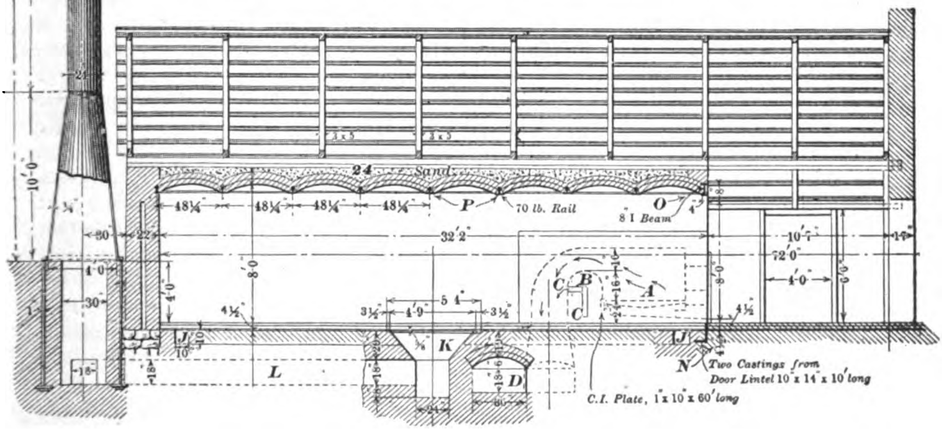

FIG. 134.—Drying Stove (Longitudinal Section).

Although, in the foregoing case, the grate is not described as a gas producer, it could almost be regarded as one, since it is the source of a current of heated air by which the moulds are dried. An external grate can be fitted in the form of a small producer, and, working on the principle of incomplete combustion, give rise to a stream of combustible gases which may be led into the stove and by admixture with air be burnt in the actual drying chamber. Reference to fig. 197 (p. 266) will show an annealing furnace worked on this principle, that is, with a self-contained producer. Whilst a stove so heated is a decided economical advance on one fired by solid fuel, a still further advance is found in having a central generating station. In the case of large foundries having several drying stoves, this plan is possible, but hardly so in the case of a small foundry having only one or two stoves. Any type of producer gas is applicable; thus, if a Mond plant is on the works, the mains may be tapped and led to the foundry drying stoves. Steel foundries may draw their gas from the same source as that supplied to the open hearth furnaces; and, if a blast furnace is available, as is often the case with pipe foundries, a portion of the waste gases can be put to good use in the foundry stoves. Methods of combustion vary, but a simple and efficient plan is to have a series of openings parallel with the carriage rails, and to burn the gas in the form of jets at each opening. Methods of regulation lie in stopping off one or more jets as required. More elaborate methods consist in having regular combustion chambers, which, in a limited sense, are comparable with the ports of an open hearth furnace. In such cases the amount of gas emitted is regulated by a mushroom valve in the gas main, and the requisite air for combustion is drawn through openings at or near the point where the gases are burnt.

Oil as a foundry fuel is naturally of greater interest to American than British foundries; however, when employed in drying stoves various devices have been designed to attain full heat value from the fuel. A point of moment lies in the fact that these devices all require compressed air, a decided drawback from a foundry point of view, since drying is more conveniently done during the night, when the mechanical plant is, as a rule, shut down. The following ingenious device is, however, well worth attention. In a paper read before the Philadelphia Foundrymen's Association, Mr S. E. Barnes described his method for heating drying stoves through the night when compressed air was not available. Steam is substituted for air, and the stove arranged to generate its own steam. The generator is a cast-iron return pipe 3 feet long, placed in the fire grate with one end connected to the town water-supply, and the other or steam end to the burner. The internal diameter of this pipe is ⅞-inch. When starting, all cold, oil is first sprayed by means of compressed air; water is admitted to the return pipe; and in a few minutes a steam-raising heat is reached. The air is then shut off and the oil sprayed by steam only. In order to attain the necessary oil pressure, town water is led into the bottom of the oil tank, thus forcing the oil upwards. The flow of oil is regulated by the steam pressure, which automatically opens or closes the oil valve with a rise or fall in steam pressure. Should this pressure cease, the oil valve is closed and locked. Fig. 135 gives a plan of the apparatus, and from it the automatic character, after the first generation of steam, will be noted. It is stated that two stoves, each 9 feet by 16 feet by 12 feet, averaging 3 or 4 tons of sand per stove per night, give an oil consumption of 90 gallons per day, crude oil at 4 cents per gallon being employed.

Bedded-in moulds, as already noted, have to be dried in the floor; and the method of open firing, apart from other objectionable features, is costly in both labour and fuel. Drying by hot air is applicable to this and other classes of work, the principle being that of forcing a current of heated air through the closed mould. Fig. 136 gives an elevation and a sectional view of Sheddon's portable mould drier, and represents a type we have found of decided advantage in drying iron, steel, and brass moulds. Briefly, the apparatus consists of a rectangular steel chest, the angle irons of the corners being continued to form legs. Internally the box is lined with fire-bricks set in fire-clay, and is divided into two portions, as shown, the dividing wall being carried up to within 2 inches of the top. At the front of the chest a valve casing is fixed containing, respectively, an admission valve and two inner valves, one at the bottom for admitting air up through the fuel, and one at the top for mixing with the heated air and rapidly forcing it over the dividing wall down through the second chamber and into the mould. The discharge pipe of fig. 136 is fixed directly over an opening in the mould for the admission of heated air. Blast may be obtained from a small direct-coupled electric motor and fan; or a stationary fan feeding a service pipe laid in the foundry floor may be used. In the latter case, suitable connections are provided, and these in turn are connected to the valve box of the drier.

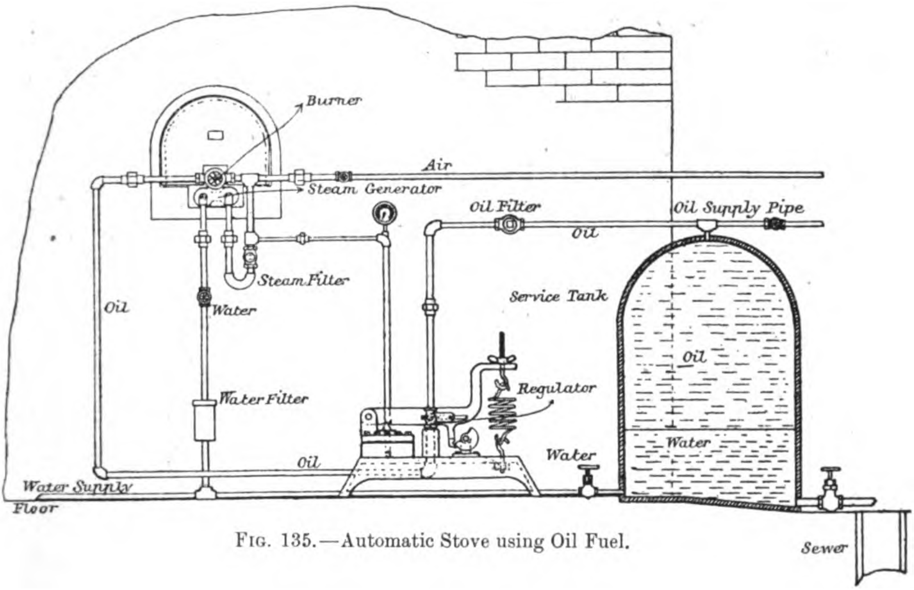

FIG. 135.—Automatic Stove using Oil Fuel.

In drying by this plan we have found the following points of value:—In the case of a deep mould, close the top part on to the joint, admit the air at one end, and provide an outlet at the other end. In the case of a mould of thin section, raise the top part a short distance from the bottom by means of packing, but seam up the joint, except at three or four points which are used as outlets. In every case it is better to start with cold or lukewarm air, gradually raising the heat by means of the regulating valves until the desired temperature is reached, as judged by peepholes placed in the second chamber. The plan will prevent scorching or cracking. Should there be any danger in

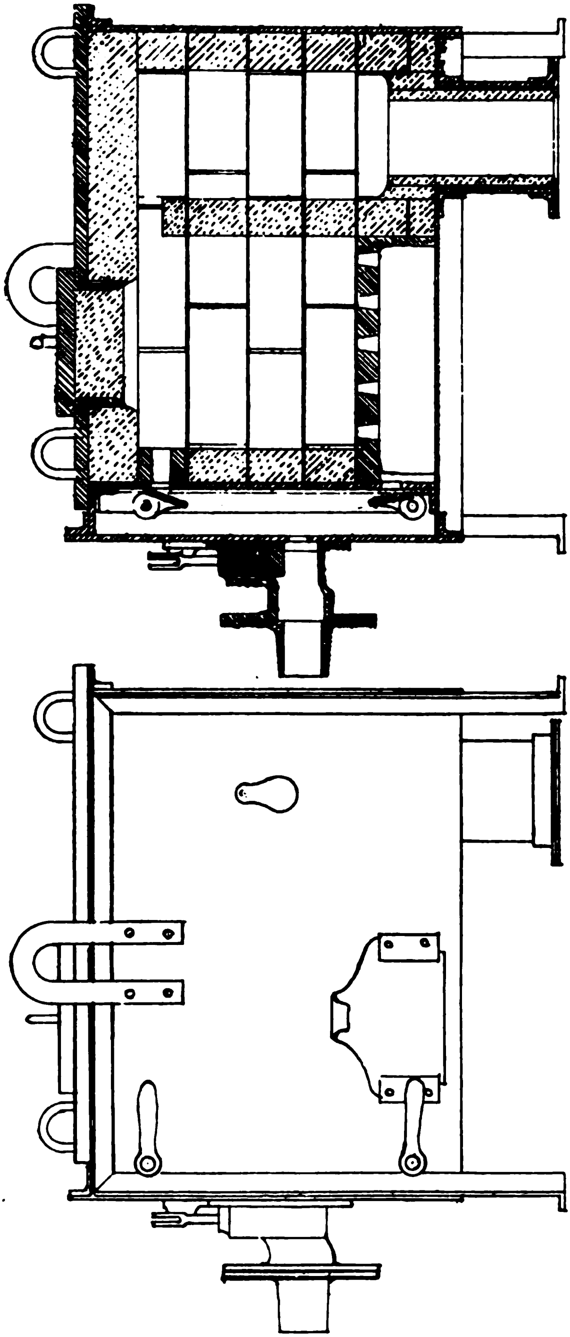

FIG. 136.—Portable Mould Drying Stove.

this direction, a further safeguard is found in laying a piece of sheet-iron or asbestos immediately below the discharge pipe. Finally, although this method of drying is now being largely adopted, many foundries in which the method has not been adopted will find it of decided advantage. Personally, we have found it of high value in every class of work, except loam moulds; and for these our strong preference is, wherever possible, to stove the moulds, although hot air, when applicable, is of service in rapidly stiffening up for further sweeping.

CHAPTER XVIII.

LOAM MOULDING.

A CURRENT definition of loam moulding is that of moulding without patterns, and, like many definitions, it has the doubtful virtue of not being applicable. Whilst sand moulds can be made without patterns, loam moulds can be, and are constantly being, made from patterns which may be solid or in skeleton form. The general notion of loam moulding is that of sweeping up to shape, and, in its simplest aspect, it is represented by a central spindle and suitable strickles for the inner and outer portions of the mould. Obviously, this confines the method to circular or semicircular castings, but any geometrical figure may be swept up by travelling strickles over guides cut to the required shape; and where this method is inadmissible, as in the case of castings which are not portions of a regular figure, then skeleton or outline patterns are substituted and used as guides.

The requisites for loam moulding are foundation or building plates of sufficient stability to carry the whole structure; building rings for strengthening the brickwork; parting plates for separating parts of the mould; building loam; coating loam; and finishing loam. Building loam is simply black sand mixed up into slurry by the addition of water. Coating loam is used for getting the form of the mould; whilst finishing loam, to some extent comparable with facing sand, is the same, except that it is in a finer state of division, and is usually obtained by sieving the loam used for coating. The characteristic features of loam vary according to district, and have to some extent been dealt with in an earlier chapter. We may, therefore, for convenience, here regard loam as a strong type of moulding sand ground under edge runners, and by the addition of water brought to the consistency of stiff sludge or mortar. The backing of a loam mould is formed by building in red bricks, which are strengthened where necessary by cast-iron plates or ties. Other equally important essentials are the provision of drawings giving a clear conception of the casting to be made, strickles, pattern bosses, gauge sticks, and outline patterns of parts which cannot be swept to shape. Gauge sticks should be cut to mould size, that is, contraction allowed for. In many cases a study of the drawing will enable the moulder to make the whole of the tackle required for the job before actually starting it; but, in other cases, the tackle may have to be made as the building progresses. At any rate, a clear idea should be obtained of how the mould is to be made before starting it, and preliminary thought will save arduous work and delays due to waiting for metal to cast tackle.

As a simple example, the case of a plain cylinder may be selected, and the first step is sweeping up the bottom plate. This plate has to carry the complete mould, comprising core, cope, and top plate, and must also serve as a guide for the cope. The top plate or top cake takes the place of the sand top part, the cope is that portion of the mould lifted away, whilst the core refers to the stationary part of the mould.

Bottom plates are cast with holes in the centre, thus allowing a socket to be bolted or cramped on the under side. A suitable plate with socket so fixed is laid on a stove carriage, and a single course of brick set in building loam laid on. For this course the bricks are set with about ¾-inch joints, and the interstices filled in with cinders. The surface is daubed with coating loam, and a second course of brick laid in a circle corresponding to the cylinder. From the spindle, and by means of rotating the joint strickle, the form shown in fig. 137 is obtained, which is simply a flat surface with a stepped joint. The spindle is removed, and the carriage run into the stove in order to stiffen this joint. After drying, the joint is blackwashed in order to obtain a clean part at a later stage, blackwash in this case serving the purpose of parting sand in sand moulding, as loam will not clag to a dried and blackwashed surface. The heat of the plate will dry the blackwash, and it is then ready for building the cope. The cope strickle is set in position, and a cope ring is laid on the joint with its upper side claywashed. This ring should be provided with four equidistant lifting snugs. On it a circle of red brick is built up, as in fig. 138, leaving a space of about 1 inch between the brick and the strickle, the latter being worked round as the bricks are laid, in order to gauge this distance. In bricking up loam moulds it must be remembered that, although the bricks give stability, they do not give porosity; hence, all venting must be between their joints, therefore brick to brick is inadvisable, and a good plan is to allow at least ½-inch joints. In a more intricate mould than the one under discussion, the joints would be varied thus, close building being followed near the face and open building at the back. The joints filled in with building loam are, when dry, practically self-venting. Having built a ring of brick, the inner face is daubed with coarse loam and finished off with fine loam to the contour left by the strickle. The whole is then stoved until the cope has stiffened sufficiently to admit of lifting, which is effected by means of a beam and chain slings passed over the snugs of the cope ring. The cope is then set on one side, and the strickle set for the core, as in fig. 139. This is bricked and swept up, as before, leaving a clear space in the centre. A point of moment lies in the fact that cores of this character are, when dry, exceedingly strong, and offer high resistance to liquid pressure; in

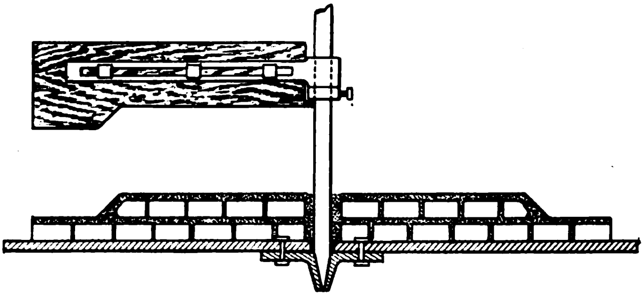

FIG. 137.—Sweeping Bottom Plate.

reality, they are arches, and, within limits, the greater the pressure the greater the resistance. This is a decided advantage so far as casting is concerned; but, when contraction commences, then the arch is a disadvantage. To make such a core capable of compression by the contracting casting, each course of red brick is broken by three or more loam bricks, which, owing to their softer nature, admit of a certain amount of yield in the core. Loam bricks are, of course, evenly distributed amongst the red bricks, the joints of which should

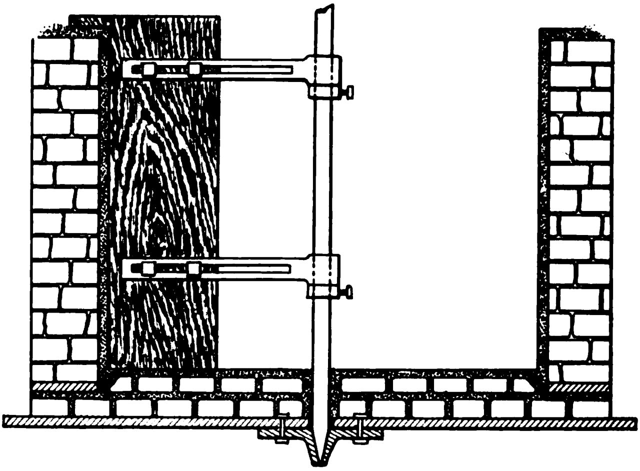

FIG. 138.—Sweeping Cope.

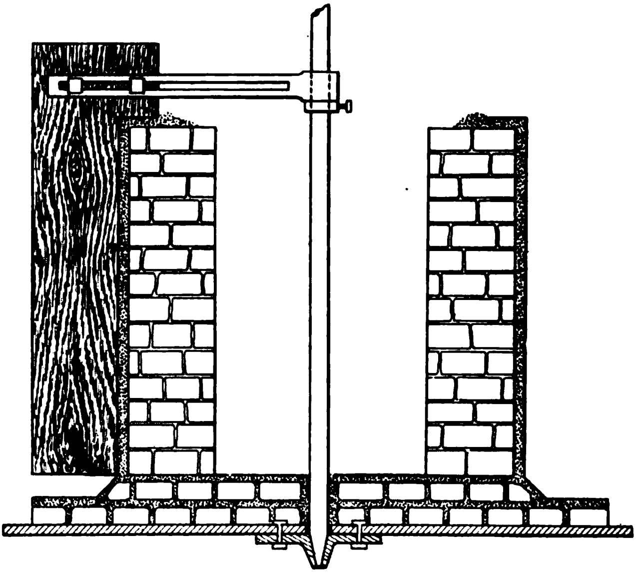

FIG. 139.—Sweeping Core.

also be sufficiently wide to admit of the bricks being brought together by the contracting casting. After bricking up the core, the face is coated with coarse loam, finished off with fine loam and stoved. The next requisite is a flat top cake, which is usually a flat plate or ring with projecting dabbers on one side and cored out in various parts so as to offer a series of holes for selecting runners and risers. The dabber side is evenly coated with loam, either from the central spindle or by means of a strickle worked over straight edges set on either side of the plate. The holes not required for runners, if they come over the casting, are filled in with loam bricks. The various parts of the mould are then stoved until bone-dry, and are then ready for finishing off. Loam moulds are often surfaced by sandpaper, but a simple mould of this type should be ready for blacking just as it left the strickle, with, of course, the intervention of drying. Blacking should be applied whilst the mould contains sufficient heat to dry it. The bottom plate carrying the core is then set in a level position, and the cope lowered over it, the bottom joint first swept up acting as a guide for its return. Whitening is spread over the top joint, and the top cake fitted on, and the position of runners and risers tested. On lifting off, the whitening shows the character of the fit, which, with proper sweeping, should be correct. The top cake is then returned and tied to the bottom plate by means of binders or cramps and wedges. Runners and risers are filled in with tow, to prevent any loose dirt falling in before the heads are made up. In considering the question of securing the mould for casting, it is obvious that the circular core entirely surrounded by metal is comparatively safe, since any pressure put on it is distributed over the circumference. Upward pressure is readily met by fastening top and bottom plates together; so that there only remains the outward pressure on the cope. In the majority of cases, this is met by lifting the complete mould into a pit, which is hard rammed level with the top plate. An alternative method, possessing many advantages, is to place an iron curbing over the mould, and to ram the space between it and the outside of the mould with sand. Curbings are extremely useful, as they save much labour in ramming pits. Adjustable curbings are formed by segmental cast-iron plates which fit one into another, and may be made up into any required diameter. After ramming the mould in a pit or inside a curbing, runner and riser heads are made up, and the mould is then ready for casting.

The foregoing outline of the simplest kind of loam moulding is a good illustration of the principles involved. More difficult cases are met by applying the methods followed in sand moulding, so as to fit the particular needs of loam moulding. For example, if, instead of a plain cylinder, a flange is required on both ends, a slight alteration in the strickles is all that is required. A rope drum or pulley would be made in the same way, save that the strickles for the cope would be cut so as to form the required grooves. If arms and hub had to be cast in the centre, these would be formed by means of cores. Assuming that the plain cylinder required external brackets, feet or other projections, these are provided for by using patterns of the shape required, and bedding them in as the building progresses. Usually loose pieces of this character are set in the position required by a patternmaker, but the moulder must see that no movement occurs after setting. In the majority of cases this pattern will require a drawback in order to effect its withdrawal. In principle, loam drawbacks are similar to sand ones, save that the pattern must always lie in the mould until the latter has stiffened, and the drawback is therefore not disturbed until the mould has been wholly or partially dried. The utility of drawbacks is further increased by joints in the mould. Thus, though it may be unnecessary, so far as the sweeping of a mould is concerned, to have a joint, yet such may be necessary in order either to draw the patterns used, or, when finishing the mould, to fix the cores in position. Partings of this character are effected by rings similar to the bottom cope ring, but the actual parting is not made until after stiffening. As regards guides, for returning either drawbacks or parts of the mould, in many cases the joint can be formed to give its own guide in returning, and the efficiency of this may be increased by cutting V-shaped notches on the outside of the mould.

Evidently, then, a combination of strickles, drawbacks, and loose pieces, with the requisite partings, will allow considerable latitude in making castings, chiefly of a cylindrical form, but embellished by additions which cannot be obtained by sweeping. This sentence practically covers the making of a steam cylinder, for, obviously, such a casting may be regarded as a simple cylinder plus accessories, such as flanges, steam and exhaust ports, etc. Flanges are provided for on the strickles, or, in the event of their not being circular, by means of pattern frames. Steam and exhaust ports are made in pattern form; and access for placing cores, if not obtained through the drawback, is obtained by suitable partings in the cope.

As a second type of loam moulding, the case of a large pan casting may be taken. Here, if the complete mould is swept up, the core part would necessarily have to be swept from a different centre to the body part of the mould; a plan which, though quite feasible, would entail more trouble than the following one. The usual plan is to sweep one part to size, thickness it, and build the cope on top of the thickness. Fig. 140 shows the arrangement adopted when the pans are cast inside down. The various stages are, first, building the core and strickling to size. This is stiffened, either in the stove or by building a fire inside, the products of combustion escaping through the hole left by the spindle. By means of a thickness strickle, the core is coated with a thickness of loam, giving the outer form required in the casting. This is stiffened, and the cope then built directly on it, being carried from a cope ring bedded on the joint; the face of the casting is loamed over by hand, and backed by brick as usual. The further stages are parting, removing the thickness, making good the hole left by the spindle, and closing ready for casting. The complete mould is well rammed in a pit, and the core vent brought away from the sides. Instead of building the cope on a ring, it may be carried by means of irons somewhat akin to the saddles of a propeller blade. These irons are simply open sand plates cast to the curvature, and keyed together, thus offering a good support for the bricks and loam wedged in between the irons. This method of casting pans, although at one time commonly followed, is not a good one. The defects are found in the space under the core permitting of an accumulation of gases, the difficulty of satisfactorily binding, and the pressure of liquid metal on the top of the core which nearly always leads to a more or less slight depression. In our own practice we have always followed the plan of making the castings with the inside of the pan up, thus permitting of more systematic binding, less pit ramming, and, if more than one casting is required, of a very considerable saving in building. Fig. 141 shows the method for the bottom part of a dynamite pan casting made from a mixture of all hematite pig-iron. Details are briefly as follows:—The outer building is comparatively open and well vented by ashes between the brick joints. Near to the casting the building is closer and more compact. A loam face is swept on, and, after stiffening, the pan thickness is laid on. In this case thin scone bricks are first laid on, and the thickness brought up by means of loam and the thickness strickle. These bricks are simply used because the thickness permits and because they offer a ready means of stripping. Fig. 142 shows the cope arrangement, the lower part of the core being lifted by means of a box grating bolted on to the top plate or ring. The lower part of the thickness is covered with loam, and the claywashed grating bedded in, being built up first with loam brick and loam, and then with hard brick and loam. The building ring shown in the core is split across the diameter in order to allow for contraction, and the rest of the building is carried on to the joint on this split ring. The joint is loamed over, and the top building ring, provided with dabbers to carry the loam over the joint, is bedded on. Hook bolts are passed through the plate and hooked into the lifters of the box grating. After stiffening, the cope is lifted off, and, as it cannot readily be turned over, is finished whilst slung in the crane. It is then set on stools carried up to the top plate, or, if a number of castings are required, a "cup" may be built to rest it in, and this will be found useful for

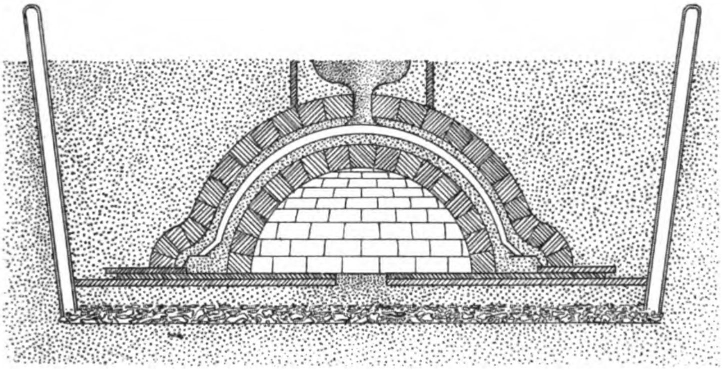

FIG. 140.—Mould for Pan.

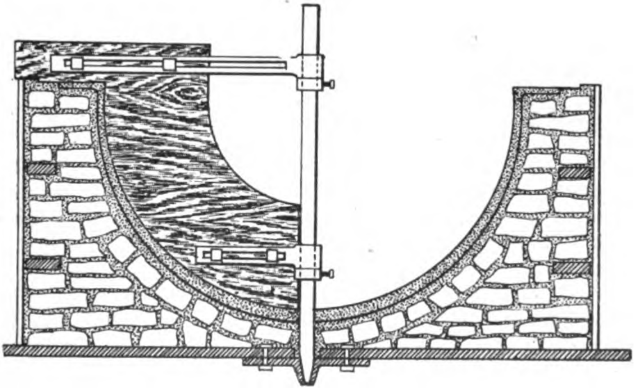

FIG. 141.—Sweeping Dynamite Pan.

sitting the cope on the stove carriage. When preparing for casting, top and bottom plates can be readily and firmly tied together; hence, there is only outward pressure on the bottom building to consider. This is met by ramming in a pit, and, generally speaking, all built up moulds should be so rammed. However, the fact remains that all loam moulds are not pit rammed; and although on paper one ought not to advocate any plan introducing an element of risk, yet, obviously, a mould, such as shown in fig. 141, can, by strong building and external binding, be made perfectly safe. Outside binding is secured by having the top and bottom plates somewhat larger than required, and cored out at intervals through which vertical bars may be passed, thus admitting of horizontal plates being wedged against the outside of the building. This, of course, implies that the mould is externally square, and, when so bound, the mould may be cast on the floor, or, if deep, simply placed in an open pit to dispense with staging from which to manipulate the ladles. Fig. 141 is shown bound by side plates in this manner; but, whilst we have cast comparatively heavy weights in cast-iron by this plan, honestly we do not recommend it, for, unless extremely careful work is followed, and a full recognition given to the pressures exerted on all, and especially the weakest, parts of the mould, a more or less serious run out or burst will follow. In any case, loam moulds for the reception of alloys, such as gun-metal or bronze, owing to higher density and greater fluidity, should always be rammed in a pit in addition to external binding.

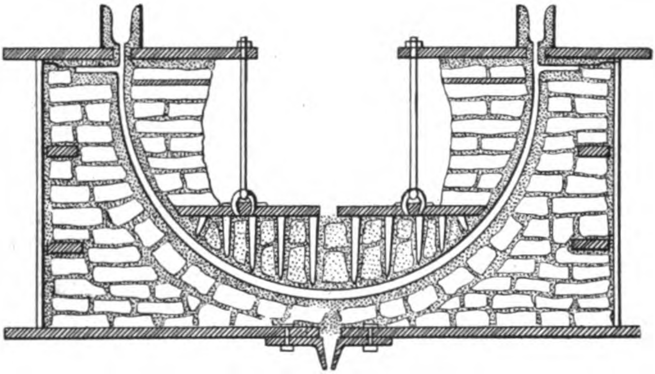

FIG. 142.—Cope for Dynamite Pan.

After pouring (fig. 142), and on solidification of the casting, the hook bolts are loosened, and the top plate lifted off in order to allow of free contraction. After the casting has cooled, to admit of removal, it will part clean from the bottom, and, therefore, all that is necessary is to scrape out the burnt loam and skin the mould up again for another casting. The top part must, of course, be made up anew for each casting. As the bottom part is only skinned over, it may be dried in position; hence, if rammed in a pit, the sand need not be disturbed, and one ramming will serve a series of castings. In loam work it is always economy to save as much as possible of the building for the next casting; and, particularly in pan castings, the bottom part of the mould may in a sense be regarded as permanent for a run of castings.

The two methods outlined only admit of tapering pans, that is, moulds in which either outside or inside may be lifted away in the top part, and, naturally, the method is inapplicable if the diameter of the pan is greater towards the centre. In such a case the chief alteration in method lies in the fact that all parts of the mould must be swept and a special allowance made for closing the mould. The core is therefore built and swept entirely on the top ring plate, but a joint is provided across the diameter so that at a later stage the core may be split into two parts. The bottom part is swept as usual, but a joint is made across the greatest diameter, allowing this part of the mould to be lifted bodily away. Therefore, when ready for closing, the stages are as follows:--The core is turned over into a cup, bolts unloosened, and separated at the joint. The top half of the core is lifted on the removable part of the bottom part of the mould, bolted to it, and then returned over the lower part of the core, which is, in turn, again bolted to the top plate. Fig. 143 shows the arrangement at this stage with the core ready for lowering into the bottom part of the mould. Fig. 144 shows the complete mould ready for casting. Another method of binding the brick work is shown in figs. 143 and 144, and is found in long dabbers cast round the outside of each building plate. This method is effective, and the only objection to it lies in the fact that the dabbers are likely to break off when taking the mould to pieces or stacking the plates.

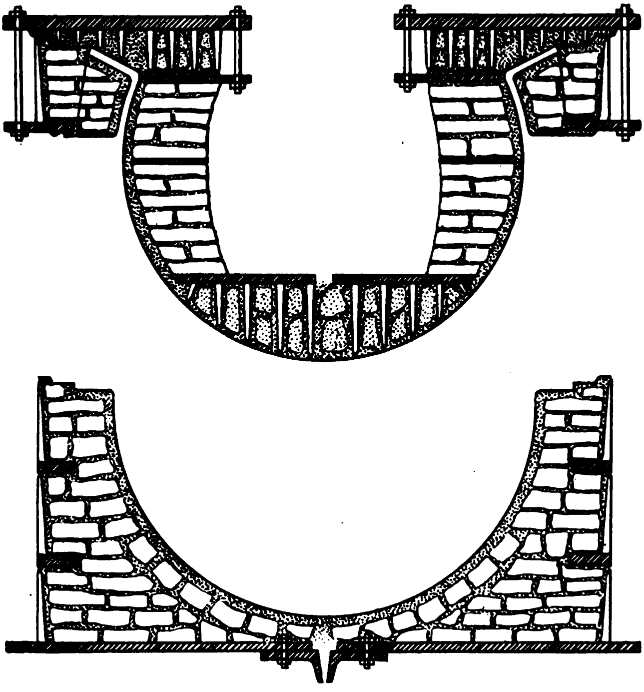

FIG. 143.—Pan with Core larger in Centre than at Top.

The spindle has so far been considered as rotating in a central socket, but in the case of tall moulds a top support will be required in order to maintain the spindle in true position. In a somewhat rough and ready manner this is obtained by laying a board across trestles, or over a pit, if the job is being built therein. This board is drilled out to fit the top of the spindle in order to maintain it in a vertical position. A much better plan is to use a horse permanently bolted on to a wall or column, as in fig. 145.

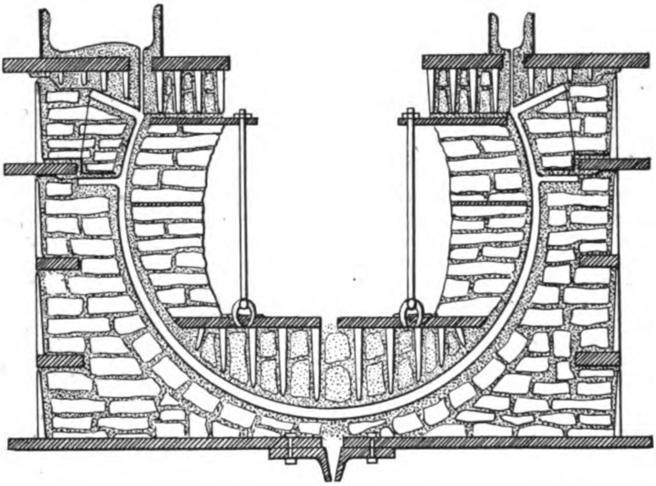

FIG. 144.—Pan with Core larger in Centre than at Top.

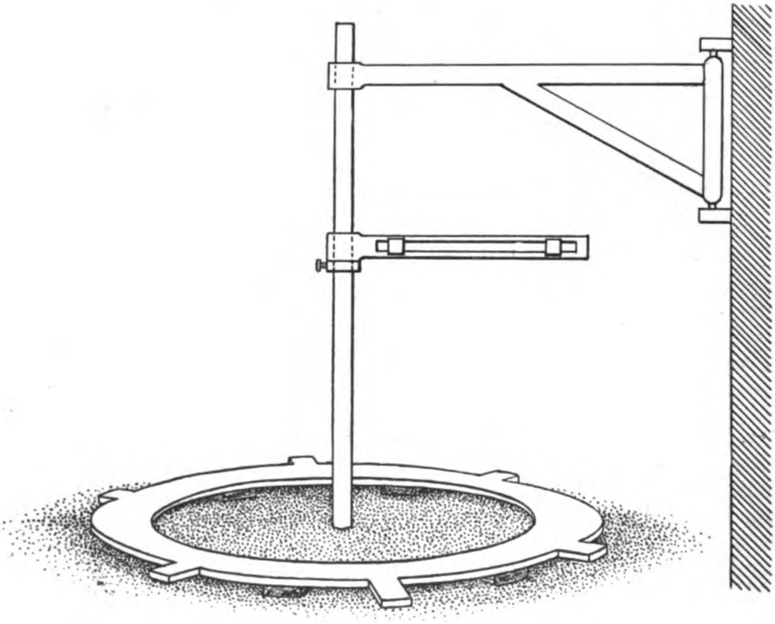

FIG. 145.—Horse and Spindle.

A third type of loam moulding is represented by sweeping, from a central spindle, horizontal moulds of regular curvature, the commonest examples being propeller blades and solid propellers. If, for a moment, we imagine a sweep having freedom of movement in two directions (1) around the axis of the spindle, and (2) vertical movement, then, if an external guide is placed on a foundation plate, the surface swept by rotating the spindle will be that imparted by the guide. Vertical movement is obtained by counterbalancing the strickle, as in fig. 146, the three sheaves there shown being a better arrangement than a single sheave at the top of the spindle. As a rule, only small propellers, such as those for torpedo boats, are cast complete, that is, blades and boss together. With larger ones the blades are cast separately from the boss. Taking a solid propeller, the various stages are as follows:—A circular bottom plate sufficiently rigid to carry the full weight of the undried mould is levelled, a single course of brick built on, and a level bed struck off. In the centre, a bed for the bottom of the boss is swept and the whole stiffened. The boss pattern has a hole through the centre, in order to admit of its passing over the spindle. Further, as the greatest diameter is at the centre, the boss is divided into segments screwed together from the inside in order that the screw heads may be readily reached and the segments withdrawn. The boss pattern is set in position, this and later setting out being usually done by a patternmaker. Having centred the boss, the next step is

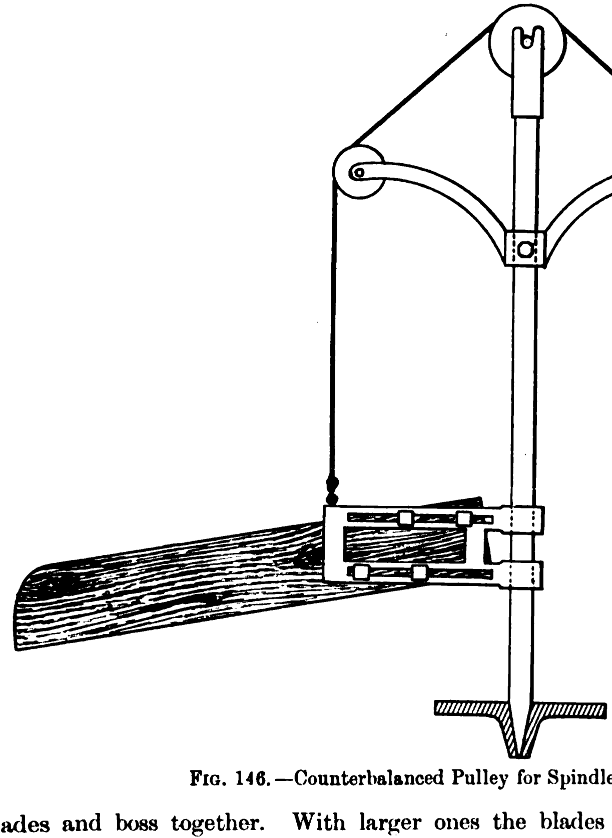

FIG. 146.—Counterbalanced Pulley for Spindle.

setting guides or "gable seats" for the blades. Gable seats are wooden frames built to sit on the level bed first struck off, and their top surfaces serve as a guide for the strickle, thus giving one face of the blade. An outline is bricked up from each gable seat to the boss, and the face finished off by rotating the sweep over the gable. The three or four blades, as the case may be, are completed and stiffened. The next step lies in forming a guide for the thickness of the blade, and for this purpose a series of wooden strips, each cut to give a section of the blade at varying points, are nailed in position. The spaces between these guides are filled in with moulding sand, and carefully smoothed over to the required shape. In this way a sand pattern of each blade is formed. For the top part a plate similar to that used for the foundation may be employed, each blade being lifted by means of a box grating bolted on to the top plate. In the same way a box part may be used; but, from personal experience, we find both plates and box parts clumsy and cumbersome. These features will be realised by considering the huge size of the top plate, or covering box, in comparison with the relatively small area occupied by the blades. Hence, we prefer a separate covering for each blade, which, in the case of standard work, may take the form of a permanent grating, or, in work of varying pitch, may take the form of a series of loose saddle bars perforated by square holes, as in fig. 147. Any number of these bars can be readily fixed together by passing square bars through the holes, and wedging each one in position.

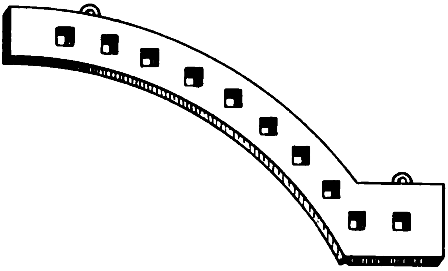
FIG. 147.—Saddle Bar.

The surface of the sand pattern is coated with loam, and the claywashed saddle, bedded in position, is then built up with brick and loam as usual. Each blade is so covered, and a separate covering part, made for the boss, which will contain runner and feeder. After stiffening, V grooves are cut for guides, and each covering part lifted off, lifting being effected by means of eye bolts in the two external bars of each saddle. The sand pattern is removed, and the mould finished, dried, and made ready for casting. Only two features call for note here. First, the usual setting for the boss core is found in prints placed on the pattern; but if, for reasons of feeding, it should be desired to continue the boss, the core must be lengthened to the same extent. The usual method of feeding is by means of round feeders placed directly on the boss, and kept open by means of feeding rods. The other point is in binding the saddles down. When the mould is completely closed, a ring plate is laid over the top, and supported on stools carried from the bottom plate. This ring is then cramped down to the bottom plate, and the top of each saddle is wedged securely down from the under side of the ring. The whole is then lifted into a pit, and rammed up as usual. Practically speaking, a single blade is moulded in the same way with the provision of a wood pattern for the head, although, in the majority of cases, when blades are made separately, full patterns are provided, and the mould is then made in dry sand.

The propeller is a good example of a spindle and sweep working over a guide; but, with certain types of castings, guides have to be used alone. For example, assuming an octagonal figure is required, then a wooden frame giving an outline of the top and bottom are set up and used as guides in building and strickling, and for the finishing coat straight edges are worked over the guides. By the aid of thicknessing, cored castings may be produced, and, with suitable guides set in line with each other, practically any form of casting can be made. Generally, however, it will be found cheaper to make a skeleton pattern of the required outline. This introduces the last aspect of loam moulding, namely, that in which the form of the mould is obtained from a more or less complete pattern.

Loam moulding from patterns is followed in many foundries, but more especially in marine shops engaged on heavy work. From the description given, it will have been noted that loam moulding implies no expensive accessories, and the required tackle can all be made on the open sand bed. Hence, under certain conditions, it may be cheaper to mould from a pattern in loam than to make boxes or tackle for a sand mould. Further, loam moulds are, generally speaking, safe, though, naturally, the choice of method will depend on the equipment of the foundry, the type of pattern, and the number of castings required.

A propeller boss may be taken as an example of a complete pattern; and the first step lies in laying an open and well-vented course of brick on a stout foundation plate. Two close courses are built on the top of this, and a level bed struck off. The pattern is bedded on, with the shaft core in a vertical position, thus placing the recesses for the blade heads at the sides of the mould. The contour of the pattern demands a central joint; accordingly, the pattern is divided, but, if not, the prints for the blade heads are loose or are loosened during the progress of building. The pattern is then bricked up to the joint, a matter easier to do than to describe. However, the face of the pattern is loamed over, and claywashed bricks are regularly pressed into the loam. Regularity is essential, for the end of the brick must not press all the loam out, thus coming into contact with the pattern, and yet it must be pressed sufficiently hard against the pattern to consolidate the loam and render it compact when dry. The external form of the building should be square, and carried well back from the pattern for the sake of stability. The latter is further increased by building rings, which should be bedded in every three courses. On reaching the joint, this is made good, and, preferably, stiffened before further work. A coat of blackwash ensures an effective parting, and on this a layer of loam is spread for the reception of the claywashed building ring. Lifters are cast into the back of this ring, in order that it may be bolted to the top plate. Building is continued with the intervention of building plates, as in the lower part, until the top of the pattern is reached. The whole top is then loamed over for the reception of the top plate, which is provided with dabbers on its lower side, a central hole for the shaft core, holes for the hook bolts, runners, feeders, etc. The hook bolts connected with the lifters in the joint plate are cleared, and the top plate lowered over them and bedded on the loam. Washers over the bolts and nuts admit of a firm connection between the two plates. Other points calling for note are the fact that, after stiffening the complete mould, the top part is lifted off as though it were a box and turned over to finish. Turning over is not an easy task, but is accomplished by setting the top part, as lifted off, on battens clear of the floor. Slings are securely passed over the snugs on one side only, and the crane brought into play. Practically, the battens are used as trunnions, and, on the top part reaching a vertical position, the crane is travelled forward until the plate departs from the vertical, when it is lowered down and brought into a horizontal position with the face of the mould uppermost. This is another example of an operation easier to do than to describe, and we should certainly not advise anyone to attempt it without very careful thought, and, if possible, only after having actually witnessed the turning over of a loam top part. Having turned it over, the top part is finished and dried. As the joint will cut the blade head cores, these are conveniently split across the diameter, one half being nailed in each half print. After closing, the mould must be securely bound, and firmly rammed in a pit. Naturally, such a mould could easily be made in dry sand; but, apart from the conditions already noted, a solid boss of this character made in loam offers exceptionally good resistance to the searching action of gun-metal, which represents the type of alloy used for the better quality of bosses. Gun-metal boss and manganese bronze blades represent the most costly type of propeller, whilst the cast-iron boss and blades represent the least expensive type as regards first cost.

When working from skeleton patterns, the inside of the pattern is usually built up to serve as a core, from which external parts of the mould are formed. Large-sized centrifugal pumps are made in loam by this plan, and, in such a case, the mould is practically composed of three main parts: (1) the central core carried on the foundation plate, (2 and 3) the two drawbacks on either side of the core. Auxiliary parts are: drawbacks for brackets, covering plates for discharge pipe, flange, etc. However, a more simple case will give a clearer illustration of the methods followed. Assuming there is a skeleton pattern of the form shown in fig. 148, then the first requirement is a bottom plate bricked with one course, and strickled level. The centre of this plate should be cored out to admit of bolting the core irons down. On the flat joint already formed, another course of brick is laid corresponding in outline to the flange of the pattern. The sides of this joint are tapered, and its surface strickled level. After stiffening, the pattern is set on this bed with a suitable core grating inside it. This grating must be of sufficient stability to support the core, an effect increased by bolting it to the bottom plate by means of hook bolts passed through the hole already mentioned. The core grating whilst rigid should, however, be considerably smaller than the casting, in order not to retard its contraction; for this is a type of core which cannot be reached in order to loosen it after casting. The inside of the pattern is built up with loam brick and loam, an ash centre being provided for venting. The outside of the core is brought flush with the ribs of the pattern, and is then strickled down to a depth equal to the thickness of metal required in the casting. This is made good by clay thickness strips, the whole surface being brought into even lines to form a good pattern, for the outside. After the core has stiffened, the outer portion of the mould is commenced. For this, two drawback plates are required, which should fit against the raised joint of the core and butt against each other at the ends. In other words, each drawback must carry one complete half of the outer part of the mould. The ends of each plate are provided with lifting snugs, over which slings may be passed from a lifting beam. One drawback is completed first, and, for stability, building plates are laid every three courses. A glance at the pattern, fig. 148, will show that the drawbacks have a considerable overhang from the drawback plate, therefore the building plates must be carried well back into the drawback in order to preserve the balance. The building is carried about three courses above the pattern, brought over to the centre, and a top plate bedded on in line with the centre line of the pattern. The second drawback is then built up against the first, and to the same height, the two top plates butting together, except for openings through which runners may be cut later. Every part of the pattern is now covered, except the face of the round flange on the discharge pipe. This is coated with loam, and a flat drawback plate bedded on. The whole structure is then stiffened and made ready for parting, guide lines being marked across the top, sides, and bottom of drawbacks. The drawbacks are lifted away by means of beam and slings, the first step being to balance carefully, then to take the weight in the crane without actually lifting, and draw away until clear of the pattern. The drawback is then hoisted up and set on the stove carriage to finish. After removing the second drawback, the core is ready for attention. All the thickness strips are removed, as also the screws holding the skeleton pattern together. Each separate piece of the pattern is drawn out, and the space filled in with loam. Core and drawbacks are then thoroughly dried, after which, the faces are dressed over with sandpaper and the thickness tested. This is done by tucking small balls of clay all over the core and then fitting the mould together. After opening out again, each clay gives an index of the thickness in its own locality, and, if thin, the core is dressed down with sandpaper, or, if too thick, the face is brought up by a coating of fine loam. In castings of this character, even thickness is an important point; hence the necessity for a careful test before closing the mould. Having attained the right thickness, the mould is blackwashed, dried, and made ready for casting. After closing, the drawback plates may be cramped together by their lifting snugs, and the mould bound down from the bottom plate. The pit should be firmly rammed, and the drawback plate over the flange wedged from the sides of the pit as the ramming progresses. Such a casting is usually run directly from the top; hence, before closing, flat gates are cut through, and, after closing, a runner head made up over them.

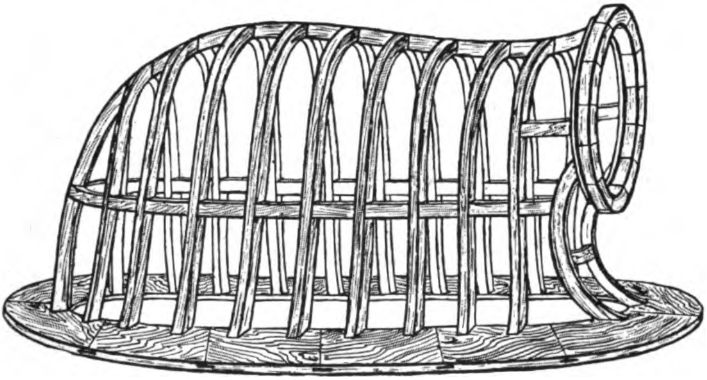

FIG. 148.—Skeleton Pattern.

One objection often raised to loam moulding from patterns is that the patterns are burnt when stiffening up the moulds, but this need not occur. Actually, the mould only requires stiffening, not drying, and this is easily effected without damage to the pattern. Drying is effected after parting the mould and removing the pattern.

In this survey of loam moulding, many aspects have necessarily been omitted, but, in the space available, we have attempted to outline the various methods followed. Finally, it may be noted that any loam mould, being practically a brick structure, should be built somewhat on the lines followed in ordinary bricklaying. One of the greatest aids to stability is found in breaking the joints, the second in ties. The latter, in the case of a loam mould, are represented by building rings or plates, and, although not essential in every case, a good practical rule is a building ring every three courses. Let it be noted that building rings in the case of internal cores should be split, and so laid that they can be forced together by the contracting casting. External stability has been discussed, and it is always advisable not to place too much reliance on pit ramming, but to regard it as an adjunct to other forms of binding. Loam brick should be plentifully used in pockets, under flanges or other parts where contraction is most forcibly felt. Loam bricks are also a valuable aid to venting. Generally the latter is effected through the joints of the hard brick, and is assisted whenever possible by ashes. Vents are led away, as in sand moulding, and vent pipes must be connected to all vents below the floor level.

CHAPTER XIX.

CHILL CASTING.

GENERALLY speaking, chills are used in conjunction with sand or loam moulds, and it is only in very exceptional cases that an entirely metallic mould is used. Such cases are common to the more fusible metals, as, for example, alloys rich in tin or zinc, and the castings made include various types of buttons, ornaments, and statuettes. In casting objects such as the last mentioned, the chill mould is filled with molten alloy, and, on solidification of the skin, the mould is inverted, thereby draining out the inside and producing an effect somewhat akin to coring. The castings are subsequently bronzed, and, as often as not, enter the market as "Antique Bronze." Such processes, whilst of interest, hardly come within the scope of the general founder, who practises chilling not because he wants a permanent mould so much as to obtain one or other of the following conditions:—

(A) An equalisation of the rate of cooling in castings of varying section.
(B) To eliminate sand cores.
(C) To obtain from one grade of metal two distinct grades in the casting.

A and B are applicable to any metal or alloy which does not become "chilled" by contact with a metallic surface, whilst C is limited to varieties of cast-iron which possess the property of chilling, that is, of becoming hardened to a greater or less depth by contact with a metallic surface.

The majority of writers regard chill moulds solely from the point of producing hard surfaces; but there is a growing tendency to use chills with many alloys and metals, the hardness of which is not affected, and in this direction much greater developments are to be expected. Generally speaking, any casting of unequal section tends to contract at different rates during cooling. Thus, that portion of the casting which is most rapidly cooled completes its contraction first, and it may be that a heavier portion with a consequently slower fall in temperature is contracting after contraction has ceased in the lighter portion. This condition of things results in stresses in the castings which are greater as the differences in thickness of section are more pronounced. For the moment, liquid shrinkage and solid contraction may be regarded as simple contraction only, and, further, it may be assumed that castings in falling to the air temperature contract towards their own centres. The latter is based on the assumption of a casting of equal section; but, obviously, in a casting of the form shown in fig. 149, two different centres of contraction will be formed. The light portion will cool rapidly, but the massive part will cool slowly, and in this way the complete casting will behave as though it consisted of two distinct parts. The natural result is that the contraction of the light part is directed towards its centre A, whilst that of the heavy part is directed towards its centre B. Hence, in both portions of the casting the metal is drawing away from the junction of the heavy and light parts. This is often sufficient to develop a fracture along the junction; but, even if this effect is not produced, a serious plane of weakness inevitably follows. Whilst this is bad with regard to strength, it is also equally bad as to soundness; and it can be taken, as a general rule, that a mechanically weak area developed in this manner is also porous and open to admit the passage of water or steam.

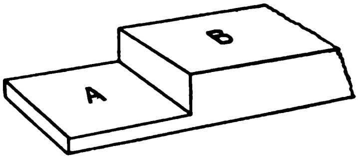

FIG. 149.—Diagram to Illustrate Unequal Contraction.

Ideal conditions are found in castings of equal section; but, unfortunately, in foundry work ideals are the exception and not the rule. Therefore, an effort must be made to obtain in castings of unequal section as nearly an equal rate of cooling as is possible under the conditions. This involves hastening or retarding the cooling of certain parts of the casting, and, in the case under discussion, this may be effected by the application of a chill to the heavy part. Thus, if the lower surface of the heavy part of the mould for fig. 149 is formed by a block of cast-iron, the light part being formed of sand as usual, then, on casting, the metal block or chill will rapidly abstract heat from the heavy part of the casting, thereby hastening its cooling and tending to bring the rate more nearly to that of the light part. The more equal is the rate of cooling the nearer do the centres of contraction A and B draw to each other; and if the rate is equal throughout the casting, the two centres merge into one; thereby neutralising the opposing forces which resulted in the development of a plane of weakness along the junction.

The heavier the chills employed the more rapid the abstraction of heat; but even comparatively light chills may be used in certain cases, in order to achieve the object of equalising the rate of cooling. Many intricate castings met with in malleable iron moulding can be saved from distortion or rupture by bedding a piece of plate, ¼-inch in thickness, against the thicker parts of the pattern when ramming up the mould. As the white iron used for malleable castings passes through a pasty stage of great weakness between its liquid and its solid state, a thin part of a casting comes to its strength so much more quickly than a thick part, that the former sometimes actually pulls the latter asunder; and the skilful use of chills in the mould, by bringing the two parts to their strength about the same time, has many times enabled an order to be fulfilled when it would have been worse than impolitic to have pointed out or attempted to alter faults in design. Concerning the use of chills for these purposes, it should be noted that their surfaces must be free from rust and evenly coated with plumbago. The latter may be rubbed on dry, or the plumbago may be mixed in water and painted on, the chill being dried before use. As the moisture of a green sand mould tends to condense on the chills, such moulds should not be closed until ready for casting.

Chills are bedded against the pattern, and rammed up with the mould. In the case of plane surfaces, flat pieces of iron of smooth surface will answer, but curved surfaces require chills specially made to fit the curvature. An example is given in fig. 150; in this case the chills are rammed up with the cores, and secured by the rods cast in the back of the chill being carried well into the body of the core. This example illustrates a ready means of overcoming a difficulty of common occurrence in cast-iron cylinders, especially the small intricate types common to motors. The double thickness, and, therefore, slower rate of cooling, is provided for by the introduction into the core of a chill with the object of obtaining a rate of cooling more nearly approaching that of the body of the casting.

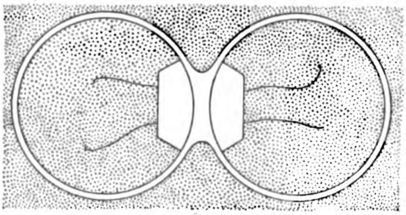

FIG. 150.—Internal Chills in Cylinder.

Complete chills used as cores may have as an object the purpose of drawing away the heat from a mass of metal, or simply that of replacing sand cores. The latter is of limited application only, but has none the less certain advantages. A common example occurs in a fire grate for a register front, fig. 151; where the print A is desired to give two round holes through the foot of the grate for subsequent bolting on to the stove front. Such a core is more conveniently formed of metal, in that it is permanent, answers equally as well as sand, and is therefore a time saver. The chill cores are readily removed from the castings, and for further use only require rubbing over with plumbago. In certain cases wheel centres may be cored out by metallic cores. True holes are thus obtained, into which a shaft or axle may be fitted without boring out the hole. The authors have for this purpose used round steel, cut to the desired length, and coated with plumbago. Certain patent coating compositions are on the market, and, whilst good, have not in our hands yielded better results than are to be obtained from plumbago coating. Turned cast-iron cores may be used with equal advantage, and, irrespective of the metal used, much better results are obtained if a slight taper can be given. In any case, metallic cores, when completely surrounded by metal, should be removed from the casting immediately after solidification.

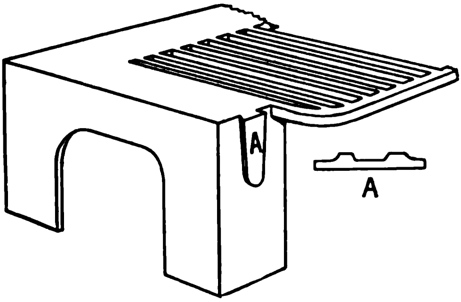

FIG. 151.—Fire Grate.

The freedom of a chill from rust has been emphasised; it may be further noted that, in gating any mould containing a chill, the gate should be so cut as not to impinge directly on the chill. Further, the weight of the chill should be such that it will not be melted by the casting; and, finally, when using cast-iron chills as cores, it should be remembered that repeated reheating of cast-iron results in an expansion or increase of volume. This only becomes of moment when very exact sizes are required; hence, a cast-iron core for a wheel centre should, after using for some time, be calipered, and the increase, if any, in diameter turned off.

A further example of the use of metallic cores is found in using screws to give an internal thread in brass castings. Before use, the screw is preferably coated with oil, and sprinkled with parting sand. Somewhat rough, but still effective threads, are obtained by this plan, and the method is useful in cases of emergency.

FIG. 152.—Chill Test Fracture.

The most familiar use of chills is found in the production of chilled cast-iron, which represents castings having a comparatively soft grey centre and an extremely hard exterior. The effect of chilling on the fracture is shown in fig. 152. The bottom part was cast against a chill, the sides against sand, and the top was open to the air. The bottom shows characteristic hard white iron fracture passing gradually into soft grey. In a later chapter it is shown that the hardness of a cast-iron is determined by the condition of the carbon present; and reference to this chapter will show that white irons which are extremely hard contain the greater part of the carbon in the combined form; whilst, on the other hand, a soft grey iron contains the greater part of the carbon in the free form as graphite. Therefore, the relation of combined to free carbon determines in a large measure the character of a cast-iron; and, obviously, if in one casting this relationship can be varied, a combination of properties can be secured, and, with what are known as "chilling irons," the quicker the rate of cooling the whiter is the iron or the deeper the chill. Therefore, by producing conditions in which external faces cool rapidly, and internal parts slowly, the tendency is to produce on the surface a white iron and in the centre a grey one. The advantages of such combination lie in the fact of obtaining an extremely hard wearing surface, the brittleness of which is to some extent minimised by the softer backing. Dies, for instance, have a dead hard face modified by a backing of grey iron, which gives a greater working life to the die. Car-wheels are chilled on the tread, which gives a hard wearing surface; similarly, certain parts of grinding or crushing machines, rolls for rolling mills, etc., are externally chilled in order more successfully to resist wear by abrasion. It is worthy of note here that certain grades of pig-iron give a deeper chill than others, the depth being also influenced by the thickness and temperature of the metallic chill and by the temperature of the molten metal. The five analyses given in the following table are of interest, and should be studied again after reading the chapter on cast-iron. The first and second are from chill samples that were taken at widely different dates, and that each gave about ¾-inch chill. The third is from a sample of pig sold for chilled roll making. The fourth and fifth are from chilled rolls which were reported to have done good work, and the fifth had about a ½-inch chill.

COMPOSITION OF CHILLING CAST IRONS AND CHILLED ROLLS.

	1	2	3	4	5
Combined carbon, . . .	0·80	0·91	0·80	...	1·16
Graphitic carbon, . . .	2·54	2·47	2·22	...	2·00
Silicon, ...	0·60	0·80	0·96	1·07	1·00
Manganese, ...	0·61	0·76	0·57	0·40	0·42
Sulphur, ...	0·05	0·06	...	0·21	0·19
Phosphorus, ...	0·46	0·50	...	0·44	0·64

The example given in fig. 149 of a chill used for equalising the rate of cooling may be also used as an illustration of the making of a die with one chilled face. The face of this chill is cut out to give the required contour to the casting, that is, beaded or fluted according to the character of the die. A pattern is bedded on the chill, and the mould formed, the chill remaining in position on removing the pattern. The method is shown in fig. 153, which is gated, as shown, in order that the metal shall not have a clear drop on to the surface of the chill. A feeding head is placed, as shown; and if the die is at all massive, this head should be fed with a rod.

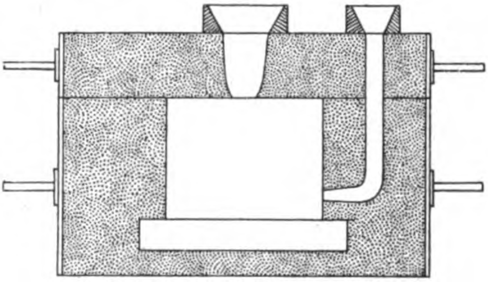
FIG. 153.—Die Mould with One Face Chilled.

Circular castings, such as wheels, which are chilled on the tread, are moulded in a three-part box, the middle part forming the chill. In repeat work, this mid-part is turned to size, and fitted with pins and snugs corresponding to the top and bottom parts of the box. The arrangement shown in fig. 154 gives a fair idea of the plan followed.

Wheels of this character are largely made in the United States, and many foundries have specialised exclusively in them. Under such conditions, large outputs are the natural order of things, but a description of the particular methods followed hardly comes within the scope of this work. However, one or two points may be noted:—The wheels are removed from the moulds at a red heat, and placed directly into annealing ovens or annealing pits, in order to obtain a slow rate of cooling, and thereby to minimise contraction stresses in the central or unchilled portions. In addition to the usual mechanical tests,

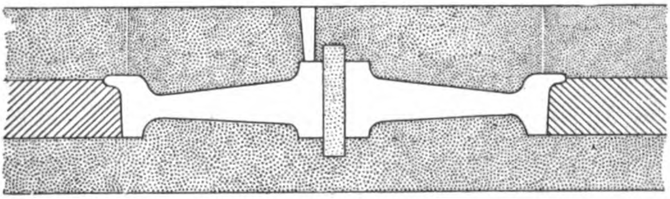
FIG. 154.—Wheel with Chill Tread.

these wheels have to pass a thermal test. This consists in surrounding the chilled tread with a band of molten metal $1\frac{1}{2}$ inch in thickness, and many railway companies specify that a certain percentage of the wheels ordered shall satisfactorily pass this test.

In British practice chilled rolls form an important class of chilled castings. A chilled roll differs from a grain roll in that the wearing surface is chilled; hence, the mould is a composite one of sand or loam and metal. The metallic portion consists of a cylinder, or series of cylinders, bored out to size, whilst the neck and coupling are moulded in sand or loam. Fig. 155 gives an idea of the arrangement usually adopted. These castings are gated from the bottom, and, as the moulds are rammed up inside a pit or curbing, the down gate is taken outside the mould, the ingate being cut horizontally, but at a tangent to the axis of the coupling. This gives the fluid metal a rotary motion around the axis of the roll, thereby tending to concentrate any sullage in the centre, and so assist in the production of a clean face. The surface of the chill is coated with plumbago, and special care must be taken to prevent the condensation of watery vapour. For this reason the chill is heated, and, immediately before casting, it should be uncomfortably warm to the hand. The thickness of the chill should be sufficient to resist cracking by expansion on the one hand, and, on the other, to conduct the heat away rapidly from the casting, in order to give the required depth of chill, while the area of its metallic cross-section should be at least equal to the area of the cross-section of the hot metal in contact with it. The feeding head of a chill roll is formed by a continuation of the coupling; and all rolls, chill, or grain should be well fed by feeding rods, frequent supplies of hot fluid metal being added at necessary intervals. In this sketch details of moulding have been omitted, since these details have already been covered under other forms. It may, however, be noted that the complete mould, when placed in the pit for casting, should, in the first place, give a good bearing for the chill; the golden rule of "iron to iron" must be followed. The gates are formed in cores, and the whole securely bound and rammed in order to withstand the strain of casting. Naturally, the couplings must be absolutely central with the chill. F. Gorman of Pittsburg has patented a method, the object of which is to maintain the roll centrally within the chill during solidification and cooling, so that all points may be equidistant from the face of the chill. This is achieved by the projecting collars of sand, shown in fig. 156. It is claimed that the thin rings of metal so formed cool quickly, and retain their cylindrical form, thus serving as a guide for the roll during its solidification and cooling. When turning the casting, these rings are cut off, and the chilled face reduced to the proper length. Another patent by Gorman has as an object an increase in the working life of the chills, and is attained by having renewable liners, as illustrated in fig. 157.

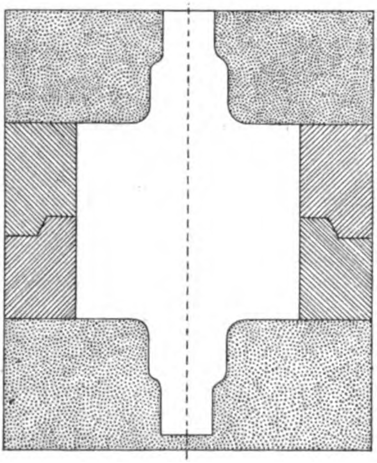

FIG. 155.—Chill Roll.

Finally, chilling must always be regarded from the attitude outlined in opening this chapter; and, although genuinely chilled castings form a distinct proportion of the total castings produced, yet the application of chills to certain types of moulds without producing a hard surface, as, for example, in steel, brass, and non-chilling cast-irons, forms a field capable of great extension. This plan will in many cases cut down wasters due to porosity or contraction stresses, and we have often found it the only solution when met with difficulties in the way of hopelessly designed castings.

It has been stated that complete metallic moulds hardly come within general founding; however, as examples of time savers, metallic moulds for lifters and core irons may be quoted. Chill moulds for these purposes are readily made, and are practically permanent. Sash weights may be also made entirely in chills; and the moulds, if continuously used, are water cooled by having wrought-iron pipes cast inside, through which cooling water is circulated.

Ingots hardly come within chill moulding; but, none the less, a series of ingot moulds is of service in both iron and brass foundries. Special iron mixtures are often passed through the cupola, and cast into pigs before melting for the production of a casting. Usually the pig moulds are formed by drawing a hand ladle over a bed of dry sand, thus forming a rough open channel. A neat and effective ingot mould is shown in fig. 158, and a series of these may be set on a gantry, and used for the production of clean pigs.

A similar method is followed in brass foundries, with the addition that every drop of spare metal should be poured into an ingot mould and not on to a sand bed. The higher intrinsic value of brass renders this not only advisable but also necessary. Naturally, if the brass is melted in crucibles, the ingots must be of comparatively small size. Generally, the moulds used stand in a row near to the furnaces, and the mould and its contents have to be turned completely over by hand to eject the ingots. A series of moulds similar to, but smaller than, fig. 158 may, by the addition of a socket to the bottom, be set on an iron bar; a girder is fixed in such a position that on throwing over the mould it arrests the fall at a point where the ingot will readily fall out. We have found an arrangement of this kind effective and serviceable.

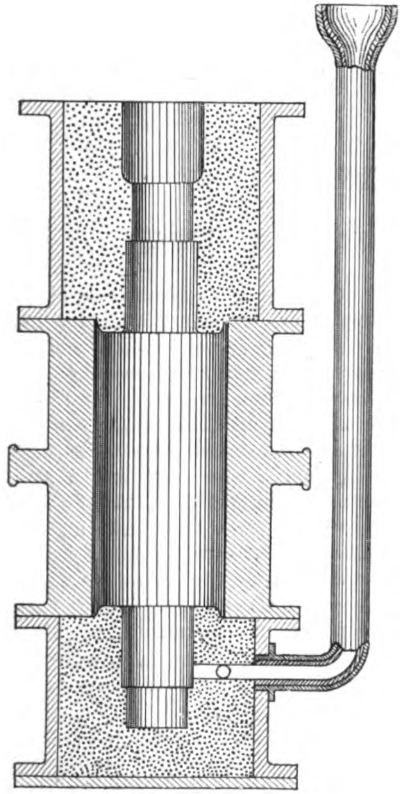

Fig. 156.—Chill Roll (Gorman's Method).

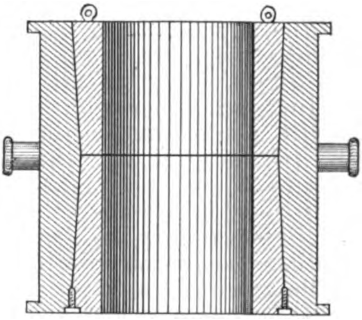

Fig. 157.—Chill Mould with Renewable Liners.

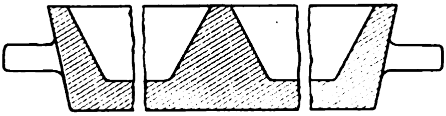

Fig. 158.—Ingot Mould.

CHAPTER XX.

CASTING ON TO OTHER METALS. BURNING.

It has been shown in Chapter XIX. that, by the use of a composite mould of metal and sand, two grades of metal are obtained in one casting. This practice is limited to certain grades of cast-iron, since neither steels nor brasses "chill" in the same sense as does cast-iron. In many cases composite castings are required, and, though it is usual to make the castings separately, and bolt them together, still, to a certain extent, two entirely distinct metals can be united in one mould. A common example is that of a cast-iron wheel, the spokes of which are formed of steel. In making such a wheel the full mould is made, and the steel arms laid in position, the ends projecting into boss and rim respectively. On closing the mould it is evident that boss and rim are isolated from each other, and practically form two separate castings; hence they are separately poured. It may be advisable to pour the two at distinct intervals, in order that the contraction of one shall be complete before that of the other commences. Other common examples are found in railings, gates, and bedstead work, which represent wrought-iron rods or tubes bound together and decorated by cast-iron ornaments. Obviously, the moulds in these cases may be comparatively large, whilst the actual castings are small.

It must be remembered that in all cases in which steel or wrought-iron is cast into other metals, no actual fusion of the two metals occurs; hence, the resulting grip is solely due to the contraction of the surrounding metal. For this reason, it is advisable to flatten, taper, or indent any projecting heads which have to be surrounded by molten metal. Thus, in stove-grate moulding, screws and staples are cast into the back of register fronts and the like, whilst hooks are cast into ranges. The object of casting in is to save subsequent fitting; and, in order to make the screws hold, their heads are flattened, thus obtaining a wedge form, as shown in fig. 159, the same form being also given to the staple and hook. Screws and staples are simply packed in the top part, leaving the head projecting to the necessary depth. Positions are marked on the back of the pattern by a small boss, in the centre of which a screw head is placed to serve as a print for the screw. Hooks are placed in position by means of a core print, which is the full length of the head of the hook; sand is then filled in, and only the head left projecting. These cases of composite castings simply represent an effort to save fitting, and herein lies the chief reason for casting iron or steel into cast-iron. Another example is found in heavy weights which have lifting eyes cast in, instead of being drilled and tapped in. Here, again, a good taper on the head buried in the casting must be allowed, and the bent over form shown in fig. 160 is often adopted. An alternative form of lifting eye, which is easily made, is shown in the same figure. Quite apart from taper or special bends, the rougher the surface the better the grip of the surrounding metal; and, as with chills, these surfaces should be clean, free from rust, and placed in the mould under conditions in which water will not condense on them. Unlike chills, the surface must not be protected by plumbago or other substance used for a similar purpose.

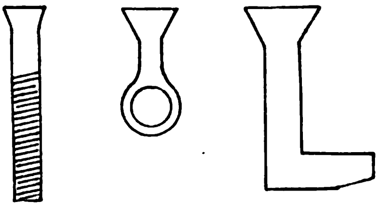
FIG. 159.—Screw, Staple, and Hook.

Wrought-iron pipes are sometimes required to be cast in a block of cast-iron, and, in such cases, if the pipe is straight, it is treated as a core, that is, laid in prints and chapletted down along its length. In order that it shall retain its shape when surrounded by fluid metal, the interior of the tube may be rammed with sand, vented, and dried, or simply filled with parting sand. The latter is preferable in the case of return pipes, as the parting sand is more readily removed when trimming the casting. Return pipes, such as are cast in steam heating plates, present various difficulties when cast on the flat. These are chiefly due to unsoundness along the top of the pipe and to the difficulty of retaining the pipe in its exact position. Reference to fig. 161 will show that if made on the flat with the two ends supported in prints, there will be a very considerable upward lift at the U-bend. Even if the bearing in the prints is absolutely rigid, the pipe, when heated by fluid metal, becomes flexible, and will readily bend upwards by the pressure. Therefore, along the length of each leg, and particularly at the bend, the pipe would require firmly binding down by means of chaplets, a matter of some little difficulty. Chaplets may be dispensed with, and all risk of unsoundness eliminated by making the mould to cast on end, as in fig. 161. In this case the top of the mould is formed by a loam plate, and the pipe is held firmly in position by a nut on either side of the plate. The lower nuts are covered over, and the surface made good after tightening the pipe in position. A green bottom part will answer in most cases; but, when the depth exceeds 2 feet, the bottom part should be dried in order to eliminate any risk of swelling.

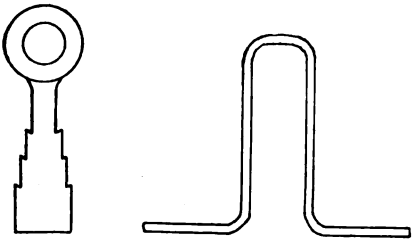
FIG. 160.—Lifting Eyes.

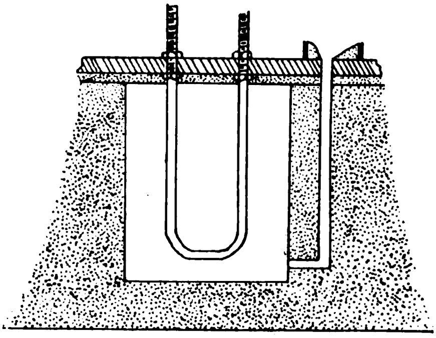
FIG. 161.—Return Pipe.

Other examples of casting steel in cast-iron are found in parts for printing machines, and the like; and in the majority of these cases the steel takes the form of rods cut to length and inserted with a view to act as journals. As a rule, and provided ordinary care is exercised, the casting of steel pieces in cast-iron, such as is indicated in the foregoing, and as found in the inclusion of steel pole pieces in cast-iron field frames, etc., offers no difficulty that cannot readily be overcome. Such is not the case with casting brass liners on shafts and plunger rods. Here difficulties arise, due to porosity in the brass, which, as a rule, only shows when the liner reaches the machine shop and has had its outer skin removed. Why this difficulty should arise is hard to say; none the less, the difficulty is there, and, as this is an important class of work in many brass foundries, has of necessity to be overcome. Various "fakes" are practised, and the authors have spent much valuable time in testing them without obtaining any results of special value. These treasured and closely-guarded fakes apply in different cases to (1) treating the shaft, (2) preparing and method of gating the mould, and (3) the composition of the brass. Whilst it is well known that certain alloys will run round an iron shaft, and give a more solid liner than others, this is useless in view of the fact that the composition of the liner is usually specified, the founder therefore having no choice. The authors' records for a number of years show that in a variety of cases, varying from small spindles up to large tail shafts, composition in 95 per cent. of the shafts lined was specified by the purchaser or engineer in charge of the work. Where a range of composition is permitted, a gun-metal of approximately 5 per cent. tin and 8 per cent. zinc, touched with aluminium just before casting, will give as good results as any alloy applicable to lining, softer brasses being useless for liners. The alloy most commonly specified is that known as Admiralty gun-metal, which, containing 10 per cent. tin and 2 per cent. zinc, is considerably harder than the foregoing.

So far as moulding fakes go, the authors have found them to savour chiefly of the nature of fads, and their experience is that the more simple and direct the procedure the better the result. Directness lies in recognising the shaft, for the time being, as a core which is non-porous and will expand as the lining contracts. Whether such a core gives off gas at the temperature of casting is a question; but it is certain that if any gases are evolved they must pass along with those of the mould through the mould itself. These conditions are the reverse of those existing in an ordinary core. As the lining contracts, the shaft expands; the latter should, therefore, be expanded as much as possible before inserting it in the mould. This is effected by heating it to a dull red heat; in other words, to a temperature at which the shaft will not bend by its own weight when handled. In a green mould the best conditions for getting away the air are found in having the shaft on end, which, under ordinary conditions of equipment, limits the process to what are in reality little more than spindles. Should a heavy shaft be lined on the flat, the prints, especially with a green mould, should be packed with metal to make an unyielding support for the shaft. However, when cast on the flat, a dry sand mould is preferable, and the following procedure is the best the authors have yet experienced:—

A pattern, as in fig. 162, is desirable, the prints of which should be of sufficient length to pass through each end of the moulding-box. These prints may be packed up by means of distance pieces from the bars of the box, but a better arrangement is to have stools at either end of the box, and use them for the double purpose of supporting the shaft and binding it down. This arrangement involves the use of a bottom plate projecting beyond the ends of the box. The bottom part and bottom plate are bolted together, and the two half stools set to the projecting prints, and firmly bolted in position. The mould is completed and gated from either end by means of plump gates, risers being placed along the centre of the top. After thoroughly drying, the bottom part and plate are set on a level bed, the shaft fitted in and thickness tested by means of clay strips; and, if the stools have been correctly set, this thickness should be uniform. The shaft is then heated to what is technically known as "a blear red heat"; and with the usual foundry equipment this can only be effected by building a fire around it, extending to the length of the lining. On attaining this temperature the shaft is slung, cleaned by brushing off any adhering soot, etc., and returned to the mould, the latter being then closed and made ready for casting. A top half stool placed over each bottom half and bolted to the bottom plate gives an effective binding for holding the shaft down. The final arrangement is shown in fig. 163, which gives a longitudinal section of the completed mould. A section through the gates is shown in fig. 164, and through the stools in fig. 165. As already stated, this is the best method the authors have experienced, and, as a rule, gives good results. If any blowholes are found along the top side of the liner, they are filled in by "burning." A moderately thick liner may be cast on in two portions, the first coating being half the desired thickness. This doubles the work, involves the preparation of two moulds, and a thorough cleaning of the first liner. The object is, however, found in the idea that the second liner effectually fills in any bad places on the first. This idea is, however, not always realised. Undoubtedly, the best practice is found in casting the liners separately, boring them out to a tight fit on the shaft, on to which they are subsequently shrunk. Liners up to 30 feet in length are so treated; and the junction of two liners, as in a propeller shaft, is subsequently "burned" in the foundry.

FIG. 162.—Liner Pattern.

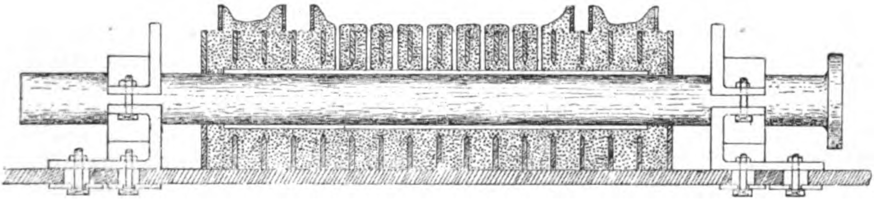

FIG. 163.—Lining a Propeller Shaft.

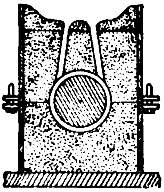

FIG. 164.—Section through Gates.

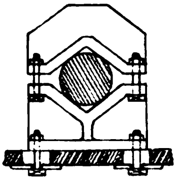

FIG. 165.—Section through Stools.

Burning is followed in foundry practice, for a variety of reasons, including the obliteration of defects in castings or repairing broken ones and joining separate pieces together. The principle of burning lies in flowing molten metal over the parts to be joined until they have fused together. This is effected by moulding a channel over the junction into which hot metal may be poured, whilst an outlet is provided for the surplus metal. The mould for a burn may be either open or boxed, according to whether the upper surface is horizontal or otherwise. Amongst the points to be noted in burning are, the surfaces should be perfectly clean; the metal or alloy used should in most cases be of the same composition as the casting, and in every case must be hot and fluid. In moulding, a sufficient head of metal should be left in order to chip out to the contour of the casting, but the smaller this head the better the result. Sufficient metal must be run through the burn in order to effect a fusion; but here, again, no good results by passing this limit.

Sheet brass may be readily burnt in the brass foundry, as, for example, in the case of a plain register front. Such fronts are fixed to a cast-iron one, and thus, when in position, give the appearance of a solid brass front. The sheet brass is cut to shape, and in three pieces, a cross piece and two legs. In the brass foundry these three pieces are laid on a level sand bed, and the legs set in line with the top piece by means of a straight edge. A piece of wood, about ½-inch wide, is laid across the joint, and sand packed up to about 1 inch in height, and, on withdrawing the wood, an open channel remains across the joint of the two pieces. One end of this channel is cut down to half an inch in height, and an open runner made from it to a small pig bed on a lower level. On flowing brass through this channel, the surplus is taken away by the cut-out end, and in the course of a few moments the sheet brass will have fused. If left at this stage to solidify, the two pieces will, when cold, be effectively joined. Whilst pouring, the pot must be travelled up and down the channel, and the stream of metal should be so manipulated as to strike the joint and not splutter over the sand. This involves a pot having a clean lip. The projecting lumps are ground or filed off, and the burnt joint will be found to be stronger than a brazed joint; and, if the composition of the burning metal is similar to the sheet metal, the colour will be uniform throughout, a point of some importance in all artistic work. This principle is applied to any brass casting which, owing to its intricacy, cannot be moulded in one piece. The pattern is made in segments, which, after casting, are fitted together and then burned. Intricate ornamental figures are often made up in this way.

A box burn is essentially the same as an open one, except that the channel is covered over and a runner and flow-off provided. The latter must in every case come off at a higher level than the casting, but also at a lower one than the runner. An example of burning an irregular surface is found in the case of a cast-iron fender curb. These curbs are made to standard sizes; and, when an odd size is required, it may be obtained by cutting the centre from a larger one, and burning the two halves. These halves are levelled off on a sand bed, face side down, and, about the locality of the burn, sand is packed up level with the outer edges and a joint made. A small top part is placed on this joint, and centred to the part to be burned. A wedge-shaped runner is placed over the junction of the two pieces, and the box rammed up, a lifter being placed in the centre to insure a clean parting. On lifting off, a line will indicate the junction of the two parts of the curb; a channel ¾-inch wide by ½-inch deep is cut along this line. This channel is continued to a hole in the side of the box, and serves as a flow-off. Reference to fig. 166 will show a section of the burn ready for pouring. It will be seen that the box, when returned, leaves a channel directly over the junction of the halves, and, on pouring metal down the runner, it will flow down one side and up the other, passing away by the flow-off into a small pig bed. The two foregoing examples are given to illustrate an open and a box burn; and, quite apart from the particular cases quoted, the general applicability of the method will be noted. It must, however, be observed that both cases represent the simplest aspects of burning, as also that the articles burned are perfectly free to expand when heated by the flowing metal, and equally free to contract when cooling. Reverting to liners on steel shafts, it will be remembered that the method advised was that of shrinking on, and, in the event of two liners being necessary, to burn the junctions. This only happens in the case of long propeller shafts, and, owing to the weight of such a shaft and the difficulty in handling it, the most convenient method of burning is by a series of open burns. If the turning shop is adjacent to the brass foundry, the shaft may be burnt whilst in a lathe, but such a course is usually debarred by the distance which the molten brass has to be carried. Failing the lathe, the shaft is left on the trucks which bring it into the foundry, and rotated as required by means of an overhead crane. Two open burns, about 4 inches long, may be made each rotation. The sand necessary for the channels and pig beds is placed on staging packed up from the truck, and the burns are so made that no metal projects over the liner. In pouring, only sufficient metal to effect a fusion is flowed through the channel, for, obviously, this is a case in which the article burned is not free to expand or contract. However, by careful manipulation, the junction may be followed round without the development of cracks; and, should any occur, they are burnt up again. It will be seen that this method involves a comparatively large number of burns and a fair amount of subsequent chipping, but it is as good a method as can be found, and the risk is slight.

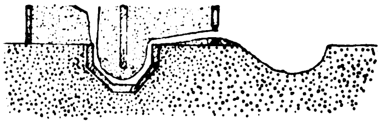

FIG. 166.—Box Burn.

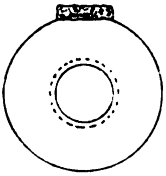

FIG. 167.—Flange Burn.

In ordinary cases, burning is followed in order to remedy defects in castings, and is often the means of saving what would otherwise be a waster. For instance, the flange of a pipe, if poured short, may be made good by burning a piece on, as in fig. 167. Similarly, if the gate is broken in, or if blowholes or dirty places are present, the defect may be remedied by means of an open burn. Burns, such as the flange shown, involve very little risk; but, when burns are required in the centre of a cylindrical casting, then risk, due to cracking, becomes of moment. In many cases this risk is lessened, if not obviated, by heating the casting before burning, and, as the casting has thus expanded before the molten metal is poured on, both burn and casting cool and contract at the same time.

In preparing burns of this character, the inside of the casting is rammed with sand and dried. The casting is then set in a pit in the position required for burning, and the necessary channels made up in either sand or loam. The latter may be in the form of loam cake, carded down to shape, or, if a close burn, the box is lifted away and dried. A fire is built round the casting, and the temperature raised to as near a red heat as possible. On attaining a high temperature, the mould for the burn is replaced and weighted in position, overflow channel and pig beds made, and the burning metal flowed through. The whole is allowed to cool slowly with the dying fire, and is not disturbed till contraction is complete.

Evidently, then, success in burning any part of a casting which has no freedom of movement lies in having the whole of the casting as fully expanded as possible before treatment, in order to eliminate as far as possible the risk of cracking due to unequal expansion and contraction. In the case of cast-iron, burning a hot casting with the resulting slow cooling has a further advantage in eliminating chill in the burned part.

If the defective part of a casting is large, it is better to cast a piece, separately, of the required shape, loosely fit it into the aperture, and then follow the joint by a series of open burns. Apart from the difficulty of contraction cracks, burning either cast-iron or brass castings is effected with comparative ease, and the process has a legitimate position in any foundry. As a means of removing unsightly, but otherwise unimportant defects, of repairing broken castings or joining separate castings together, it has a very useful purpose, and from experience the authors can state that comparatively few founders carry burning beyond its legitimate sphere.

Steel castings, owing to the higher temperatures involved, offer greater difficulties in burning than cast-iron or brass. This feature largely explains the adoption of electric welding by steel founders. Where molten cast-iron is available, as, for instance, in a Bessemer steel foundry, effective burns are made by washing out with cast-iron first and then immediately following on with a stream of steel. Burning steel castings by means of thermit possesses advantages, chief of which is that the work can be effected away from or independent of melting furnaces. Practically, the method is the same as flowing molten steel through or over the part to be burned. The difference consists not so much in making ready for burning as in readily obtaining extremely hot and fluid metal. The latter depends on the thermit reaction, viz., that when powdered aluminium and an oxide are in contact the reaction started by an elevated temperature results in a rapid oxidation of the aluminium. This oxidation develops a very high temperature, and the oxygen of the oxide passing over to the aluminium leaves the metallic portion free, with the consequent formation of alumina. The dual *rôle* of thermit lies in reducing an oxide, and delivering from it the metal in a state of perfect fluidity and of a temperature eminently suitable for burning.

CHAPTER XXI.

WEIGHTING AND BINDING MOULDS.

For the general run of work the usual methods of securing a mould are found in (1) weights, (2) cramps, and (3) cotters through the box pins. These methods have, to some extent, been discussed, and the only further points calling for note are, first, the self-evident fact that in the case of loose weights the weight employed should be ample for the purpose. As a rule, this is obtained; but it does not always follow that the weight is properly placed. For example, the weight should be distributed evenly over the box edges, and an equal bearing obtained on all parts of the joint. In cases where the pattern comes relatively high in the top part, the weight should also bed directly on the mould, in order to prevent a burst through. This is of special moment in the case of brass castings or alloys of high specific gravity, and a good rule is always to bed the weight directly on the top of the box, thus obtaining a bearing on the sand as well as on the sides of the box. The weights shown in figs. 13 and 14 are very suitable for this purpose. Where the top part is larger than can be covered by one weight, a turning board may be bedded over it, on which the weights are laid, thus increasing their effectiveness. With regard to cramps and cotters, a point of note lies in the fact that they are chiefly effective round the joint of the box, and, if the latter be of large area and light section, there may be a tendency to spring in the centre when casting. In such a case the efficiency of the cramps should be increased by weights placed over any parts likely to spring.

Whilst in many cases weights are essential, in the case of large work they are, at the best, only a makeshift, and a tendency in many foundries is to rely on weights and pit ramming to a greater extent than is safely permissible. A dead weight, provided it has an effective bearing, cannot reasonably be objected to, and it will be safe up to within its limit of resistance to the pressure or movement below it. However, the difficulty with intricate or built-up moulds lies in making a dead weight effective on all parts of the mould. Pit ramming as a security for binding is of secondary value only, and the net security is dependent entirely on the character of the backing beyond the rammed part of the pit. Thus, an unyielding curbing surrounding the mould offers a good and safe backing for ramming sand between mould and curbing. A hole dug in the floor some three or four feet larger than the mould, and, after the latter is placed in position, simply rammed up, can only be regarded as a preventative of run-outs through bad joints. The resistance offered to pressure is entirely dependent on the character of the floor backing the rammed part of the pit. In the case of tank or brick pits, if originally rammed in even courses to the top, then, on digging out to place a mould, more or less compact sand surrounds the hole so formed, and a more solid backing is thus obtained for the sand rammed between the mould and the sides of the hole dug out. It is absolutely necessary to regard these limitations to both weights and pit ramming, and some recognition of them in the past would have saved many wasters, and, in several cases, accidents to members of the casting squad. At any rate, the lessons of these wasters most forcibly show that pit ramming should never be regarded as a substitute for binding, and that there is more in placing a weight on a mould than actually meets the eye.

Complete boxes offer no difficulty in securing. When the mould is contained in several distinct parts, as, for example, a heavy bedded-in job with several drawbacks, and covered by a top part in two or more pieces, the difficulties increase; a remark also applicable to all classes of loam moulds. Taking heavy bedded-in work first, if a plate is set below the coke bed, an unyielding support for the sand of the mould is obtained. Not only so, but bringing stools from the plate to the level of the joint gives a solid bearing for the top part. Rings passed over the snugs of the plate may be caught in a hook-ended bolt, the screwed end of which may be passed through a girder placed over the top part. A washer and nut complete the outfit, and a mould so bound down is "iron to iron" throughout; the top part cannot crush by reason of the stools, it cannot lift by reason of its attachment to the bottom plate. This method is followed in all modern foundries, and its virtues are simplicity and security. The bottom plate may take the form of any convenient loam building plate, and it takes no longer to bed than if the mould were made without it. Fig. 168 gives details of useful binding tackle. The stool shown at *a* is of cast-iron, and a series of different sizes are handy. Failing this, distance pieces must be used to give different heights. The coupling ring, *b*, is made of metal 1¼-inch in diameter, and the hook bolt, *c*, is cut with a 1½-inch thread at the top. The binding bar, *d*, may seem elaborate, but actually it is not so, and we have found it of high value. It is made in open sand, with two pieces of round iron, cast one in each side for convenience in lifting.

The method of binding is as follows:—After the bottom plate has been bedded down, the requisite number of stools are set to give a bearing for the top part, and, if too low, the correct height is obtained by flat plates of packing. Coupling rings are passed over the snugs of the plate, and the moulding is then proceeded with. When the sand sides of the mould reach the top of the coupling rings, hook bolts are passed through and rammed up with the sides, care being taken to keep them in a vertical position.

These bolts should be set to clear the top part, and come outside when the latter is lowered in position. Should the top be of such a width that the bolts come inside, then a space around them is left clear and not rammed. When ready for binding down, the bar, *d*, is lowered over two opposite bolts, a washer passed over, and the bolts tightened by nuts. The actual number of bolts and binding bars used will depend on the character of the mould and on the number of top parts covering it. Assuming that one side of the mould has to be lifted away as a drawback, then the hook bolts on that side are not placed in position until the drawback has been returned. In such a case the bolts serve a further purpose in that they can be used for supporting the back of the drawback. Thus, a plate may be bedded up against the drawback, and after the bolts have been tightened over the top part, they are sufficiently rigid to admit of wedging from them to the plate. This plan considerably enhances the value of the subsequent ramming at the back of the drawback.

Another aspect of binding in this fashion is found in the case of a large top part, which may be of light section or subject to great stress in the centre. The binding bars, of course, considerably stiffen the centre; but, assuming that only two are used and their effect is desired over the whole surface, then, before placing the binding bars, flat bars of a similar length to the top part are bedded on at right angles to the binders. The latter, laid across these bars and screwed down, convert the top part into an exceedingly rigid structure. This effect is only obtained when the bars are bedded directly on the top part and the binders in turn bear directly on each bar; hence, it may be necessary to wedge between certain of the bars and binder after the latter has been screwed down.

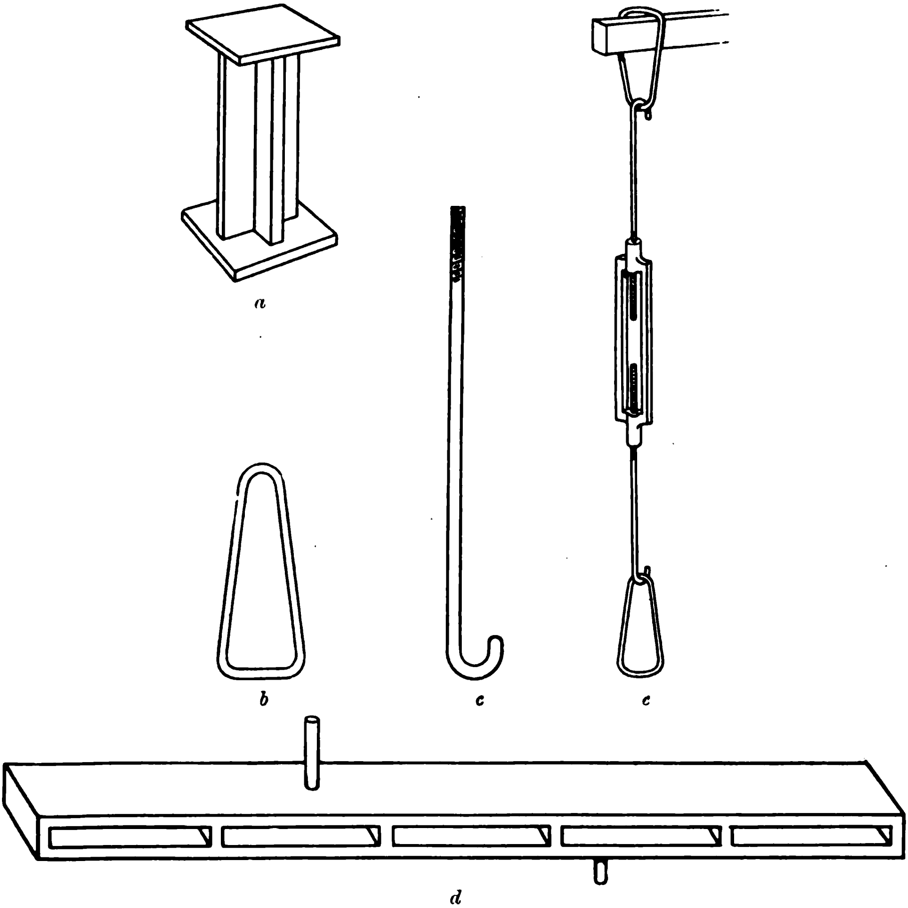

FIG. 168.—Binding Tackle.

Loam moulds are bound down by very similar tackle, though, in a simple case, the top and bottom plates may be directly tied together by means of cramps and wedges. A loam mould is always more conveniently closed on the floor than in the pit, and this plan is followed when circumstances allow of it. Limiting conditions are found in the weight of the mould and its relation to the lifting capacity of the crane, and also in the character of the bottom plate. If the latter is liable to spring, then the mould should be closed in the pit, but, assuming conditions favour closing on the floor, then the mould may be bound down ready for placing in a pit. Whilst a mould covered by a flat top plate is comparatively easy to bind, this does not apply to a mould consisting of several drawbacks and possibly an irregular top. So far as irregularity on the top is concerned, this may, by means of metal packing and cross-bars, be made to give a level surface on which to place binding bars for connection with the snugs of the bottom plate. Drawbacks may, in certain cases, be wedged directly from the hook bolts, or, in other cases of greater intricacy, top and bottom plates are made with projecting snugs through which bars are passed and wedged, thus offering a means of packing the drawback by means of horizontal bars, plates, wedges, etc. In other cases, especially the covering plates of flanges and the like, the drawback plate is necessarily set at such an inclination that wedging by these means is difficult. Here the sides of the pit are useful, and a series of props may be carried back to the wall of the pit and firmly wedged. This, of course, should be done as the pit ramming proceeds, and care should be taken that the rammers do not loosen the wedges. Practically, every loam mould built with drawbacks should be rammed in a pit, but simple rammed sand should not be regarded as sufficient security for maintaining the drawbacks in position; hence, the note on wedging either from the binding bolts or from the solid and unyielding sides of the pit. Finally, in concluding this short chapter the chief intention of which is to be suggestive, we would emphasise the fact that, wherever possible, a screw should replace cumbersome and uncertain weights. Tackle of the type shown in fig. 168 is not costly, actually cheaper than weights, takes up practically no valuable floor space, and has the advantage of making the most intricate mould, so that it can neither be crushed nor strained. As noted, simplicity and security are represented in a mould so tied down. If, for any reason, the open girder shown in *d*, fig. 168, should be objected to, a solid bar may be substituted, and screw bolts connected by a shackle of right and left hand threads, used as in *e*.

CHAPTER XXII.

SHRINKAGE, CONTRACTION, AND WARPING.

THESE three headings are conveniently taken together, as they have a very direct relationship to each other. Technically, "shrinkage" refers to the gradual lessening in volume of fluid metal as it approaches the solidification point at which shrinkage ceases and "contraction" commences, contraction being understood to refer to the lessening in length or in volume of the solid metal. Warping is simply unequal contraction induced by different thicknesses of metal in the casting. Total contraction is found in the difference in size between the mould, or the pattern if only slightly rapped, and the casting; this, under normal conditions, is fairly constant for a given grade of metal. Variables which influence the amount of contraction are the contour of the pattern, the temperature of the metal when poured, the presence of blowholes, etc. As a case in point, mild steel castings should show a contraction of $\frac{3}{16}$-inch per foot, yet we have occasionally seen them come out of the mould at full pattern size, probably owing to the presence of blowholes. In other cases, contraction is influenced by the mass of the casting; thus, the allowance in the case of light cast-iron is $\frac{1}{8}$-inch per foot, whilst in the case of heavy cast-iron it is $\frac{1}{10}$-inch per foot. Variations of similar degree are also found between light and heavy brass and light and heavy steel castings.

Whilst it is comparatively easy to measure total contraction, it is by no means easy to measure liquid shrinkage; but that shrinkage must be met if a sound casting is to result. Generally speaking, a mass of fluid metal in solidifying forms, first, a shell of solid metal; and then the liquid metal in shrinking draws to the solid, leaving a depression in that part which solidifies last. Contraction varies with the character of the metal; thus, with white cast-iron and steel it takes place at a uniform and quick rate, but, with grey cast-iron, the rate meets with one or more actual retardations, during which the metal expands instead of shrinking. These expansions are more or less a function of composition; but, after completion, the casting steadily contracts until atmospheric temperature is reached. Keep, and more recently, Turner have done valuable work in investigating these expansions, but the chief interest to the founder lies in the fact that expansion in the solid or semi-solid state implies less apparent fluid shrinkage. In Prof. Turner's experiments, *Iron and Steel Institute Journal*, 1906, No. 1, copper, aluminium, lead, tin, zinc, and aluminium-zinc alloys contract evenly from the moment of solidification. White iron shows a pasty stage, and then contracts regularly till about 665° C. is reached, when there is a slight retardation. Non-phosphoric grey iron shows two marked expansions, one immediately after the metal has become sufficiently solid to move the pointer of the measuring instrument used, and at a temperature of about 1140° C., the second at 695° C. Phosphoric grey pig (1·25 per cent. P.) has three actual expansions, one from the moment of solidification, but reaching its maximum at 1060° C.; the second about 900° C.; and the third very marked and long continued about 730° C. Combining Turner's and W. H. Hatfield's experiments, given in the same volume of the Iron and Steel Institute, it seems clear that these lowest changes are due to the formation of amorphous free carbon produced by the decomposition of carbide of iron.

Shrinkage, whether great or little, must be met by further supplies of fluid metal until solidification of the casting is complete. This is obtained either through the gate or the feeder, either of which is designed to solidify at a later period than the casting. This practice of feeding is one of the most important aspects in the production of castings, and it is possibly the one to which the least systematic attention is given. Whilst the first aim should be a solid casting, it should not be forgotten that gates and feeders have to be removed from the casting, and that when removed their value is only that of returned scrap. Taking grey cast-iron first: in light work, liquid shrinkage is practically negligible, and the gates need only be cut of sufficient section to run the casting. Heavy cylindrical castings are best fed by carrying the mould two or three inches higher than the pattern, thus leaving a head of the same size as the casting, which is subsequently cut off when machining the casting. Solid cylindrical castings may also be fed by this plan; but, if the diameter and length are large, the head will require continuing for a considerable length. This plan has the advantage of collecting sullage or dirt as well as supplying a reservoir of liquid metal to feed the shrinking casting below it. Obviously, in the case of circular castings, *e.g.* cannon balls, rectangular blocks, etc., it is impossible to continue the casting upwards for direct feeding, and the plan followed is to place a feeder on the highest or heaviest part. These feeders vary in diameter according to the size of the casting; and whilst, in certain cases, a "whistler" the size of a lead-pencil may act as a feeder, in other cases a reservoir some 8 or 10 inches in diameter may be required. All feeders should be recessed at the junction of the casting, and even a small recess is a very considerable aid to removing the feeder. Naturally, even a large feeder, say 10 inches in diameter, if placed on a massive casting, will solidify before the casting; hence the purport of mechanical feeding, the sole object of which is to keep a channel open between feeder and casting for the admission of further supplies of liquid metal. This object is secured by means of the "feeding rod," simply an iron rod worked up and down the feeder, and passing well into the body of the casting at each stroke, in order to maintain an open connection. New supplies of metal are poured into the feeder as required, and thus pass directly into the casting. A heavy grey iron casting will be taking metal in this fashion for a long time after the actual pouring; hence, the feeder should be kept well open for its admission. The feeding rod should be kept clean, any metal solidifying on it being knocked off; and, further, the rod should not move up and down in one spot only, or the feeder will soon choke, except for a small orifice the size of the rod. By travelling the rod in its up and down movement round the feeder, watching that no part of it chokes, a comparatively small feeder can be kept open for a very long time, and the legitimate demands of the shrinking casting fully met by periodical supplies of fluid metal. The object sought should always be that of last solidification in the feeder, and, provided this is attained, the smaller the feeder the better the practice.

As already noted, light grey iron castings do not require feeding in the ordinary sense; but, in this class of work, "draws" are often met with, which constitute another aspect of liquid shrinkage. For example, if the gate is lighter than the casting, by solidifying early it may, under certain conditions, draw metal from the casting during solidification. The result is that, on breaking off the gate, a pin hole is shown in the casting. Even comparatively small lumps on the back of a thin flat casting tend to draw the metal away from the face. This, in the case of work that has to be ground and polished, is often sufficient to condemn the casting, as the depression is not removed in grinding. This defect does not occur if screws are cast in the lump, which leads to the conclusion that the chilling influence of the screw head is sufficient to cause the several portions of a casting of slightly varying section to solidify more nearly at the same time, and thereby to eliminate the draw. In any case, when screws are not cast in, a remedy lies in casting in either a sprig or a small piece of cast-iron, so as to hasten the cooling of the lump. Another interesting remedy lies in pricking the face of the mould immediately below the lump, the pricking being effected by means of a needle, and the holes made almost touching each other.

Steel, unlike grey iron, has a narrow range of fluidity, a feature which almost excludes the feeding-rod; and, as liquid shrinkage has to be automatically met from the head, necessitates the adoption in heavy work of much larger feeders than would be employed on the same casting if made in cast-iron. As the heads, like the moulds, are faced with compo, which is a bad conductor of heat, some benefit is obtained by heating the head mould to as high a temperature as possible before placing it on the mould and then casting immediately. Further protection is also obtained by covering the head with charcoal dust immediately after filling, which, being also a non-conductor, to some extent retains the heat. In any case, with heavy steel castings, large feeders are essential, and must be so placed as to provide a reservoir for the casting during its limited interval in reaching the solidification stage. In the case of small work, several castings may be fed from one feeder, the usual plan being to arrange the feeder in the centre of the box, cutting a runner to supply it, and gating each casting from the feeder. In such cases it is always well to cut the runner into the feeder at a tangent, thus obtaining a circular movement of metal in the feeder, which tends to drive any dirt or other light material to the centre. We have used this method of feeding small castings, and obtained good results by it, but it is inadmissible in the case of larger work. Medium-sized work offers more difficulty in successful feeding than either bulky, but compact, castings or small work. Plain rings, for example, when of three or four inches in width by similar thickness are almost impossible to feed from one or two heavy feeders. In such cases, we have found the only solution to be in distributing a series of small feeders around the ring, each one being effective on a comparatively small part, but assisting its neighbours on either side by meeting them half way. To sum up, as regards steel, the feeding heads have necessarily to be large, and, in many cases, their volume totals a third of that of the casting. Whilst in plain bulky work one central feeder will be effective, in other cases it may be more effective to split the one feeder into several units, each having a local effect. Finally, liquid shrinkage in the case of steel is high and quick acting, and must therefore be promptly met.

The majority of alloys coming under the common term brass have a comparatively long range of fluidity, and may, therefore, be fed by kindred means to those followed with cast-iron, that is, feeding heads can be kept open by means of iron rods, which should be coated with plumbago, and liquid metal added as required. However, it may be well to take the alloys in detail, and in the first place emphasis should be laid on the fact that almost any weight of brass (copper-zinc alloys) or gun-metal (copper, tin, and zinc alloys) may be successfully cast without the use of a feeding rod, as is illustrated in every marine brass foundry daily, and it can be tested by simple experiment. This feature is often a surprise to iron or steel moulders first taking up work in a heavy brass foundry. Whilst the feeding rod is perfectly admissible, practically the same or a better effect can be obtained without it. Generally speaking, the whole of the feeding in ordinary brass work is done through the gate, which should be so cut as to attain this end and not draw metal from the casting. It therefore follows that the runner pegs and gates usual in brass-founding are considerably heavier than would be used on a similar range of iron castings, and effective feeding may be obtained by the gates only, supplemented in special cases by risers, which may be either placed on the casting or at the side and connected by a channel.

Special alloys offer somewhat different conditions, and experience shows that certain of them yield better results when fed by the rod, the chief examples of which are manganese bronze and phosphor bronze. Castings of the latter are sometimes made up to 20 tons in weight, whilst castings in manganese bronze often scale 4 or 5 tons. The method of feeding is practically that followed with grey iron castings, the heads being kept open by rods, and metal added as required. Unlike the grey iron foundry, a constant supply of feeding metal is not available from the cupola, as these castings are made from air furnace metal; therefore, a series of crucibles are charged in separate holes, and so timed as to be ready at suitable intervals for feeding purposes. Of the special bronzes, manganese bronze is characteristic in its demand for good feeding, and even small castings untouched by the rod should be plentifully supplied with risers or effective feeding heads. These bronzes have the advantage that chills induce no hardness in them; therefore, when a feeder is inapplicable, a chill may be used to obtain the same end, the object being to hasten the solidification of a heavy part, and bring it into line with a lighter part of the same casting. In other words, the chill is used for equalising shrinkage in the same way that a chill is used for equalising the rate of contraction.

The last aspect of shrinkage is found in white iron as used for the production of malleable castings. As a rule, these castings are comparatively small; hence, the high shrinkage is efficiently met by gates supplemented by risers, and, in special cases, chills.

Shrinkage and contraction, although closely akin, have been differentiated here since shrinkage must be met entirely by feeding, an operation which is without effect on contraction. After assuming the solid state, most metals or alloys contract regularly with a falling temperature. There are one or two exceptions, but they must be regarded as exceptions. These have, however, led to our receiving inquiries from moulders, who have been troubled by castings cracking during contraction, for a remedy based on the lines of a noncontractible alloy. It cannot be too strongly stated that contraction is a natural function, and, within the limits of the particular metal used, the more of it that takes place the better, for every casting should show its full contraction, or there are certain to be either blowholes in the metal, or stresses present which may or may not be removed by heat treatment, such as slow cooling. The following table shows the usual contraction allowances; but experience indicates that the actual amount of contraction is influenced by several conditions, the chief of them being the contour of the casting and the freedom it offers to movement:—

Metal.	Contraction.	Usual Allowance.
Yellow brass, ...	$\frac{1}{8}$ to $\frac{3}{16}$ inch per foot.	$\frac{1}{8}$ inch per 10 inches.
Gun-metal, ...	$\frac{1}{8}$ to $\frac{3}{16}$,, ,,	$\frac{3}{16}$,, foot.
Copper, ...	$\frac{7}{32}$,, ,,	$\frac{1}{4}$,, ,,
Zinc, ...	$\frac{1}{8}$ to $\frac{5}{32}$,, ,,	$\frac{1}{8}$,, ,,
Aluminium, . . .	$\frac{5}{16}$ to $\frac{3}{8}$,, ,,	$\frac{5}{16}$,, ,,
Grey cast-iron, . .	$\frac{1}{10}$ to $\frac{1}{8}$,, ,,	$\frac{1}{8}$,, ,,
White cast-iron, . .	$\frac{1}{4}$,, ,,	$\frac{1}{8}$,, ,,
Steel, ...	$\frac{3}{16}$,, ,,	$\frac{3}{16}$,, ,,

Note.—White iron castings are annealed before use, and during this process an expansion of $\frac{1}{8}$-inch per foot takes place; hence, the same contraction allowance as for grey iron is usual.

We confess to some hesitation in giving the foregoing table, for our researches on contraction have shown the existence of several factors which influence the amount, and practical experience conclusively shows that castings of intricate form seldom absolutely conform to any given rule. However, the point is that contraction not only does, but also must, occur if a sound casting is to be made. Taking the case of a steel liner, 20 feet long, with flanges at each end, then, with a contraction of $\frac{3}{16}$-inch per foot of length, the total contraction is $3\frac{3}{4}$ inches. Each flange must, therefore, travel towards the centre of the liner a distance of $1\frac{7}{8}$ inch. If the character of the mould will not permit of this movement, then an inherent weakness or actual fracture will develop in the casting. Actually, a fracture is the safer in that the casting is at once condemned; whereas, in the case of undetected stresses, the casting may enter working life with a distinct risk of failing under a comparatively low load or light shock.

In describing a vertically built loam core it was compared, from the point of strength, to an arch. Assuming such a core built entirely of hard brick, and faced with only a thin coating of loam, then the arch would be too strong for the contracting casting, and fracture or a hidden flaw would inevitably follow.

Therefore, as contraction must occur, the natural remedy lies in constructing the mould to yield as the solid casting draws together. Green sand moulds offer little difficulty in this respect, and the usual run of dry sand moulds for iron or brass are sufficiently yielding to be compressed by the casting. However, in the case of intricate forms, provision should be made either by placing ash beds in parts likely to resist contraction or by digging out the mould in those parts, immediately on solidification. The latter method, termed "relieving" or "releasing," must be followed with all intricate steel castings, since compo-faced moulds are very unyielding things. Relieving must be quickly accomplished if it is to be effective, yet not too quickly, or the metal may not be strong enough to keep its shape. All that is necessary is to loosen any part of the mould likely to bind, thus giving the casting a free path in its contraction. Cores, owing to their inaccessibility, offer greater difficulty, but in most cases a yielding body is provided when the interior of the cores have ash beds. A point of note lies in the fact that it is useless providing a body of sand which will yield if the core irons themselves bind; and many a casting has been cracked by the irons being practically on the metal, thus allowing no movement whatever. Collapsible core barrels in the case of pipe castings are familiar, and in their absence straw ropes are the great saving medium. In the case of cores almost completely surrounded by metal, such as centrifugal pumps when cast on the side, a perfectly solid core may be made by keeping the core gratings sufficiently far from the face to allow of the contracting casting forcing the sand into ash vents in the centre. Loam moulds and cores are, by their very nature, the most difficult to relieve; and here, as regards building, loam brick and ashes are the great remedies. When sufficient freedom cannot be obtained by these means, all binding parts must be dug out, a laborious occupation, as it has to be quickly performed. In many cases relieving bars can be built in cope or core. These bars, being provided with a ring or staple in the top, may be pulled out by the crane, and, apart from the space left, will start the building sufficiently to allow of the casting contracting.

Contraction can, therefore, be met, by providing yielding cores, or yielding moulds, or by loosening all parts which retard movement in the casting. There can be no excuse for a distorted or cracked casting when the fault is due to the mould; but in many cases distortion is solely due to the distribution of metal in the casting, and, obviously, attention to the mould can only partially remedy a defect due to design.

Warped or cracked castings, when due to unequal distribution of metal, are not only extremely vexing, but also are hard to remedy. The cause of such fault is found in the differing rates of contraction induced in one casting by the different thicknesses of metal. Having stated the cause, the obvious remedy lies in setting the pattern out of truth to the extent of the pull, so that in cooling, the casting will straighten itself. Thus, long castings poured on the flat tend to lift at the ends, and if the amount of lift is known, the ends of the pattern can be set down, thus curving the face of the pattern, and giving a chance of obtaining a straight casting. Lathe beds, according to design, either lift at the ends, or the centre, usually the latter. With beds that warp in this fashion, the common plan is to camber the pattern by setting the ends higher than the centre, an allowance of $\frac{1}{8}$ inch per 6 feet of length being usual. Should the casting warp in the other direction, then the pattern is set the reverse way. Register fronts often show a tendency to draw in at the bottom, and these represent another type of pattern, which may be set out of truth to the extent of the "pull." However, no definite rule can be given for setting patterns; existing knowledge is at the best empirical, and one can only proceed by actual trial under the particular conditions in which the casting has to be made. This statement is made after attempting to deduce a law from our own and other records. Failure lies in the fact that so many variables enter into the question of retarded contraction, and no general statement of a positive character could be made.

Assuming that the pattern has not been set, or, as often happens, that it has been set in the wrong direction, then the only thing remaining is to straighten or set the casting. With brass or bronze castings, this is effected in the cold; but, with cast-iron or steel, straightening should be effected only on a hot casting. In a simple case the casting is heated to a red heat, laid on a straightening plate, brought into shape by weights and allowed to cool down with the weights in position. The weights should not be disturbed until contraction is again complete. Another aspect of the same plan is to take a casting red-hot from the mould, and weight it down, a plan more expedient than advisable, although it is certainly successful from the one point of preventing warping. Some castings cannot be reheated to a red heat and then conveniently handled. For example, long lathe beds, when high in the centre, are brought down by a simple but effective plan. The bed is levelled on two stools, one at each end, a fire is built under the centre, and, as the casting gets hot, it commences to sink by reason of its own weight and the influence of heat. Evidently, then, if the sinking is arrested by drawing away the fire, any desired amount of setting may be obtained; but the point is that, on again cooling, contraction, and therefore warping, again commences, with the result that the bed, if only brought down to the extent required, will, after cooling, be again out of truth. If the bed is, say, ⅜-inch up in the centre, then it should be brought down by the fire a total distance of ¾ inch, which allowance will cover returning contraction on cooling. It need hardly be stated that straightening by this plan requires very careful treatment, or more harm than good will be done.

Finally, some reference is required to contraction cracks. If the casting in cooling down cannot contract or relieve itself by warping, then a fracture will follow, or, if not, dangerous internal stresses are developed. When this is the fault of the mould, the remedy is apparent, but, when due to the design of the casting, the remedy is not so apparent. Of all metals, steel and aluminium are perhaps the worst in this respect; but, whatever the metal, the best solution is found in equalising the rate of cooling throughout the casting. The effect of chills in this direction has been noted, and practically the same end is obtained if the thin parts of the casting can be thickened. This, of course, is not always permissible; but the thin parts may be indirectly thickened, and thereby strengthened, by means of fins about ¼-inch thick, 2 or 3 inches deep, and running the full length of the thin part. These fins are readily chipped off the casting, and we have found them of distinct value in saving castings. All junctions between light and heavy parts should be tapered by the moulder, a remark also applicable to sharp corners, junctions between flanges and bodies, etc., all of which should be well filleted. Flat plates, cast with large square or rectangular cores, can often be saved by taking the corners off the cores. In other cases, wrought-iron cramps are cast in. Another example designed to reach the same end is found in the curved arms of a pulley, the curvature admitting of a certain amount of straightening without bringing a direct pull on to the rim of the pulley. An opposite method to thickening up a thin part is found in lightening a heavy one, and, where permissible, as in the bosses of wheels, this will give considerable relief.

CHAPTER XXIII.

DRESSING CASTINGS.

HAVING made the casting, its further treatment, in the event of no annealing being required, lies in dressing it to shape by removing adhering sand, fins, runners, feeders, etc. Naturally, the less dressing required the better for the casting; and the trite remark that "Castings should be made on the moulding floor, and not in the dressing shop," is worth consideration by every moulder.

Naturally, the tools required and conveniences for work vary with the class of castings produced. Assuming these to be of a light and small type, then the chief tools required will be convenient benches and vices, a good supply of files and small coring tools, emery wheels and tumbling barrels. The emery wheel is familiar, and is chiefly used for grinding off accessible fins, removing projecting gates, etc. The tumbling barrel or rattler is simply a revolving drum packed with castings which rub against each other, thereby removing adhering sand. The rubbing effect may be intensified by packing the castings with sharp pieces of iron; convenient white iron stars are sold for this purpose. Tumbling barrels vary in design, but all have the common object of cleaning by rubbing. With brittle castings it is fairly obvious that a barrel must not be packed so that on each revolution the castings receive a heavy bump, otherwise breakages will occur. Similarly, in the case of brass castings a loosely packed barrel will result in bent or distorted castings. Tumbling is applicable to all small iron, steel, or brass castings, save those having sharp corners, which are apt to become slightly rounded, or those having ornamented surfaces, the detail of which is likely to become dulled. Practically, these limitations only apply to soft metal castings, such as brass, and a method for tumbling these is given later.

Small iron or steel castings, if properly moulded, should, after tumbling, only require the cores cleaning out and the gates grinding off. Although a side issue, it is worth noting here that iron castings are, after tumbling, stronger than before. Small brass castings, such as plumbers' work, fire, steam and water fittings, may easily be given a good appearance, which lends much to the beauty of the casting. It is better to "blow" cored work of this character, that is, to break the castings off the runner whilst hot, and dip them in cold water. This, if caught at the right heat, has the effect of blowing out the core and leaving the casting without a particle of sand adhering to it. Brass castings so treated do not require to be tumbled, but, after the gates are ground off, to improve their appearance further, they may be put through one of the following processes:—

(1) A water-tight rattler, constructed of hard wood, is used. The castings are packed in this with coarse and sharp sand and a pailful of water added. After closing up, the rattler is revolved at a slow speed for twenty minutes or thereabouts. The castings are taken out, washed off in cold running water, dipped into hot water, and left to dry. This treatment gives valve bodies and similar castings, which are not afterwards machined, a dead bright and smooth surface with comparatively little trouble.

(2) The second method is that of dipping in acids. In the case of yellow metal castings this is comparatively simple, and commercial aqua fortis (nitric acid) can be employed with advantage. After treatment, all traces of acid must be removed by washing in a stream of water. With triple alloys, as, for instance, copper, tin, and zinc, acid treatment becomes more complex; in these cases the authors have found it advisable to use two separate acids, viz., nitric and hydrochloric. The castings are first dipped into nitric acid, then into hydrochloric acid, well washed in water and dried off in sawdust. Generally speaking, sand scrubbing is preferable, as it produces a good finish at little cost. Aqua fortis is largely used for ornamental yellow metal castings, and extensive treatment in this direction is practically a business beyond the scope of the founder. It should, however, be noted that alloys for treatment by aqua fortis should be free from lead, otherwise discoloured stains will result after acid treatment. Hence the term "dipping metal," signifying dual alloys of copper and zinc free from lead.

Personally, we have found the second form of acid treatment of use for cleaning brass castings where sand blast was not available. It is of special advantage in the case of brass bearings which have to be subsequently lined with white metal. The reason for the second acid, hydrochloric, is due to the fact that, after dipping into the first, nitric, a white oxide of tin remains on the surface. This is readily removed by the dip into the hydrochloric acid.

Naturally, all brass castings will not permit of blowing or breaking off gates whilst hot. In such cases a band saw is a decided advantage, as this saw will cut through a large number of gates per day. Sawing is preferable to a gate cutter, and is a distinct gain on the hand hammer and chisel. Apart from a band saw, the dressing shop should be equipped with pneumatic chipping hammers for the larger castings. These hammers will quickly remove a fin or core, and are exceedingly valuable tools.

So far as iron castings are concerned, saws are not required, but the equipment should include pneumatic chippers, tumbling barrels, and emery wheels, in addition to the usual run of hand tools. Dressing is simplified by the fact that runners and feeders can be removed in the majority of cases by hand or striking hammers. The acid treatment of iron castings has for its object the removal of the adhering sand, in order to facilitate machining, and is only applied to those castings which cannot be tumbled. Dilute sulphuric acid is a favourite pickling medium, and the castings are either soaked in it for a short time, or the casting is laid on a wooden tray, and the acid ladled over it at intervals, being finally soused with water from a hose.

Hydrofluoric acid is also used as a pickling medium, and in this case the sand only is dissolved off. The effect of sulphuric acid is to eat into the skin of the casting, thereby loosening adhering sand; as a rule, machinists prefer a casting pickled in this acid to one treated with hydrofluoric acid.

The equipment for dressing steel castings is practically the same as for iron, with the addition of saws. Provided the castings are hard, runners and feeders can be removed by nicking with a pneumatic chipper and then breaking off. To a certain extent this treatment is applicable to mild steel castings, but, if there is danger of distortion, runners and feeders should be sawn off. The band saw, so successful with brass castings, is not quite so successful with steels. If, however, the castings can be suitably packed, and regularly fed up to the saw, fairly good results follow. Circular saws are also used, and, in certain cases, with decided advantages. Large feeders are left on the castings, and subsequently slotted off in the machine shop. Owing to the number and comparatively large size of feeders required on steel castings, their removal is a distinct drawback towards economical dressing. A proposal recently brought forward for removing large heads is that of using the oxyhydrogen flame for heating a spot of the steel to the burning point and then cutting a slot through by means of compressed oxygen. In this case the blowpipe is directed at a spot on the feeder until a melting heat is obtained, the hydrogen is then cut off, and the pressure of the oxygen gradually increased until about 30 atmospheres is reached. Oxygen at this pressure causes the combustion of the steel, and a narrow slot is rapidly burnt through the head. The oxygen cuts the steel with astonishing rapidity, but the economical applicability of the process has yet to be proved; hence, the idea is merely offered as a suggestion.

Acid treatment is not advisable in the case of steel castings. A good method of removing burnt sand, scale after annealing, and generally improving the surface is by means of the sand blast. This method is applicable to all castings, and, where available, is decidedly preferable to any form of acid treatment. In its simplest form the compressed sand blast is directed by means of a flexible pipe on to the castings, the operator being protected by a helmet which serves the purpose of protecting the face and providing pure air for respiration. This involves a separate sand blast room in which to treat the castings. The abrasive used is sharp sand, or chilled iron shot, in certain cases a mixture of the two being employed; and the propelling medium is compressed air. Various types of apparatus are in use, but the latest development is Matthewson's patent sand blast tumbling barrel, which includes an automatic sand elevator, sand and dust separator, and air sieve.

The principle is that of a slowly rotating cylinder, supported at its circumference on rollers. Sand blast is directed through one or both ends of the cylinder, and impinges against the castings placed inside. By the rotation of the cylinder fresh surfaces are constantly exposed to the action of the sand blast. Sand and dust escape through perforations in the cylinder into the barrel box, and are returned by means of an air current through a pipe to the sand apparatus. The upper portion of the latter is a separator which allows the heavy sand to fall into an air sieve ready for use again, whilst the dust is carried away. A further improvement is found in Matthewson's continuous sand blast tumbling barrel, in which, whilst utilising the foregoing principle, continuity of operation is given. Reference to fig. 169 will explain the details. Castings are fed into the hopper A, and travel slowly through the barrel, being exposed in the journey to the action of four or more sand blast jets, which are equally divided along the length of the barrel. From thence the castings fall on to a slanting grate, which is partially enclosed in the exhaust chamber B, and slide into the lower hopper C. Sand, dust and scale are automatically separated from the castings in the chamber B, and returned through the pipe DD into the sand blast apparatus. The elevation of the sand and dust is effected by a current of air from an exhaust fan, and in the sand blast apparatus, dust is separated as before. Both forms of apparatus are made by the Tilghman's Patent Sand Blast Co.

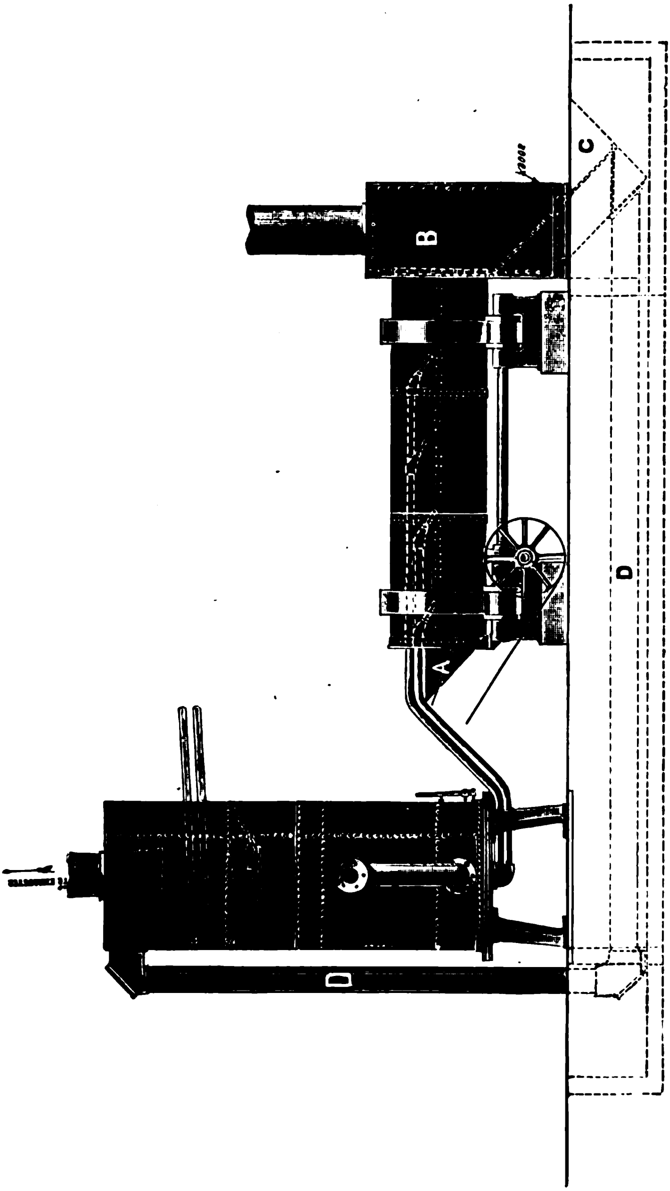

Fig. 169.—Continuous Sand Blast Tumbling Barrel.

In giving this outline many details are necessarily omitted, but sufficient has been stated to show the applicability of sand blast cleaning. From personal experience, we believe it to be the best method of effectively cleaning iron, steel, or gun-metal castings. Should the surfaces have to be tinned, coated with white metal, or painted, they are in excellent condition as regards cleanliness for any one of these purposes.

Finally, the dressed castings are ready for dispatch, and, whilst in the case of large pieces, no difficulty of identification is offered, such is not the case with small work. One good method of sorting out small details from a miscellaneous heap of castings is as follows:—Each order received by the foundry is given an order number, and the moulders are supplied with sets of small loose figures from 0 to 9. The order number may be printed into the mould, and when the casting is ready for delivery, it may be easily traced by its number.

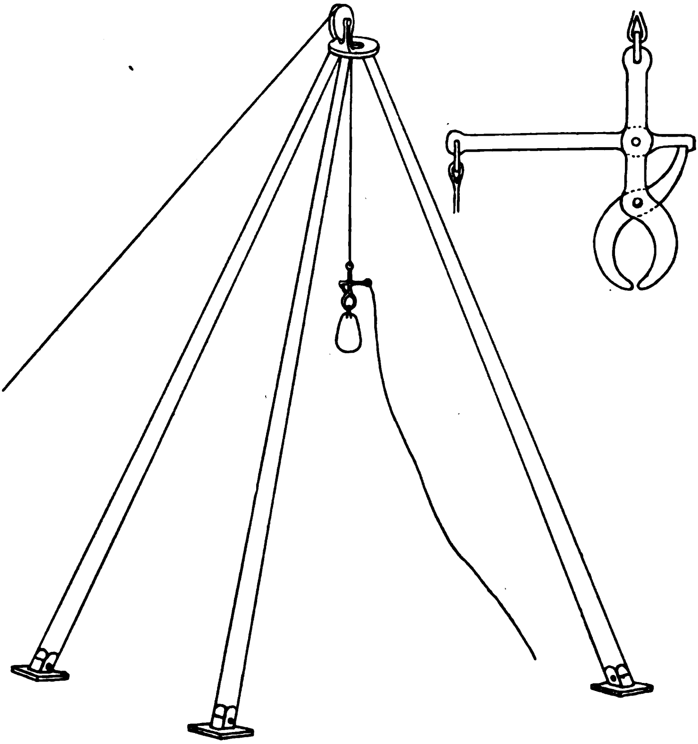

Fig. 170.—Casting Breaker.

This plan will admit of any amount of amplification, such as separate numbers from 1 upwards for each separate casting in one order. This plan, or a modification of it, will save countless worry when assembling orders for delivery.

A further aspect of the dressing shop is found in the return of scrap to the furnaces. As a rule, cast-iron and steels produced in one foundry do not vary greatly in quality, and the scrap may be safely returned in lots as it accumulates. On the other hand, brasses vary enormously in grade, and each grade of scrap should be kept to itself. This is facilitated by having a system of marks for each distinct grade; and the moulder, before closing his mould, makes a print on the runner which readily identifies the runners after removal from the castings.

Before returning wasters from the dressing shop to the furnaces, core irons, especially in the case of brass castings, should be removed. Concerning the treatment of wasters to bring them into shape for remelting, if beyond the hope of a striking hammer, a falling weight is effective with all iron and most steel castings. A tripod arrangement, as in fig. 170, placed in a convenient corner of the foundry yard, will prove useful. An arrangement for releasing the weight is shown, and the height of drop and weight of ball will be determined by the character of the casting to be broken. In the case of heavy steel pieces it may be necessary to drill them, in order to assist fracture; and sometimes these and large waster rolls must be blown up by the help of gelatine dynamite or other high explosive placed in drill holes.

Heavy brass castings are most effectively broken up by building a fire round them, and, when at a red heat, applying a sledge.

Naturally, no casting should require breaking up; but, even in the best regulated foundries, accidents sometimes occur, and, though we have often heard of foundries which produce no wasters, we have not had the pleasure of working in such an ideal establishment.

CHAPTER XXIV.

COMMON FAULTS DUE TO MOULD AND PATTERN.

It has been stated in an earlier chapter that each new casting constitutes a fresh problem, and every moulder will recognise the truth of this statement. In many occupations the effect of each stage of the work is shown at once; therefore, any false step may be remedied before further work is put on the article. These conditions do not hold in founding, and the only test of the suitability of a mould is to fill it with metal and study the results. Should the result be wrong, all the work put on the mould has to be repeated, and the metal of the casting can only be regarded as of scrap value. This necessarily demands that every stage followed in the production of a casting should receive careful attention, and more especially the minor stages, for, as a rule, when a casting is a waster it is due to the neglect of some small detail. Naturally, the fewer wasters produced the better; but he would be an irrational writer who dared say that no wasters need be produced. At any rate, practical experience induces a feeling of humility, but it is certain that every bad casting is an inexcusable waster if its lesson is not wrested from it by a determined effort made to lay bare the cause of the failure. Every waster should be regarded as a subject for investigation, and, having once found the cause, the same mistake should be avoided in the future. If this is faithfully followed out, the experience gained becomes priceless; but, unfortunately, this is not always the case, and wasters from the same cause occur, at times, with painful monotony.

A waster may be due either to the condition of the mould or of the metal. For the present, we propose to examine briefly some of the more common faults due to the mould or to the pattern, leaving the condition of the metal for a later chapter. This examination can only be general, for each waster should be studied under the particular conditions of its production.

In the first place, wasters are often caused by run-outs, misruns, or short pours. Run-outs, in the case of box castings, may be due to bad joints, insufficient or unequal weighting, or to bad making up of the core vent. No excuse can be offered for any waster due to a run-out, and the fault is simply carelessness. When a run-out does occur, no earthly good is obtained by throwing sand at it. A ball of sand should be taken in the hand, seamed into the joint, and firmly held there until the run-out stops. If this is calmly done, the hand will be well protected by the sand, and at the same time the pressure behind the sand will stop the run-out. If the stream is too large for attention in this way, the cupola bod stick will probably prove of use, and we have heard a hose advocated as useful in chilling the metal and so stopping the run-out.

A still better plan is not to have a run-out at all, and this condition should be easily reached by an apprentice of only a few months' standing. Run-outs or bursts, in the case of loam moulds, may be also classed as preventible, and, with proper attention to the stability of the building, the fitting of cores and joints, effective binding and solid ramming, they need never occur. In the case of heavy bedded-in work, the floor, if at all risky, should be plated, and, whilst attending to downward pressure, side pressure on the mould should not be forgotten. Hence, under certain conditions, it may be necessary to bed in side plates as well as bottom plates.

As with run-outs so with short pours, there is little or no excuse for pouring a casting short. It is not a difficult task to estimate the weight of a casting to within a few per cent., and, under normal conditions, wasters due to scarcity of metal can be most easily avoided.

Misrun castings come under a slightly different heading, and, although they should not occur in heavy work, still in light work of large surface it may be difficult to obtain a fully run casting. Large castings of, say, $\frac{3}{16}$-inch in thickness, demand a free running metal, which must be sharply poured into the mould. Fluidity is a function of composition and temperature; the latter being of the greatest moment, it follows that dull metal should never enter a mould of thin section. Hot metal and quick pouring are the chief remedies, and these are aided by setting the mould at an inclination or "casting on the bank." This is only applicable when one gate is used. Thin cast-iron articles may be poured from many points, and the various streams on meeting will unite. Thus, fenders are often poured from three hand ladles, whilst a large mantel mould may require as many as eight hand ladles. The object aimed at is to force hot metal into the mould from as many different points as possible, and so quickly cover the surface. The down gates of such moulds are connected with long sprues, thereby increasing the area of effective entrance. However, the total area of the sprues should not exceed the area of the down gate, or their effect will be lost.

Whilst separate streams of brass meeting in a mould will unite, the union is not so readily effected as with cast-iron. Further, in a cast-iron foundry it is easy to place as many hand ladles as desired on any one mould; whilst in a brass foundry it is not always convenient to place a series of crucibles at the disposal of one mould. Therefore, one crucible is made to cover as large an area as possible, and this often involves long channels and sprues. The down gates should, therefore, be proportionate to the area of the sprues, and a good plan is to place two or more down gates about eight inches apart, making a head on the top part to connect them. With large but thin tread plates, we have found this plan very effective. The head should be made to hold slightly more brass than is required to fill the mould, and the contents of the crucible plumped without hesitation into the head. The same method is also useful for large oil boxes, which, in point of thickness, scarcely exceed that of thin sheet; at any rate, we have had them 24 inches long, 6 inches broad by 6 inches in depth, and scarcely $\frac{1}{8}$-inch thick. This, added to an intricate shape, renders the production of a fully run casting no easy task. A series of flat gates on the top of an oil box, a head on the top part large enough to hold all the metal required, and instantly filled, are the best aids to a sharp casting. A little judgment will enable anyone to empty the right amount of metal into the head, so that the casting and gates will about drain it; but, should a surplus remain in the head, it should be loosened whilst pasty and before the metal becomes too strong or ductile.

With all classes of thin work sharp pouring is as essential as fluid metal, and a dribbling or hesitating pour is fatal to sharp castings. Whilst a thin casting may not be actually misrun, it may show the junction of two streams of metal which, though possibly dovetailed one into the other, will still make the casting a waster. Such defects are termed cold shuts, and clearly indicate that the metal has not entered the mould at a suitable heat and with sufficient rapidity. It is often the fashion to blame the metal for cold shuts, but the most practical remedy lies in attention to the method of casting, and a solution will be found in quickly covering the surface of the mould with hot metal. Cold shots represent solidified drops of hot metal, which have been trapped in the mould and not fused by the surrounding molten metal. If, when first starting pouring, the stream of metal is broken, solid shots are formed and injected into the mould. These shots are subsequently trapped by the molten metal, but are not always melted again; hence, on grinding the surface, a ring round the embedded shot may be shown.

Other types of defects are found in cores out of truth and twisted castings. It is evident that the core should be properly centred in its prints, and so fixed that it cannot move from position. Twisted or shifted castings represent an aggravating type of defect sufficiently self-evident to warrant a little attention to the moulding-box pins.

Briefly, the foregoing defects represent the more usual types, and, with the exception of misrun castings, are easily preventible. The exception referred to requires some little thought and planning, but in most cases can be overcome without recourse to thickening, a practice not palatable to the customer. Passing from these defects to a general examination of the production of sound castings, we note, first, a few features applicable to the mould, irrespective of the type of metal entering it. In the first place, dirty castings, if not actual wasters, are, at any rate, displeasing to the eye. On machined faces dirt is, of course, inadmissible; hence the plan of casting these parts face down; but the object should be to make the whole of the casting as clean as possible. Naturally, this object is attained by pouring clean metal into a clean mould. Not only should the mould be free from loose sand, but the facing put on should also be such that it will not shell off or gather in the form of dross in front of the stream of metal. Much attention is often given to the mould, and comparatively little to runners and risers. Every particle of sand traversed by the metal is necessarily part of the mould, and should, therefore, be treated as such. Runners must be clean, and, when making up runner, riser, or feeder heads, care should be taken to prevent any loose sand falling into the mould. After a mould has been closed there is not much inclination to open it again to remove any loose dirt; hence, double care should be taken to prevent the entrance of any. A good plan, where practicable, lies in having cut-off risers, and in making heads over these any dirt falling in does not enter the casting. Clean skimming is necessary, and, whilst easily effected in the case of a hand ladle or shank, is hardly so easy in the case of a 10-ton ladle. With small ladles a length of flat iron about 1½ inch broad, and turned over at one end to fit the lip, is effective. Large ladles require special skimmers, which are usually formed by rivetting a flat plate on the end of a length of iron rod. Such a ladle should, before casting, be turned back and skimmed over the lip not used for pouring. A layer of parting sand thrown over the surface will, under certain conditions, tend to convert the cinder or slag into a more or less sticky covering, which is not so liable to be carried over by the metal. Just before casting, the lip of the ladle should be cleaned; an old dry brush will effect this better than a few blows from the skimmer's cap. Cylindrical castings are poured on end in order that the bore shall be clean; and, in many cases, the mould is carried higher than required, in order to provide a receptacle for any dirt floated up by the metal. Points of note lie in the fact that the metal rising in the mould must not be sluggish, or the dirt will not be carried up. With moulds poured by plump gates from the top, each gate tends to break up and liven the rising metal; hence, there is every chance of the dirt being brought up into the sullage head. Very long castings cannot, however, be poured from the top, owing to the long drop of the first metal and the risk of washing. A combination of top and bottom pouring is permissible in many cases; or the mould may be gated, as shown in fig. 171. Here the first metal enters through the lowest gate, and as the level rises in the mould the upper gates successively come into play, each contributing their quota of hot metal which livens that already in the mould.

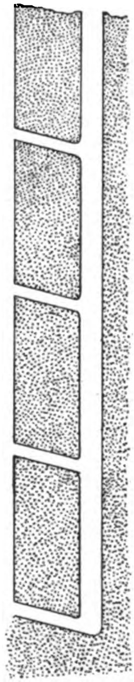
FIG. 171. — Bottom Pouring, with Side Gates.

Solid circular castings may be gated at a tangent, thus imparting a rotary motion to the metal, which tends to throw the heavy metal to the periphery, and to concentrate the sullage in the centre. The same principle may be utilised with various types of smaller castings by gating them from a feeder of the type shown in fig. 172. An ordinary gate peg is set in the top part, and a connecting runner, of the form shown, cut in the top part. The mould is gated in the bottom part from the feeder, and the gate should be small enough to admit of the feeder being kept full during pouring. Another type of skimming gate for flat articles is found in cutting small sprues in the bottom part and the connecting channel in the top part, the idea being to retain light dirt in this channel and allow only heavy metal to enter the sprues. In fact, all types of skimming gates are based on the principle of providing a receptacle through which the metal must pass before entering the mould, which will also tend to retain all light matter, while admitting of the egress of heavy matter.

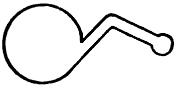
FIG. 172.—Skimming Gate.

Whilst filling the mould with metal, dirt may be formed by the washing away of any part of the mould face, and, in this respect, thin projecting pockets require special attention. Deep green sand moulds are gated from as low a point as possible, in order to have a gentle wash of metal; but should a deep green mould of necessity have to be cast from the top, then a dry core or loam cake may be bedded in the mould to catch the first heavy fall of metal. Sprigging is also useful for this purpose, and, quite apart from its utility in the case of projecting pieces of sand or green cores, may be applied to flat surfaces on which a heavy washing action may occur. The debatable point of open or closed risers has a very direct connection with the disintegrating action of metal on a mould. Generally speaking, with closed risers the air in the mould is under compression, so that it can only escape through the pores of the mould. This compression tends to hold up the sides and top of the mould, thereby, to some extent, preventing the detachment of sand. In a heavy type of mould this is an advantage, and therefore all risers should be closed by clay balls, which keep their position until floated away by the rising metal. In a mould difficult to run, the risers should be open, as a rapid escape of air favours a sharply run casting. When risers are left open they should be of large area, for the smaller the area the greater the compression of the escaping air, and, naturally, the greater the tear on the mould. The origin of the term "whistler" is due to the whistling noise made by the rush of compressed air. Owing to the causes noted, it becomes necessary, with some large green sand moulds, to cover them with a dry sand top part, for a green top part "draws in," that is, sand is detached, partly by the heat and partly by the rush of air, before the level of metal reaches the top. Sand detached in this manner, or by washing, is, of course, broken up and distributed as so much dirt in the higher parts of the casting. Further, sand so loosened must be sharply distinguished from what is technically known as a scab or buckle.

A scab on a green sand mould represents conditions which have retarded the escape of air and mould gases; in other words, faulty venting, too hard ramming, or too much moisture in the sand. Ramming and venting are the usual causes, and, in considering the covering of the face of a mould, it is at once apparent that the air displaced, as well as the gases of the moulding sand, must escape downwards through the sand. This escape must be free and uniform at all points of the sand below the metal. Assuming that this is so, then the gases readily pass through the sand and the metal lies quietly on the sand face; but if even one part of the face is impervious to the passage of gases, then, as downward movement is forbidden, the gases must necessarily bubble upwards through the metal. Local bubbling of this character works on the sand and detaches a piece corresponding in size to the hard or unvented area. The face of the casting is then disfigured to the extent of the sand detached, and the loosened sand is distributed as dirt through the casting. The remedy in such cases is self-evident. As the metal has to lie on the bottom of a mould, this should always receive the most care in venting and ramming; straight sides are usually comparatively safe, but, if the sides contain any narrow projections, these should be specially vented, or scabbing will occur. It has been noted that projecting parts are liable to wash; hence a tendency to make them harder than is desirable for efficient venting. Over-anxiety in either direction will produce a bad result; therefore, the happy mean must be chosen, and any part of the mould liable to scab should be made sufficiently compact to resist wash or pressure of fluid metal and yet kept sufficiently porous to admit of free and uniform escape of gases. Scabs in dry sand or loam moulds can, in the majority of cases, be traced to insufficient drying; in other words, to the presence of steam which cannot escape. A difference between these and green sand scabs is often found in the fact that the loam or sand face is just turned over and the detached piece is not broken up. Such a defect constitutes a buckle, and, in the cold casting, the dirt will all be found together. The remedy is efficient drying, but this should not be interpreted as a burnt mould; all that is necessary is the expulsion of the whole of the steam present. Dry sand or loam moulds should always be bone dry, although, by the very exigencies of work, such moulds are often cast with steam freely escaping. The practice is risky, and can only be successful when the steam or vapour present has an uninterrupted escape through the mould and not through the metal. A steaming mould should never be allowed to go cold before casting, or the vapour will condense, and the mould will then be in a far worse state than a green sand one, and the best plan of all is to give the mould another night's stoving.

Porosity in the mould or cores is the chief solution of many of the defects met with, and this aspect has been fully noted in other sections of this work. A porous mould will readily take care of the air displaced by the metal and of the gases generated by casting, but it will not remove any gases contained in the metal before casting. Hence, blowholes are divided into two classes: (1) those due to the mould; and (2) those due to the metal. In this chapter we consider only those due to the mould. Practically, any source of disturbance which leads to bubbling will result in the trapping of gas bubbles. The source of a blowhole is, therefore, the same as that of a scab, but in the latter case the disturbance is sufficiently violent to tear away the sand and thus offer a route for the escape of gas. Blowholes, when present in grey cast-iron or brass, are, in the majority of cases, due to the mould, not to the metal; and with green sand moulds especially, a hard or too damp mould is morally certain to blow. This applies to the mould as a whole, or to parts of it; local hard or wet spots give the same effect. Such a case is illustrated in fig. 173, where it will be noted that the upper portion of the fracture is honeycombed with blowholes, the lower portion being comparatively solid. Here, sufficient moisture has been present to cause bubbling from the bottom, the gas bubbles and shots of metal having risen to the top, where escape has been retarded by a solidified outer crust. As a final result the bottom of the casting, where the disturbance originated, is solid and free from blowholes. The wet spot typified in fig. 173 represents excessive dampness in one portion of the mould, and not wet in a literal sense of the word. Naturally, had the mould been actually wet, the fluid metal would have been violently ejected by the sudden generation of steam. However, sufficient was present to cause the effect shown. Local hard spots on the face of the mould have a very similar effect, except that the disturbance is due to the non-escape of the gases of the mould, and not to the formation of steam. Apart from the condition of the sand, mould or core, blowholes may originate from the presence of other metals, for example, chaplets in the mould. Fig. 174 shows an actual, though somewhat unusual, type of such a blowhole. In this instance it will be noted that a screw has been cast in by leaving the head projecting, and this head must have been either damp or rusty, hence the blowhole. Similarly, any metal forming part of the mould, for example, chills, spindles, rods, etc., will, unless free from rust and moisture, give rise to blowholes. Lining shafts is most commonly practised in brass foundries, but, quite apart from the metal or alloy employed, the metallic core must not only be perfectly dry but must also be free from rust, which is a chemical combination of oxide of iron with water. Rust or scale, quite apart from preventing metallic contact, will, under certain conditions, give rise to the formation of gas, which, trapped within the metal, results in blowholes. The practice of heating a clean metallic core or chill is therefore good, and in dry sand moulds practically always leads to success. With a green sand mould the

FIG. 173.—Fracture showing Blowholes.

introduction of a warm core or chill should be quickly followed by casting, otherwise moisture will condense and blowholes result. Practically, then, blowholes in grey iron or brass castings are caused in the majority of cases by (*a*) the formation of steam, or (*b*) the impervious nature of a part or the whole of the mould to the passage of gases generated in the mould during casting. Blowholes in steel and white iron castings may be due to the condition of the mould or to the condition of the metal, but it is always well to be certain of the mould before blaming the metal. This can be readily assured by the appearance of the blowholes themselves, as those due to the mould always show oxidation tints, the effect of which, from a colour point of view, are very pretty, but from a moulder's point of view are very bad. Gases absorbed during melting, and liberated on solidification, give bright blowholes free from oxidation tints.

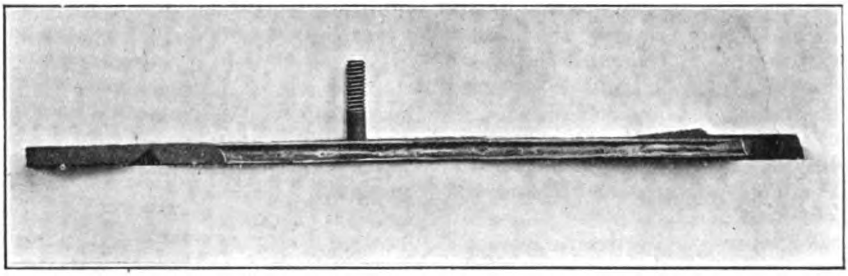

FIG. 174.—Blowhole.

Faults due to the pattern represent a practically inexhaustible topic, but in the majority of cases may be simply expressed as due to a departure from that canon of foundry faith, gradual change in thickness of section. Familiar examples of abrupt changes in thickness of section are often found in the junction of flange and bodies.

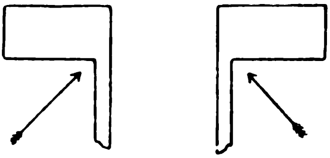

FIG. 175.—Flange and Body.

Hydraulic castings in gun-metal, steam and water castings in brass or steel are especially guilty in this respect, and it is no unusual thing to see flanges of a thickness out of all proportion to that of the body of the casting. Hence, unequal shrinkage is bound to occur, and the weakest part of such a casting will be the junction indicated by arrows in fig. 175. A valve body of this type, in which the flange bears a ratio to that of the body of 4 to 1, is very likely to leak at the junction when tested by water or steam under pressure. Similar conditions prevail when heavy bosses are cast on light bodies, and the junction of boss and body offers a very favourable locality for leakage when under pressure. When possible, a core through such a boss will offer material assistance in unifying the shrinkage rates. All sharp corners should be filleted, and junctions, such as fig. 175, if left on the pattern in that form, would be filleted by the moulder. Suitable filleting is of assistance in remedying faults of design, and when practised should be followed with the one object of minimising abrupt changes. In experimenting with heavy flanges, in which the ratio of flange to body was 8 to 1, we have obtained castings in which the flange was completely severed from the body; this occurred even in a green sand mould with a filleted junction. In other cases, whilst an actual severance was not obtained, a series of fine holes, technically known as "draws," were shown around the junction.

A further aspect of the same question is found in crystallisation; if, during cooling, conditions are present which affect the crystal growth or cause it to take a particular direction, such retardation may give rise to planes of weakness, if not of actual fracture. As an instance, a rectangular casting sectionally shown in fig. 176 may be cited. In cooling from a molten condition, the four angles containing the greater mass of metal are the last to solidify. The crystals will take their direction from the cooling surface; hence, a disturbance is naturally to be expected in the corners; not only so, but each plate in process of contraction will tend to approach its own centre, thereby further weakening the corners. Evidently, then, these angles, when the casting is subjected to hydraulic pressure, will offer channels which, though exceedingly minute, are none the less effective in permitting the passage of water to the exterior. This is intensified by the fact that the internal water pressure tends to force the plates outwards or away from each other, thus exaggerating the structural weakness of the angles, and imperceptibly widening the paths along which the penetrating water travels. This is illustrated in fig. 177, the internal pressure, acting in the direction of the arrows, tending to intensify the already porous structure of the corners.

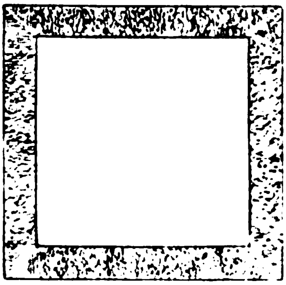

FIG. 176. - Rectangular Casting.

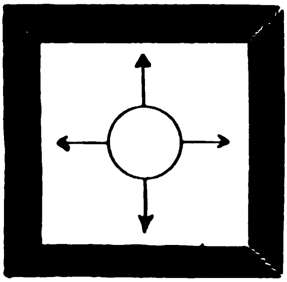

FIG. 177.—Diagram showing Expansion by Water.

The foregoing aspect has been noted, since faulty design shows most in the case of castings subjected to water or steam tests; and it is often not sufficiently realised that, when under such a test, the casting is temporarily expanded by the internal pressure, an effect which intensifies any local porosity. Generally speaking, it is harder to meet water or steam tests than mechanical tests, because, in the one case, the whole of the casting is tested, whilst in the other only a straight bar, which may or may not be cast on the casting. At any rate, when the complete casting is tested, any local defect due to faulty design or moulding is at once shown up. When a casting fails under water or steam, the leakage or sweating is due to inter-crystalline porosity. Molecular porosity is a myth so far as commercial castings are concerned. The ideal casting will, therefore, be one which passes from the liquid to the solid state at a uniform rate in all parts, and one in which solid contraction is fully shown without developing any stresses, the result of contraction, or particular routes caused by crystallisation. The metallurgical aspect of this will be considered later; the moulding part of it is found in obtaining an equal rate of cooling throughout. This sentence practically covers all that the moulder can do, and various aspects have already been noted, but, without repetition, the following features may be mentioned:—

So far as the general run of castings is concerned, the chief aid to equalising the rate of cooling lies in the application of chills to the heavy parts. The converse of this method consists in keeping the thin part of the casting hot, and, as an example, the following method may be quoted:—Pulley castings with very light rims and heavy arms may, immediately on solidification, have the top part removed and a trench dug round the rim, but separated from it by a 2-inch wall of sand, care being taken not to expose the rim. This trench, filled with molten metal, acts as a heat reservoir for the thin walls of the rim, and to some extent tends towards equalising the rate of cooling. Other methods, having the same end in view, consist in exposing heavy parts of the casting, and allowing air to play on them, whilst the lighter parts remain covered by sand. The sand round a heavy boss may, on completion of feeding, be removed, and water sprinkled on the boss; for instance, the boss core of a heavy fly-wheel may be dug out, and water used as above, and this method will often prevent contraction stresses developing at the junction of boss and arm. A wider application lies in the circulation of water through the core of a heavy casting, as was customary in the days of cast-iron ordnance. By this method the water does not come into actual contact with the casting, and, if generally applicable, would have many advantages. Unfortunately, the method is not applicable to varying classes of work; the expense of fitting up piping for each separate job, and the risk in the case of leaking joints, are its chief drawbacks. However, whilst the circulation of water through the core of a casting possesses certain possible advantages, the actual application of water to a solid red-hot casting should only be adopted as a last resort to save a hopelessly designed casting. Types of such castings are by no means unfamiliar in many foundries. Whilst the properties of certain brasses and bronzes are improved by water cooling, such treatment in the case of cast-iron and steel is, owing to the sensitivity of iron and carbon at high temperatures, not advisable except in the direction indicated. Under these conditions all cooling water should be applied by means of a water brush or swab, and the outside of the casting should be allowed to become partly reheated by drawing heat from the hotter centre between each application.

As a final word on patterns it may be noted that the balance of a pattern should not be thrown out by the gates. Thus, in the case of a symmetrical casting, the gates, which are part and parcel of it, may be cut in such a fashion as themselves to develop contraction stresses in the casting. The authors had this fact very forcibly impressed upon them by the loss of a large brass tread plate which cracked across the width in cooling. As comparatively large runners and sprues had to be used, and as only one large crucible was available, the contracting gates on one side simply pulled the casting in two. Under the same condition a grey iron casting would have hopelessly warped. The remedy lay in cutting dummy gates along the opposite side to that from which the casting was run. Therefore, if the casting has to be thrown out of balance by the gates it should be brought in again by cutting dummies to neutralise the effect of the gates.

In concluding this chapter it may be noted that wasters often arise from no apparent causes; there must, of course, be a reason for every waster, but the point is that the reasons may not be known. Whilst writing this chapter we have had this truth forcibly demonstrated. An experiment in which three castings with heavy ends and light centres were made, and cast under normal foundry conditions, showed contraction flaws in two of the castings, whilst the third was entirely free from such flaws. Apparently, the three should have behaved in the same way; in point of fact, they did not; this is typical of much that happens in foundry work. The moulder, having done his very best, should, in the event of wasters occurring, use them as a means of research, and, having found out the cause of failure, he has, in future work at any rate, one stumbling-block removed. Care and thought will save much trouble, but that care should never extend to over-anxiety or nervousness. In our own experience we have found nervousness responsible for as many lost castings as carelessness, and therefore that golden rule of the happy mean should be aimed at in every case.

CHAPTER XXV.

MALLEABLE OR WROUGHT-IRON, STEEL, CAST-IRON, AND MALLEABLE CAST-IRON.

THE basis of all these materials is the metal iron, modified by the amount, the combinations, and the distribution of the impurities, and by heat and other treatment. The metal iron has been obtained in its greatest perfection as to chemical purity by electrolytic deposition; and, probably, the purest sample known was that obtained by Dr Hicks and Mr L. T. O'Shea, in which no trace of impurity of any kind could be detected after heating the sample to a red heat and cooling it in the air. The authors have had the privilege of experimenting with a portion of this very pure iron. The sample was bright and metallic, very brittle as taken off the cathode, owing to a strong crystallisation at right angles to its surface; but, on heating and cooling, it became tough. It is soft, and can be easily cut with scissors. Both before and after annealing, the iron easily scratches calcite and only scratches fluor spar with difficulty, being scratched by fluor spar, so that its hardness is certainly more than 3½ and is just barely 4 on Mohs' scale of hardness.

The purest iron that can be obtained in quantity in commerce is Swedish wrought-iron, the best samples of which contain only 0·04 per cent. combined carbon, 0·02 per cent. silicon, 0·07 per cent. manganese, 0·02 per cent. phosphorus, 0·02 per cent. sulphur; and are thus of over 99·8 per cent. purity. It is extremely soft, malleable, and ductile. When tested in tension it takes a permanent set when the stress reaches about 12 tons per square inch, bears a maximum stress of about 20 tons per square inch of the original section, and a test piece 2 inches long × ·564 inch diameter elongates 50 to 55 per cent. of its length, and contracts at the point of fracture 75 per cent. of its original area. Professor Arnold, in experiments on the properties of steel castings, has melted some of this pure material, and made it into castings of almost equal purity (99·81 per cent. Fe, 0·07 per cent. C.C.), which gave the following tests:—

	Tons per Square Inch.		Elongation per cent. on 2 Inches.	Reduction of Area per cent.
	Elastic Limit.	Maximum Stress.		
As cast, . . .	10·7	19·8	30	39
Annealed, . . .	9·1	19·2	46	65

The corresponding figures for the forged samples were 14·4 tons elastic limit, 22 tons maximum stress, 47 per cent. elongation on 2 inches, and 76·5 per cent. reduction in area. Best Yorkshire iron, a wrought-iron made from best native ores and special fuel, may be exemplified from a 1905 analysis and test of Farnley iron. Its composition is C.C. 0·05; Si, 0·1; Mn, 0·07; P, 0·12; S, 0·01; under tensile test elastic limit 18 tons per square inch; maximum stress 25½ tons; elongation 39 per cent. on 2 inches; and reduction in area 51 per cent. Best Staffordshire iron tested on 1 inch round stood 24 tons per square inch maximum stress, with 30 per cent. elongation on 8 inches, and 45 per cent. reduction in area. While very common or poor quality wrought-iron may contain 0·3 or even 0·5 per cent. of phosphorus, and break so short that, while its tenacity may be lower than that of the purest iron, the elongation and reduction of area may be under 5 per cent.

These are examples of wrought-iron, which, as a general rule, contains more phosphorus than a similar steel, although Swedish wrought-iron is an exception; generally, also, less manganese than in mild steel, the only material with which it may be confounded; and may have the same amounts of combined carbon, silicon, or sulphur. Hence, chemical composition, though a fair guide, cannot be relied upon for a definition of wrought-iron.

Pig-iron is generally defined as the crude product of the blast furnace, but, as the phrase does not seem to give sufficient credit to the very high order of skill and care at present bestowed on the blast furnace to obtain materials of well-designed composition, it would perhaps be better to define pig-iron as the metallic product of the blast furnace, as cast for convenience in handling in the form of a sow and pigs. When this material is subject to remelting and casting only, with merely the changes that may inevitably take place during the process, it is called cast-iron. Cast-iron, of all the commercial forms of iron used in comparatively large quantities, has the greatest amount of impurities, containing generally from 2 to over 4 per cent. of carbon, 0·1 to over 3 per cent. of silicon, with very varying amounts of manganese, sulphur, and phosphorus, an average pig or cast-iron containing from 4½ to nearly 10 per cent. of impurity, and therefore is an iron of 95½ to 90 per cent. purity.

Wrought-iron is the type of the purest commercial iron, cast-iron of the least pure, but the most characteristic difference between the two is that masses of wrought-iron of practically any size may be hammered or rolled at suitable temperatures down to the smallest sections, while cast-iron can neither be hammered nor rolled at any heat; in fact, it is said to be not malleable. The tenacity of cast-iron varies from about 5 to 15 tons per square inch, or in exceptional cases even up to 18 tons, with practically no elongation or reduction of area.

Steel is something intermediate between these two. The amount of carbon it may contain varies from even less than 0·1 per cent. up to at least 2·25 per cent. Again, it is seen that the amount of carbon present will not distinguish between steel and wrought-iron on the one hand and between steel and cast-iron on the other. Steel, however, should be malleable, and so malleable that comparatively large masses of it may be worked down into small sections. Thus, a true application of the malleability test separates cast-iron from wrought-iron and steel. In early days any iron material that could be forged, hardened, and tempered was called steel; but, when the structural products from the Siemens furnace and the Bessemer converter arrived, they also were called steels, although they will not sensibly harden or temper. An attempt has been made to call these and similar products ingot iron, but the name steel for these is too widespread, convenient, and well known to be easily changed. Another attempt has been made to classify according to the percentage of carbon contained. This also seems doomed to failure by reason of its non-compliance with the usages of commonsense among those handling the materials. Thus, it was suggested that all materials containing over 2 per cent. carbon be called cast-iron, while the authors and many others have made tons of steel for the open market that was freely malleable, being hammered from 3-inch square ingots to bars, say, 2½ inches × ½-inch, could be hardened, tempered, and softened by annealing without the production of free carbon as amorphous or annealing carbon, and yet contained over 2 per cent. of combined carbon. That this material should be classed as cast-iron is manifestly absurd. Malleability of this degree is the characteristic feature dividing cast-iron from wrought-iron and steel. Nothing has yet been stated that will distinguish between wrought-iron and some steels. Dead mild steels may have even less than 0·1 per cent. of carbon, while ordinary commercial wrought-irons often contain up to 0·2 or even 0·3 per cent. carbon. Wrought-iron, however, as such, has never been in a molten condition. It is produced by the puddling process; and, although the pig-iron from which it is made has by certain processes been molten, still the iron "comes to nature" as small particles in a pasty condition, is gathered into balls, and the particles welded together by hammering or by pressure. Thus, there always remains some slag or cinder, which, even in the purest of Swedish wrought-irons, is a characteristic feature, and plainly visible under the microscope with suitably prepared sections. Mild steels may, occasionally, contain involved cinder; and sulphides, under certain special conditions, are difficult to distinguish from cinder, but with care may be so distinguished; while in the case of wrought-irons undoubted cinder is always present. When wrought-iron has been heated in charcoal for several days it becomes blister steel. It still contains the cinder, but has taken up sufficient carbon to enable it to be hardened and tempered, and is malleable to the degree already indicated. There yet remains malleable cast-iron to be considered. Malleable cast-iron has been cast as a hard white cast-iron, and either the combined carbon partly or wholly changed to free carbon, or a large proportion of the carbon actually removed by annealing processes; the resulting comparatively small casting being in many cases sufficiently malleable to be drawn out under the hammer, but not sufficiently so to be worked down from large masses to small sections. Some of these malleable castings are made of such a composition, and with such treatment, that they can be forged, as mentioned, and also hardened and tempered; still, having been cast as white cast-iron, and the result obtained by heat treatment, the general verdict of the trade would be that such articles are special malleable castings, and do not come under the heading of steel. Such materials might have been aptly called semi-steel, if the Americans had not already applied the term to cupola metal obtained by melting cast-iron and steel scrap. Good steel should never contain any free carbon, either as graphite or amorphous carbon; while free carbon is a characteristic feature of malleable castings. It will readily be seen that the classification is no easy one, and that, as in all cases of one substance merging into another, boundaries are the subject of much disputation; but the matter has been given with a fair amount of detail, as free from bias as possible; and with an endeavour to represent the meanings of the names as they are understood by the vast majority of makers and users of iron and its modifications. The above points must not be passed lightly over with the idea that names matter little, for these very names must be used in writing and speaking of the materials, and should be capable of giving clear ideas when used. It would be inconvenient to enter into an elaborate specification each time, and a careful study of the difficulties of the case will result in a better knowledge of the types of materials available. Withal, many will expect a specifically worded definition for each of the varieties, and this will now be attempted.

Steel consists mainly of iron, with varying quantities of combined carbon (0·05 to at least 2·25 per cent.), silicon, manganese, sulphur, phosphorus, and, in many cases, other elements; it can be forged from comparatively large masses into the smallest sections, and either it can be hardened and tempered, or it has been poured direct from the fluid state into a malleable mass.

Malleable or wrought-iron consists of the same materials (combined carbon generally less than 0·3 per cent.), always contains involved cinder, is eminently malleable, has never, as such, been in the molten condition, and is not sensibly hardened when heated to a good red heat and quenched in cold water.

Cast-iron also consists of the same materials (total carbon generally between 2 and 4 per cent.), but it is not malleable.

Malleable cast-iron has been cast in the form of a hard white iron, and given a degree of malleability and toughness by subsequent annealing, during which either the carbon is partially eliminated and the remainder partly combined carbon and partly amorphous or free carbon; or, the amount of the carbon is scarcely altered, but the condition of the bulk of it is changed to amorphous or free carbon, and the remainder left as combined carbon.

CHAPTER XXVI.

CAST-IRON.

Pig-iron.—Pig-iron has already deen defined as the metallic product of the blast-furnace roughly cast for convenience into masses known as pigs, and cast-iron the same after being merely remelted and poured into castings without necessarily any intentional alteration in composition, the actual alterations being, as a rule, only those that inevitably accompany the particular process of remelting used.

When pig-iron is melted under oxidising conditions to decrease, or even almost to remove, certain constituents, as, for instance, silicon, it is known as refined cast-iron or sometimes merely refined iron. In certain cases the purification or oxidising action is carried so far and under such conditions as to remove practically all the silicon, manganese, sulphur, and phosphorus, leaving only the carbon, and this product is known as washed metal. To give an idea of the extraordinary degree of purity attained, the following experience with one of the earliest samples of the special American washed metal received from Mr E. L. Ford is worthy of record. It was drilled, and the drillings distributed in the laboratory so as to give, in the end, at least duplicate determinations of each element. Silicon and manganese could not be detected, the yellow precipitate indicating the presence of phosphorus was not weighable, sulphur showed about 0·012 per cent., and the combined carbon was returned at 3·25 per cent. Two qualities were at that time offered for sale, and samples of the better quality bought in the ordinary way of commerce differed but little from the results given, namely, combined carbon 3¼ per cent., sulphur 0·015 per cent., manganese, silicon, and phosphorus a mere trace. Cast-iron generally contains more carbon than steels; although, in a very small minority of cases, steels are made containing more carbon than an exceptionally small quantity of cast-iron. Although these cases are exceptional and insignificant in quantity yet they serve to emphasise the fact that the amount of carbon present is not the essential difference between cast-iron and steel; but that the essential difference is that cast-iron is not malleable, while steel is malleable. Although the American washed metal is practically pure iron, with about 3¼ per cent. of carbon, the purest example of cast-iron untreated from the blast furnace is the Swedish white iron, a characteristic sample of which contains about 4 per cent. of carbon and small amounts of silicon, manganese, sulphur, and phosphorus, a typical analysis of one of the purest brands being combined carbon, 4 per cent.; silicon, 0·2 per cent.; manganese, 0·3 per cent.; sulphur, 0·02 per cent.; phosphorus, 0·02 per cent. Practically, all the carbon is in the combined form, and, neglecting the small amounts of silicon, manganese, sulphur, and phosphorus present, the material consists of about 53 per cent. of the carbide of iron Fe_3C as cementite, containing 6·7 per cent. of carbon, and having practically a hardness of 7, equal to that of quartz (grains of silica sand) or of flint; and 43 per cent. of the constituent pearlite, the latter practically of the nature of a best quality steel for cold setts unhardened. These constituents are very evenly distributed, and so fine that they can only be properly seen by the aid of a microscope (see fig. 235). A consideration of the nature of its constituents will, however, make clear the position of this material as the hardest among cast-irons, as also the fact that with skill and care it can be drilled by a properly hardened steel drill of special quality, as the hardened steel drill is entirely composed of constituents of hardness, 7, or equal to that of flint. Probably the next in point of purity that has come within the practical experience of the authors was also a specially pure Swedish brand, extensively used for some particular commercial work not connected with the foundry. This iron was soft to the file, difficult to break with the sledge hammer, and, when broken, showed a fine grey fracture; whereas, we have seen that the other was hard, brittle, and had a white fracture. On analysis this pig proved to be of a very pure nature, but the carbon was mainly in the form of graphite, the manganese was only 0·1 per cent., the sulphur and phosphorus as before, and the silicon 0·60 per cent. Another Swedish iron, containing practically the same amounts of sulphur and phosphorus, but with ·3 per cent. of manganese and 1 per cent. of silicon, was also soft and grey, with a fracture almost exactly the same as the other, and had most of its carbon in the free or graphitic form. As with the white iron, consider the constitution of the grey iron as revealed by the microscope. Plates or crystals of graphite exactly similar to the ordinary plumbago or black lead of commerce, with a hardness of about 1 to 2, that is, easily scratched by the thumb nail. The main mass of the material is ferrite, which contains most of the iron and of the silicon, and is as soft as ordinary wrought-iron. A small portion, the pearlite, mentioned in discussing the white pig, practically completes the series, and the whole constitution shows how it is that the grey iron is so typically soft.

All these pig-irons, having been cooled at substantially the same rates, run at about the same temperature, and been made by the same process under similar conditions, it will be evident, on thinking well over this simple case, that a pure iron and 3½ to 4 per cent. carbon form hard white iron; that the presence of silicon determines the liberation of free carbon as graphite, as witness the 0·6 per cent. silicon grey pig; while the series at least suggests that manganese has an opposite effect to that of silicon in this matter, and tends to keep the carbon in the combined form. Taking, for the moment, the more ordinary amount of 0·3 per cent. manganese, if the 0·2 per cent. silicon gives a white iron and the 1 per cent. silicon gives a grey iron, then about a 0·5 per cent. silicon pig of this series has a curious fracture, small portions of grey fracture alternating with small portions of white fracture forming what is very graphically called a mottled pig-iron. As with the Swedish charcoal pig-iron series, so with the coke series of this country. Some pig-irons have an entirely grey fracture, others are completely white, while others intermediate between these have a mottled fracture. The corresponding compositions, even with regard to silicon content, are not the same; for in an English hematite series the grey of a similar fracture would generally contain over 1¼ per cent., the mottled about ¾ per cent., and the white about ¼ per cent. of silicon.

There are other important differences, which will be taken in detail later in this chapter; but, at present, it is advisable to remember those three types of pig-iron—grey, mottled, and white.

Although the members of the series of pure Swedish pigs chosen to introduce certain fundamental principles are seldom used in the foundry as cast-iron, yet, by reason of their purity, these very principles are less difficult to follow than when results are modified by other elements present. Taking the hematite as the next example, we have an illustration of the general run of things in other series of pigs. We see the usual alterations in the amounts of the various elements as we descend the series; and, altogether, the table of figures given is worthy of very careful study by those who would become familiar with what to expect from different grades and qualities of pig-iron available. The following table was supplied by the makers of the Carnforth brand of hematite as representing typical compositions of their various numbers:—

HEMATITE PIG-IRON.

No.	Graphitic C.	Combined C.	Silicon.	Manganese.	Sulphur.	Phosphorus.
1. Bessemer, .	3·50	0·50	2·0 to 3·0	0·1 to 0·3	Trace	·02 to ·05
2. ,, .	3·30	0·60	2·0 to 2·5	,,	0·02	,,
3. ,, .	3·10	0·80	1·5 to 2·0	,,	0·04	,,
3. Foundry, .	2·80	0·90	2·0 to 2·5	,,	0·05	,,
4. Forge, . .	2·50	1·10	1·50	,,	0·08	,,
5. ,, . .	2·10	1·30	1·20	,,	0·11	,,
Mottled, . .	1·40	1·80	0·70	,,	0·15	,,
White, . .	Trace	3·00	0·30	,,	0·20	,,

It will be noticed that the silicon content of the pig-iron diminishes in a fairly regular manner from No. 1 grey to white, that the manganese and phosphorus are almost steady throughout the series, that the sulphur tends to rise and is at ·2 and often 0·3 in the white iron, while the C.C. also increases from No. 1 grey to white. For coke blast-furnace practice these results are fairly typical, and perhaps a few words of explanation on the causes of these differences would help the memory and aid in avoiding pitfalls. With normal amounts of phosphorus and manganese in the ore, practically all the phosphorus and a large proportion of the manganese in the blast furnace charge pass into the pig. Taking a slag that would produce a No. 4 pig, if more lime be used a more basic and less fusible slag will be formed, more coke and a higher temperature will be required. The higher temperature tends to reduce more silicon into the pig, and the more basic slag, more completely to prevent sulphur passing into the pig by holding it bound in the slag. Similarly, the conditions which produce a low silicon white iron also admit of a high sulphur content in the pig. The Swedish series shows no such rise in sulphur in their white irons, but it must be remembered that their ore as it reaches the blast furnace is almost free; and their fuel, charcoal, may be said to be quite free from sulphur, so that none can pass into the pig-iron, as compared with English blast furnace coke, which is difficult to procure regularly with less than 1 per cent. of sulphur. Hence, to obtain a white iron low in sulphur in the ordinary practice of this country it is necessary to refine a grey iron. We have still, however, one native charcoal cold blast pig-iron produced in

Cumberland, brand "The Lorn," and its grey and white irons have been specially analysed for insertion here.

"LORN" ENGLISH CHARCOAL COLD BLAST PIG.

	C.C.	Gr.	Si.	Mn.	S.	P.
Grey, . .	·88	3·35	0·84	0·12	0·015	0·08
White, . .	3·35	...	0·25	0·09	0·055	0·112

Although in pigs of small section, this grey iron had a beautifully regular fine grey fracture, with no sign of mottle in it.

In all the different brands of pig-iron made from different types of ores or charges there are certain general principles which must be remembered in order to get a fair idea of the material available. The percentages of silicon, of sulphur, of graphite, and of combined carbon, vary after the same fashion, and with a similar kind of interpendence, as is the case in the hematite series.

As nearly all the phosphorus in the charge passes into the pig-iron, the percentage of phosphorus in the various numbers of pigs is fairly constant. Thus, the phosphorus in Staffordshire All Mine pig (that is all ore, no admixture of puddler's cinder in the iron producing part of the burden) is about 0·6 per cent., in Yorkshire about 0·7 per cent., in Scotch 0·7 per cent., in the pigs from the Northampton and Lincolnshire ores about 1·2 to 1·4 per cent., in pigs from Cleveland ore 1·4 to 1·6 per cent., in pigs for stove grates and similar work up to 2 per cent., and in pigs from burdens with varying proportions of puddler's cinder and phosphoric ores anything up to, say, 3½ per cent. of phosphorus. Part of the manganese is found in the slag and part in the iron, but the result is that in any one series from the same ores the manganese is fairly constant. Thus, in special West Coast irons from Cumberland ore manganese will run to about 0·3 per cent.; while hematites from Spanish ore have about 1·0 per cent.; from Northampton, Leicester, and Lincolnshire ores, say, 0·4 to over 1 per cent.; from Cleveland ores about 0·5 per cent.; and special Scotch, 1¼ to 2.

The following table of analyses of a set of pig-iron samples, chosen to illustrate the appearances of the fractures of the various numbers, will also serve well to illustrate how, under certain conditions of management and driving, not known to the founder who uses the pigs, the fractures give but little indication of the compositions of the pigs:—

HEMATITE PIG-IRONS.

No.	Gr. C.	C.C.	Si.	Mn.	S.	P.
1	3·28	0·39	1·44	0·70	0·011	0·016
2	3·92	0·33	1·31	0·69	0·012	0·052
3	3·80	0·33	2·10	0·72	0·043	0·042
4	2·95	0·52	0·83	0·72	0·122	0·054
5	3·33	0·49	1·27	0·58	0·141	0·042
Mottled	2·05	1·60	0·75	0·60	0·086	0·041
White	traces	3·80	0·46	0·55	0·320	0·040

The percentages of silicon vary in a most erratic manner, the phosphorus content is fairly regular, as also the manganese, but mixing by fracture from this assortment of pigs would be expected to give a very unsatisfactory result; and such has been the experience of the authors and that of two other users known to them. In mixing pig-irons for the manufacture of steel and also for the manufacture of cast-iron castings, composition is the guide, and, where the appearance of the fracture does not indicate the composition, it is at the best misleading. Such a series of compositions attached to the numbers shown in the above table should compel those who have not already done so to give their most serious consideration to the subject of mixing by analysis, which is so very widespread in America, where, perhaps, the conditions of blast-furnace working make its use more imperative, but which, nevertheless, should be much more widely used in this country than it seems to be at present. For mixing by analysis some knowledge of the influence of the various impurities in cast-iron on its properties is requisite, and, after considering the following brief account of the several influences separately, their combined effect must be sought after.

Combined carbon is the material which, within the limits generally found in castings, increases the strength, the hardness, and, ultimately, also the brittleness of the iron. In ordinary castings to be used as cooled from the mould without further heat treatment, the combined carbon varies from about 0·1 per cent. to about 1 per cent.; the carbide of iron, therefore, from 1·5 per cent. to 15 per cent.; the amount of this constituent and the nature of its distribution have probably the most powerful influence on the properties of the iron. It is not practicable, however, to calculate a mixture on the combined carbon in the materials used in the mixture, as the amount in the final casting has no definite relation to this, and varies not solely according to the rate of cooling, but, assuming the same rate of cooling, is mainly determined by the influence of the other elements present. Hence, the rate of cooling generally being roughly fixed by the size of the casting, the amount of the combined carbon is mainly determined by the nature and amount of the other impurities present.

Graphitic Carbon.—In a cast-iron the total carbon is generally fairly constant somewhere about 3 or 4 per cent.; and, as all the carbon not combined is graphitic in an ordinary cast-iron, the conditions tending to decrease the amount of combined carbon tend to increase the graphitic carbon and *vice versâ*. The extreme softness and weakness of graphite have been noted, and, as it is merely mechanically mixed in the substance of the cast-iron, it merely tends to weaken the metal as a whole in tensile stress; and, for any one grade of graphitic carbon, the more so the greater its amount; while, generally, the coarser its crystallisation the greater is the weakening effect in tenacity of a given amount. It is obvious that in crushing tests this weakening will not hold to the same extent, and the general effect will be to increase rigidity.

Silicon.—Of all the elements usually present in cast-iron, silicon plays probably the most important *rôle*, not that its own influence on the nature of the material is so great within the amounts generally present in the finished material, say, up to 3½ per cent., but because of its effect on the condition of the carbon. For an ordinary rate of cooling, the simplest cast-iron, iron with about 3 to 4 per cent. of carbon, is a white iron, while the presence of silicon tends to throw the carbon out of the combined form and to make it appear in the metal as free or graphitic; and, as a general rule, within the usual limits, the rate of cooling being kept constant, the higher the percentage of silicon the lower the percentage of combined carbon in the casting; and, also, the more rapid the cooling, the greater is the amount of silicon required to prevent more than the desired amount of carbon remaining as combined carbon. It will thus be obvious that, in cast-iron castings, to produce a given type of fracture, the thinner the section the quicker the rate of cooling and the higher the silicon must be. This is well exemplified in the subjoined table of the percentages of silicon, which the authors have found serviceable as a guide in the manufacture of the given types of castings, the other elements being present in normal amounts.

SILICON STANDARDS AS USED BY THE AUTHORS.

Type of Casting.	Silicon per cent.
Malleable cast-iron, ...	0·6 to 0·8
Chilled grey iron casting, ...	0·75 to 1·0
High-pressure cylinders, valve bodies, etc., . .	1·3
General machine and engine details, gearing, etc., .	1·5
Soft engineering and millwright castings, pulleys, etc.,	2·5
Soft thin castings, stove grate and similar work, . .	2·5 to 3·0
Hollow ware, ...	3·0 to 3·5

Silicon not only tends to change carbon from the combined to the graphitic form, but, when present in increasing amounts, seems more and more to prevent the absorption of carbon or to drive it out, if present. Thus, a ferro-silicon of about 14 per cent. silicon generally only contains about 1¼ per cent. of carbon, practically all in the graphitic form, and at this stage the silicon has shown its own influence, for the material is comparatively hard and brittle; just as, to a less degree lower down in the scale, are the glazed or silvery pigs of about 5 per cent. silicon.

Manganese.—When manganese is present in a pig-iron the simple carbide of iron of the pure iron and carbon material is probably, partly at least, replaced by a double carbide of iron and manganese, which is generally of a finer structure and stronger nature than the ordinary carbide, and also seems to resist decomposition by silicon better; so that while silicon has a tendency to increase the graphitic carbon, manganese has the tendency to keep more of the carbon in the combined form. Hence, silicon is often spoken of as a softener for cast-iron, and manganese as having a hardening tendency.

Sulphur.—In the absence of manganese, sulphur is present in iron as sulphide of iron, while, with a sufficiency of manganese, it is present as sulphide of manganese. Sulphur, like manganese, has in some way the tendency to make castings harder, and particularly so if present as sulphide of iron. Sulphide of manganese will separate out from the iron, and, if given a chance, will float to the top. Hence, if these two hardeners are brought together, they may combine and partly remove one another, and thus have a softening effect, an action which explains the occasional and apparently anomalous result of manganese acting as a softener. Sulphur, besides its hardening effect (which may be counteracted), has a deteriorating influence on the properties of cast-iron tending to make it brittle; excess should be carefully avoided, and, undoubtedly, in general foundry work as little as possible, less than 0·1 (if feasible), and never more than 0·2 for material not to be given some further treatment. Still, with material of great purity, such as the iron of the

Swedes, with its 0·02 per cent. content, it has been stated that it was found necessary by the Swedes themselves to add a small amount of pyrites to get the requisite strength, in the old days, when they used it for casting cannon. This might be explained by assuming their lack of knowledge of silicon manipulation; but the authors were informed by a celebrated maker of chilled rolls, who had not only long practical but deep scientific knowledge of his subject, that he had endeavoured to use Swedish iron, and found that, although he could obtain the necessary chill, he could not make his rolls to wear without the normal amount of sulphur present. Assuming the truth of these two cases, might it not be that, as in the case of steel castings with a few blowholes, it is easy to avoid hot cracks and shrinkages owing to the formation of the blowholes preventing strain at a critical time, the small amount of sulphide might have some similar effect? Be that as it may, the vast majority of founders need have no heart-searchings over such matters, for the general rule is that there is sulphur enough and to spare, and the founder has to watch carefully to keep it at a low enough limit.

Phosphorus.—Unless in greater amounts than is generally met with in foundry practice, phosphorus seems to have little effect on the conditions of the carbon. Mr J. E. Stead, F.R.S., in a classical research, has proved that the phosphorus is present as Fe_3P, and is present in pig-irons as a eutectic in striped patches containing 10·2 per cent. of phosphorus. Phosphorus increases the fluidity of cast-iron, and gives it a very fine skin, so that a phosphoric mixture runs into the fine details of art work, such as ornamental designs on stove grates, and faithfully reproduces the beauties of the pattern in the casting. Mixtures for some work of this kind may contain as much as 2 per cent. phosphorus. Phosphorus has, however, a weakening effect on the iron, so that where strength is required the phosphorus is kept as low as the price will allow. In thick castings also, the phosphide remaining liquid to the last has the tendency to liquate away from thicker parts and thus leave them spongy. Hence, for castings of uneven section, like valves to stand hydraulic pressure, the phosphorus should be as low as possible, and should not be over 1 per cent., or the castings are likely to fail under hydraulic test. Phosphorus also makes the iron more easily fusible; hence, for ingot moulds for receiving molten steel, hematite mixtures should be used, keeping the phosphorus as low as 0·06 per cent., which has the further advantage that, when the ingot mould is worn out or has an ingot stuck in it, the mould (with the sticker, if it contains one) can be used as part of the charge in a Siemens furnace, instead of being resold to the mould-maker as scrap.

Nickel.—In 1892 A. M'William, experimenting with ferro-nickels for the Martino Steel Co., noticed that a 50 per cent. ferro-nickel made from the purest Swedish white iron and the best refined nickel formed a beautifully soft, fine grey metal, even when cast in from 1-inch to 3-inch sections in chills. At that time no elements other than silicon and perhaps aluminium were known to him which had the same effect; and, although there was no prospect of the commercial application of nickel as a softener of cast-iron, the result was of scientific interest, and would have been followed up had other work allowed. As the result was not published, no claim of priority is made, and the incident is mentioned to impress the influence of nickel. In 1899 Mr Hadfield, in his paper on "Nickel and Iron," mentions that a steel with 0·74 per cent. nickel and 1·3 per cent. combined carbon, on annealing, had 1·2 per cent. of its carbon precipitated as graphite; and Prof. Arnold, in his contribution to the discussion, stated that a steel containing 1·3 per cent. carbon and

34 per cent. nickel, after rolling, had all but 0·05 per cent. precipitated as graphitic carbon, and that annealing produced a similar result.

Titanium.—Recently titanium has been recommended by the American expert, Dr Moldenke, as well worthy of a trial as a remover of oxygen when very special qualities of cast-iron are required.

Vanadium.—Vanadium, which has been so much before the metallurgist recently by reason of its wonderful effects in vanadium-chrome and vanadium-nickel steels, originally worked out by Prof. Arnold and later by Messrs Sankey and Kent Smith, and in the less useful limits by Dr Guillet, has also been tried in cast-irons in some preliminary experiments at the Sheffield University, in which it produced a finer grain and showed a distinct, but, so far as tried, unimportant improvement in the tensile, transverse, and crushing tests.

Grading by Fracture.—The system of numbering the pig-irons of a series varies widely in different districts, but, as examples, the hematites are generally called Nos. 1, 2, 3, 4, 5, mottled and white reckoning from the most open grey No. 1. The first three are generally spoken of as Bessemer numbers, for obvious reasons; and sometimes, instead of 4 and 5, the terms 4 foundry and 4 forge are used. The Holwell pig, again, is numbered 1, 2, 3, 4 foundry, 4 forge, mottled and white. Photographs of characteristic fractures of Nos. 1, 5, mottled, and white, of the purer hematite series, are shown in figs. 178 to 181; whilst similarly characteristic fractures of Nos. 1, 4 foundry, mottled, and white, of the more phosphoric Holwell series are shown in figs. 182 to 185.

Selecting Pig-Irons for the Making of Cast-Iron Castings.—If for malleable iron for chill-casting or for steel-making purposes, the reader is referred to the chapters on these subjects (XIX. and XXXII). The first point will generally be the amount of phosphorus to be allowed in the finished castings. Perhaps a fair average for general castings is about 1 per cent., although, as we have seen, some, such as ingot moulds for steel, contain 0·06 per cent., whilst others may be suitable for ornamental work from 1 per cent. even up to 2 per cent. It will be clear that, as the different brands give plenty of choice from 0·04 up to 2 per cent., while the several numbers of each brand vary little in phosphorus, the choice is a simple one. The governing feature is that the lower the phosphorus content the higher the price, as a rule. Having decided on the final phosphorus, the next element that varies but little with different numbers is manganese; and, as manganese has in most cases a fining and strengthening influence on cast-iron by its effect on the structure, by its mastery over the sulphur (keeping that element in its less dangerous form of sulphide of manganese), by its tendency even to eliminate some of the sulphur under suitable conditions, and to prevent the iron taking up more from the coke, a content of up to 1 per cent. manganese is aimed at where sulphur may be high. It is probably the high manganese and comparatively low phosphorus that has given the special Scotch brands their renown as constituents of mixtures. The sulphur, as has already been seen, is chosen as low as practicable, and now only the silicon and carbon remain. By this time we have decided on the particular brands, and in all cases there should be a mixture of brands, for, with the best management, a blast furnace is subject to bouts of internal derangement; if the result of this is sent out and reaches the founder, with a mixture of three brands the effect on the casting will be reduced to one-third, not more than one out of the three furnaces being likely to be out of order at one time. Each brand has its series of numbers or compositions, and, as we have seen that for a given thickness of casting or rate of cooling the percentage of silicon present particularly controls the amount of

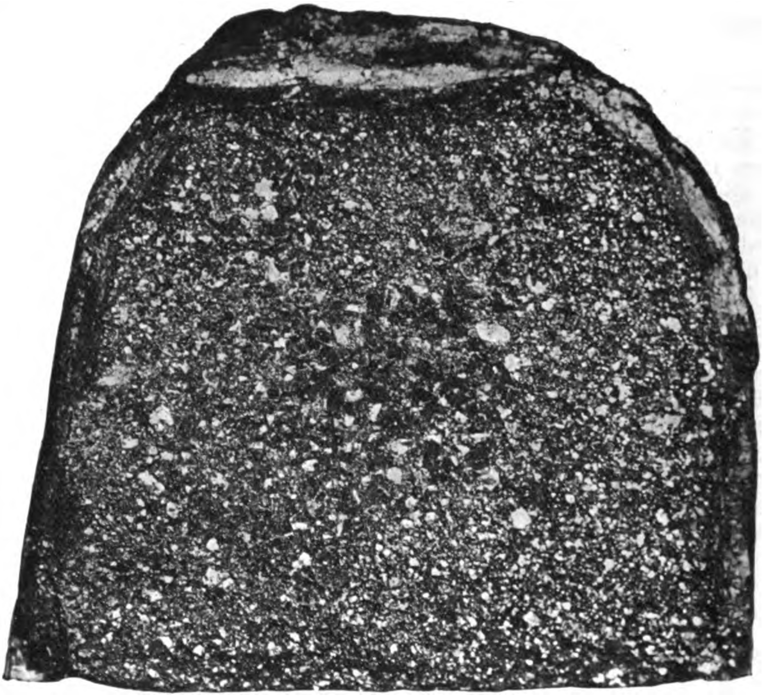

FIG. 178.—Hematite, No. 1.

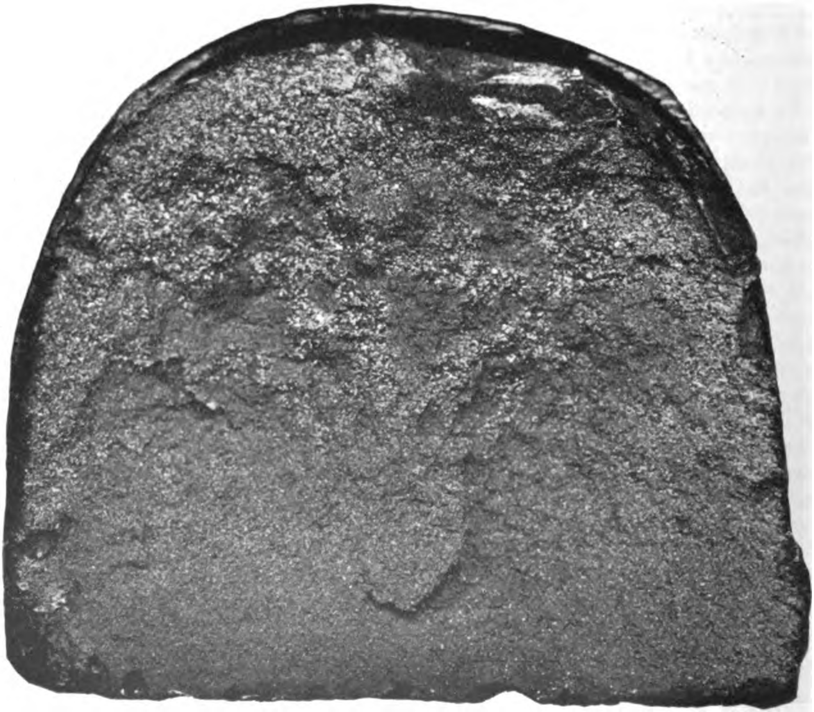

FIG. 179.—Hematite, No. 5.

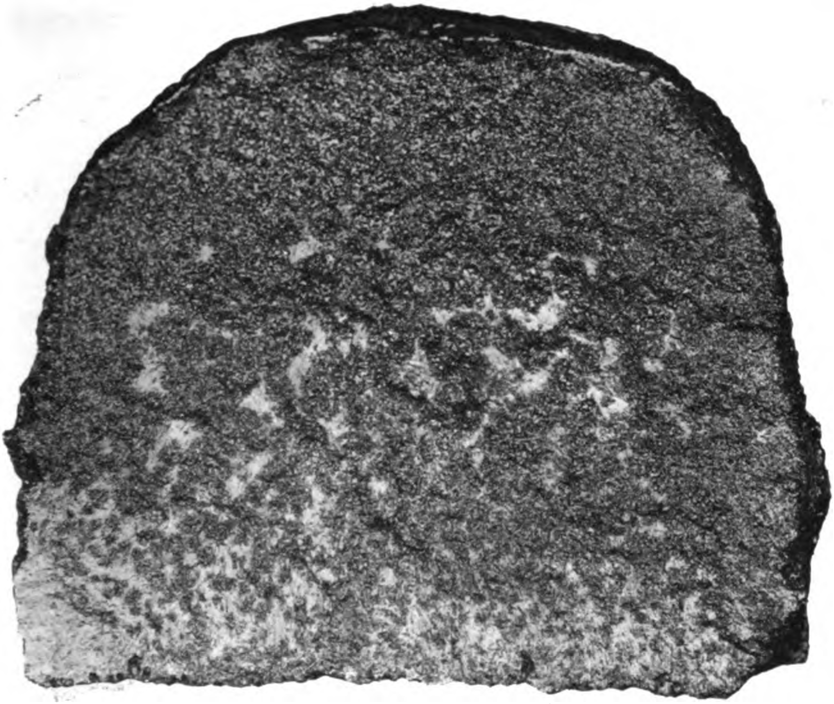

FIG. 180.—Hematite (Mottled).

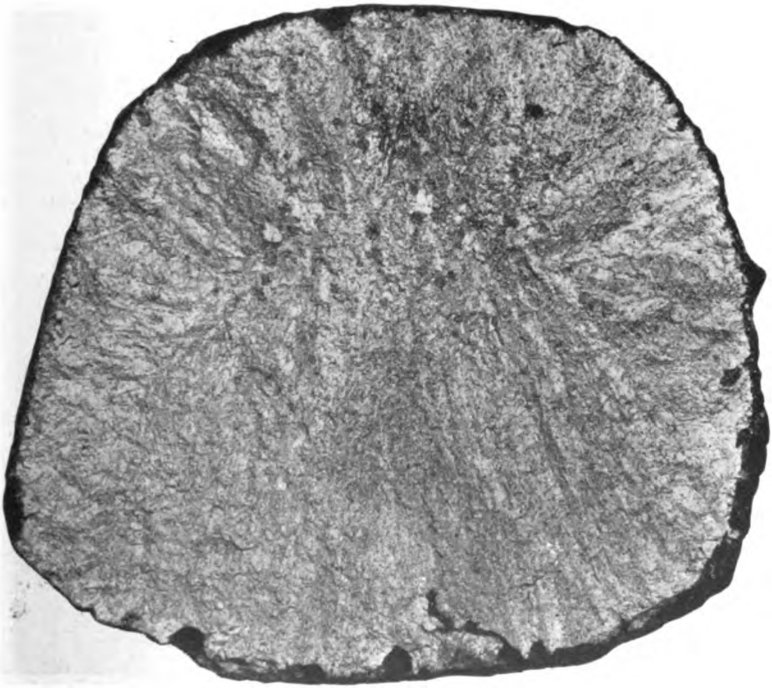

FIG. 181.—Hematite (White).

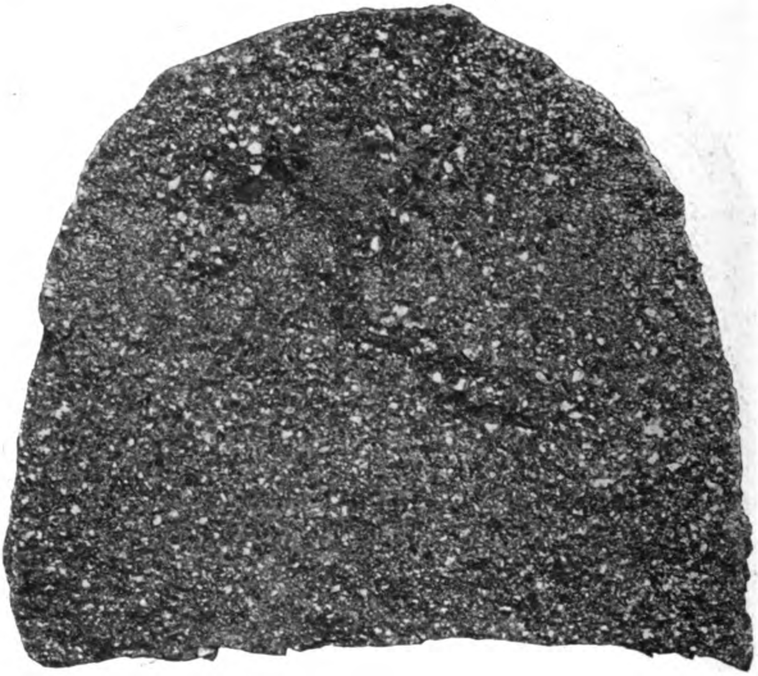

Fig. 182.—Holwell, No. 1

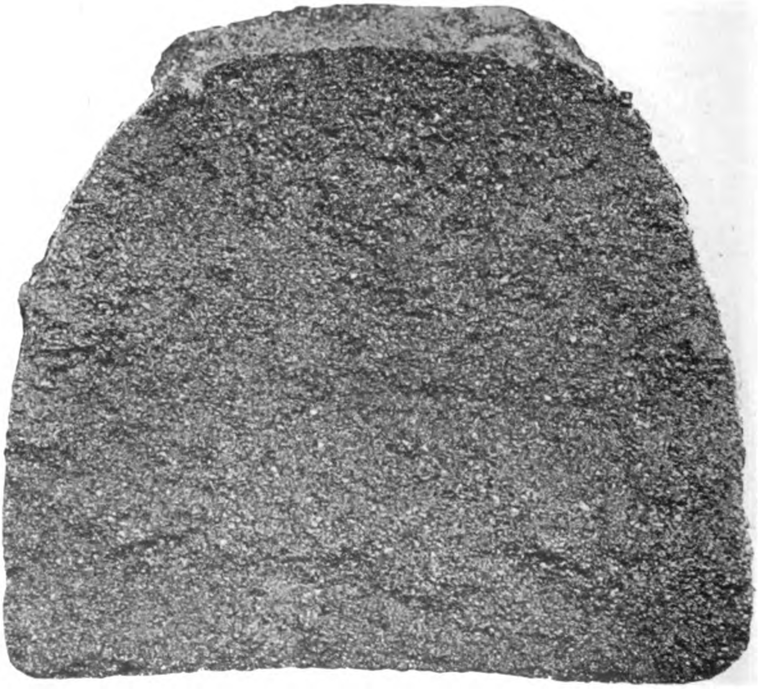

Fig. 183.—Holwell, No. 4, Foundry.

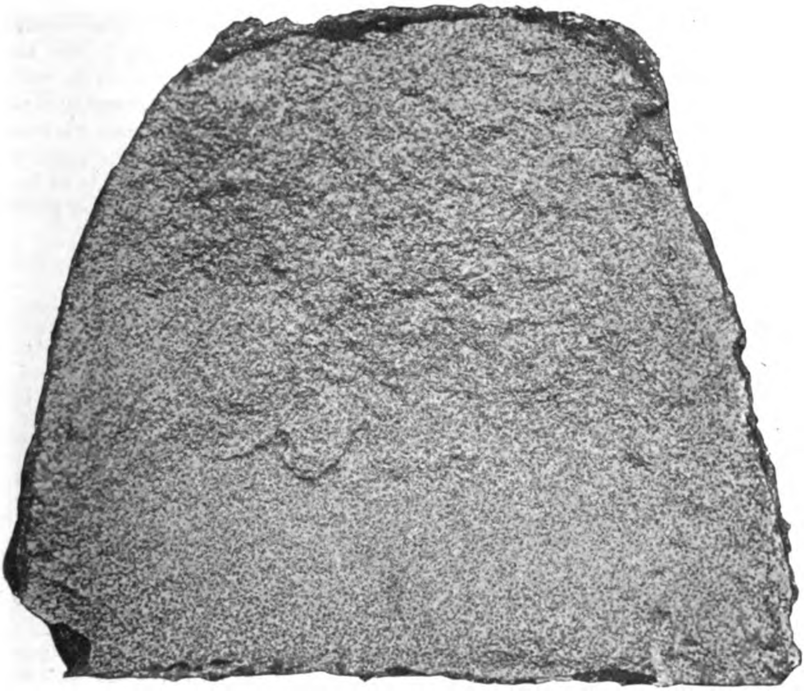

FIG. 184.—Holwell (Mottled).

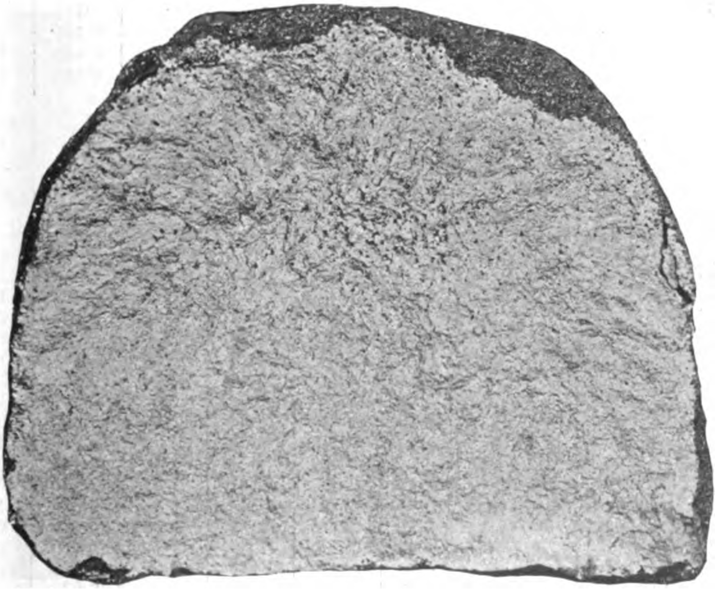

FIG. 185.—Holwell (White).

combined carbon, the numbers required must be chosen to give the required silicon and result in the final casting, in a way that will be shown in the next chapter. Finally, the total amount of carbon will be seen not to be under control in this way; but, if too great for the purpose desired, it may be varied by allowing a suitable proportion of steel scrap which (in most cases where the total mixture, steel scrap included, has been calculated on the above lines) will be found to have a good influence on the result, and in many districts to be a powerful help in endeavouring to arrive at a certain strength, grade, or purity.

TYPICAL ANALYSES OF PIG-IRONS.

Name.	No.	C.C.	Gr. C.	Si.	Mn.	S.	P.
Holwell, . .	1	0·14	3·43	2·80	0·60	0·027	1·15
,, . .	2	0·10	3·70	3·47	0·54	0·025	1·26
,, . .	3	0·10	3·71	3·05	0·64	0·023	1·22
,, . .	4 Foundry	0·14	3·61	3·15	0·60	0·048	1·11
,, .	4 Forge	0·25	3·29	2·70	0·65	0·051	1·16
,, . .	5	0·80	2·93	1·50	0·60	0·145	1·17
,, . .	Mottled	1·30	2·90	0·70	0·55	0·175	1·14
,, . .	White	3·10	0·67	1·12	0·55	0·240	1·10
Pig-iron from Leicester ore only	3	0·33	3·30	2·74	0·70	0·073	0·90
Average compositions of a well-known Derbyshire brand, .	1	0·22	3·32	2·80	0·80	0·030	1·37
	2	0·14	3·54	2·75	0·75	0·040	1·38
	3	0·05	3·38	2·70	0·80	0·060	1·44
	4 Foundry	0·50	2·98	2·30	0·85	0·090	1·43
	4 Forge	0·25	3·16	2·20	0·73	0·105	1·30
	4 Grey forge	0·44	3·05	1·90	0·58	0·115	1·40
	Close forge	0·67	2·85	1·75	1·05	0·145	1·50
	Mottled	1·08	2·18	0·80	1·33	0·165	1·44
	White	3·10	0·90	0·50	1·33	0·180	1·36
Redbourne series, .	...	...	...	...	...	...	about 1·30
Clarence series, .	...	...	...	...	...	...	about 1·5
Renishaw, . . .	...	0·08	3·30	3·10	0·31	0·040	1·60
Parkgate, . .	...	0·40	3·20	2·50	0·80	0·020	1·50
Staveley, . .	...	0·06	3·40	2·50	1·10	0·065	1·30
,, . .	...	0·14	3·00	3·60	1·25	0·048	1·25
Bestwood, . .	...	0·12	3·30	2·90	0·50	0·085	1·25
Sheepbridge, . .	...	0·07	3·31	3·10	1·05	0·055	1·25
Stanton, . .	...	0·08	3·50	3·01	0·40	0·050	1·22
Frodingham, . .	...	0·30	3·20	2·06	1·00	0·061	1·20
Scotch, . . .	...	0·20	3·60	3·00	1·30	0·020	0·71
Carron, . . .	1	0·20	3·60	4·00	2·00	0·012	0·64
Blænavon, . .	Siliceous	...	1·75	9·25	0·45	0·108	0·09
,, . .	Ordinary	0·40	3·65	3·31	1·47	0·065	0·84
Staffordshire . .	Phosphoric	0·79	2·04	1·62	0·97	0·030	1·45
Staffordshire Dud Cold Blast,	...	0·72	2·80	1·61	0·76	0·120	0·47
		0·45	3·30	1·26	1·12	0·070	0·56
		0·72	2·15	1·10	1·08	0·110	0·63
Siliceous pig, .	...	*Nil*	2·60	4·60	1·39	0·030	1·12

STEEL-MAKING HEMATITE IRONS.

Name.	No.	C.C.	Gr. C.	Si.	Mn.	S.	P.
East Coast.							
Ayresome,	1 Bessemer	0·43	3·40	3·38	1·40	0·030	0·045
,,	2 ,,	...	...	3·50	1·42	0·024	0·050
,,	3 ,,	0·30	3·60	3·10	1·38	0·023	0·048
Seaton Carew,	1 ,,	...	...	3·18	0·70	0·014	0·038
,,	2 ,,	...	...	3·35	0·70	0·020	0·035
,,	3 ,,	...	...	3·20	0·70	0·030	0·034
Thornaby,	Bessemer	...	...	2·47	1·32	0·035	0·050
West Coast.							
Carnforth,	Bessemer	...	...	3·03	0·72	0·025	0·035
Lowther,	,,	...	..	3·03	0·36	0·050	0·050
Harrington,	,,	...	...	2·84	0·18	0·030	0·048
Millom,	,,	...	...	3·03	0·72	0·040	0·052
Ulverston,	,,	...	...	3·19	0·32	0·025	0·040

CHAPTER XXVII.

REFRACTORY MATERIALS.

THE materials of construction for furnaces consist of those which are used primarily to take the weight of the erection, to establish its form, to hold it together or to a certain shape, but not necessarily to withstand the effects of ordinary furnace operations; and, secondly, those which, while they may take certain weights and help in any or all of the functions mentioned, are primarily required not to give way under the conditions of furnace work, and hence are called refractory materials. The former are such as the ordinary builder uses with an eye to the comparatively high temperatures that even the outside portions of furnaces may attain, thus debarring, as a rule, the use of any easily combustible substance, and originally consisting mainly of masses of red bricks; but for many years past these have been more and more replaced by iron work, cast-iron, wrought-iron, or mild steel, bolted or rivetted together. The ideal refractory material would withstand the high temperatures incident to the process without undue softening, the more or less great and rapid alternations of temperature without cracking, crumbling, or flaking off, the mechanical wearing action of fluids and solids in motion, the alteration in composition produced by oxidising or by reducing atmospheres, and the chemically scouring action of basic oxides, or of highly basic or highly acid slags. Refractory materials well known and much used in furnaces are fire-clay; silica in its various forms, such as ganister, Dinas stone, flints or silica sand; lime, and, more largely, calcined dolomite (lime and magnesia), and calcined magnesite (magnesia); carbon in various forms, such as charcoal, coke dust, plumbago (graphite or black lead); chromite (chrome iron ore); alumina; oxides of iron; and even metallic iron itself. All these materials may be grouped under the three heads of acid, basic, and neutral. Silica being the important acid in nature, all the acid group are more or less pure silica. The basic are more varied, as, for example, lime, calcined dolomite, magnesia, alumina, oxides of iron. The neutral group may be neutral, either because of their indifference to acid or to bases; or because they consist of acid and base combined in normal and satisfying quantities; the latter are generally liable to be acted upon by another acid or another basic material. Thus, "burnt" fire-clay is more or less pure silicate of alumina or a combination of the acid silica with the base alumina. Chromite is a compound of chromic acid with the base ferrous oxide; while the various forms of carbon are neutral because they have no affinity for either acid or base.

Although refractoriness is a question of degree, in most cases it will be found that there is an essential standard of the process and then a standard representing the highest attainment to date. Thus, a mixture of clays, such that they will not allow of one heat of a certain steel being properly melted and poured, is not a refractory mixture for that steel and process; while if even one heat could be successfully negotiated the mixture would for that process be a refractory material; further, the authors have known cases where, with machine-mixed clay and machine-made crucibles, this was considered sufficient for the rich alloys made. Again, crucibles of the Sheffield hand-and-foot worked mixture will withstand three, and sometimes four, heats of steel, provided the crucibles are not allowed to cool between the heats, and here the question of ideal and practical may be considered. In ideal definitions of refractories one of the points mentioned is that they must withstand sudden and considerable alternations of temperature without cracking or flaking off. In practice, the best compromise must be chosen, for this same Sheffield crucible worked up to stand severe handling at high temperatures, and to turn out the maximum number of rounds with the smallest percentage of runners (that is, heats that run through the crucible), and to have the minimum of evil effect on the steel, will not stand cooling to a black heat without cracking; hence, the work is so arranged that it shall always be at a temperature above the cracking point. The materials mentioned generally have a higher softening or melting point the freer they are from impurities. Any substance added to an acid or a basic refractory which would tend to form a new silicate will make it more fusible, and, where mixed silicates are formed, the fusibility is still further increased for a given amount of impurity. Thus, silica present in magnesia is bad for the highest temperatures, and in dolomite is still worse, forming some silicate of magnesia in the one case and double silicate of lime and magnesia in the other. The presence of ferrous oxide in fire-clay is very injurious, for then a ferrous silicate is formed, and silicate of alumina is present; while ferric oxide is not nearly so bad, for, unless converted to ferrous oxide, it does not combine with silica, and there is only the effect of its own fusibility.

Similarly, lime is injurious to fire-clays, and potash and soda most injurious, owing to the great fusibility of the silicates of potash and soda. Lime added to siliceous refractories increases their fusibility, and more so in the presence of clay; yet lime is purposely added to pure ganister in the making of silica bricks; for infusibility, though of great importance, is not the only point; since the bricks must hold together until they are built into the furnace, and bind, not crumble, when put under the furnace temperature; hence the addition of lime to frit the particles together. In the case of fire-clays, the clay itself (hydrated silicate of alumina) is plastic when moistened, and a strong binding material, but very close in texture; therefore, in the making of fire-bricks, in many cases, good sand or ganister is added to prevent cracking in drying while increasing the refractoriness. In the case of a moulding sand, which is an important refractory material (generally mainly silica sand), a certain amount of clay is necessary for binding; but excess will injure the sand with regard to porosity; and generally a "red" sand, that is, one in which each particle of quartz is roughened by a coating of red or brown oxide of iron, will take a good bind with a minimum of clay present. These general principles must be kept in view when examining each group in detail, and, particularly, when studying the different tables of figures to give them a living interest.

Acid Refractories.—The acid group are mainly composed of silica, and are, in fact, more or less pure silica. According to Boudouard, pure silica softens or practically fuses at 1830° C. As silica is the most important and most abundant constituent in the crust of the earth, it would seem that there should be no shortage of good acid refractories. Nor does any shortage appear likely. The accumulations of siliceous materials are, however, of very varying degrees of purity; and as, in practice, it is found that in many cases the shapes of the particles and the character of their surfaces are also important, the deposits of the very highest order are more limited. Typical examples of the finest for all very high temperature needs are found in the ganister of the Sheffield district or the Dinas stone of Wales, personally selected samples of the former from the best beds having been tested in several cases and given over 98 per cent. of SiO_2. Near to these beds there are others of almost every grade of admixture with clayey material down to an argillaceous or clayey sandstone. The purest ganister, when viewed under the microscope, is seen to be composed of exceedingly small particles of quartz, cemented together by silica, which has itself crystallised as quartz, making a fine-grained pure and compact rock. This very feature is important in many of its applications, for it is the cause of the rock breaking up into sharp angular fragments, instead of pulverising into its constituent rounder grains, as in an ordinary sandstone. These sharp angular fragments of varying sizes, from the largest used for the particular purpose to the finest powder when mixed with a small amount of clay and moistened, may be rammed round a pattern (as in rebuilding crucible holes or in lining a Bessemer converter) in a state almost like a liquid under the rammer; so that no hole or joint is left, and still such that when the mould is drawn the sides keep their shape in a way that no rounded particles would do when moistened to the same consistency. In other circumstances the angular pieces of silica, however pure, would not suit the purpose; and a white silica sand, such as Calais sand, almost entirely composed of rounded grains of quartz, must be used. For example, in forming the bottom or basin-shaped receptacle for the bath of an acid Siemens furnace many layers of sand are burnt on, one after the other, with the furnace at full heat; and here the rounded particles are necessary, for by running down the sides in a way that the angular particles would not do, they give a solid bed with banks of the proper slope. In this case, also, the pure white sand is considered by many melters to be too infusible, and is mixed with 5 per cent. or so of red sand, in order that the particles may be so fritted together as to stand the wash of the metal, and the rubbing of the tools, and, by binding more firmly, reduce the rising of portions of the bottom through the steel to a minimum. Calais sand is merely pure quartz particles not bound in any way. It has been seen that ganister consists of particles of quartz, cemented together by silica that has crystallised from one particle to the other. Other sandstones are found consisting of quartz particles bound together by more or less clay, and these are ground and made into grades of silica bricks, which gradually approach fire-bricks in appearance and in properties; and, the percentage of injurious oxides being allowed for, may be said to be less refractory as the proportion of clay increases and they approach the composition of ordinary fire-bricks. Moulding sands, which have been already dealt with in detail, are but acid refractories of a special kind, being grains of quartz, each of which is coated usually with a thin layer of the brown oxide of iron, an excellent binding material itself, and giving a rough surface, so that a minimum of clay will give a good binding sand, and, for a given size of particles, thus give a maximum of porosity, clay being of such a close nature. In certain places, such as parts of Scotland, flints are the purest available siliceous material, and, as flints are composed of silica only partially crystalline, the material is so strong that it is too difficult to break or grind to the required fineness. The difficulty is overcome by heating the flints to a high temperature and slacking them out in water, when the typical waxy appearance of the flint is destroyed and the material becomes white and brittle, and is easily ground for making into silica bricks.

Basic.—Refractory materials being used in such large quantities it is naturally expected that they will be drawn from the common constituents of the earth's crust. We have already seen that the most abundant is silica, *the* acid of the metallurgist. The next in quantity are alumina, oxides of iron, lime and magnesia, potash and soda, all basic oxides found either free or in combination with silica or some other acid. Of these, alumina in a very impure form, as bauxite, oxides of iron in various forms, lime and magnesia as calcined dolomite or calcined magnesite are most important basic refractories; alumina combined with silica and water forming clay is of world-wide distribution, while potash and soda are but dreaded impurities.

The natural minerals magnesite (magnesium carbonate, $MgCO_3$) and dolomite (magnesium carbonate and calcium carbonate in varying proportions, but tending to the formula $MgCO_3,CaCO_3$) are calcined or heated to a high temperature to drive off the carbon dioxide, and yield respectively magnesia (MgO) and calcined dolomite (MgO,CaO), which are extensively used as basic refractory materials for the making of open hearth furnace bottoms and for the ramming up of Bessemer vessels for the basic process of steel manufacture. As these materials combine with water, and are thereby reduced to a powder, not only must they not be made into bricks by mixing with water, but they must be prevented, as far as possible, from absorbing water from the air. They are, therefore, mixed with anhydrous tar, and ground in a mill while hot, pressed or rammed into the desired shapes, and consolidated by heating in as reducing an atmosphere as possible. This process leaves a carbonaceous binding material, which acts as a fairly efficient protection from the influence of moisture for a convenient period; and the high temperature produces all the contraction and admits of the bricks or other forms being fitted into place. As might be expected, the magnesia wears longer in the furnace; but being, in Great Britain at least, much more expensive, the dolomite is more extensively used, although the authors have recently been informed by some founders that they find the greater durability of the magnesia in their work more than compensates them for its extra price. Quite recently magnesia has been treated at high temperatures, principally by electrical means, until it has become highly crystalline, and the authors have been much interested in experimenting with a sample presented to them for the purpose by Mr H. G. Turner. Kept in water for several months it showed no sign of change, and it has also been successfully used in the Sheffield University Metallurgical Department for lining plumbago crucibles so as to manufacture low carbon and silicon, but high manganese, alloys with iron for research purposes.

Neutral.—Of the refractory materials which may be considered as neutral, because of their consisting of base satisfied with acid, the greatest example, whether as to quantity, universal distribution, or importance, is clay. Clay is a combination of alumina with silica and with water, forming a hydrated silicate of alumina, and the insistance of the term hydrated to indicate its chemical nature has no pedantic origin, for the presence of water of hydration is, in some way, the cause of the valuable plastic property of clay.

Plastic clay, when dried, may be easily reduced to an impalpable powder, and, when dried so carefully that all moisture or uncombined water is driven off, it absorbs water again on mixing and becomes once more plastic; while, if once it be heated to a red heat, so that all the combined water or water of hydration is driven off, then it becomes "burnt clay"; and, although reduced to an impalpable powder and mixed with water, it will not again become plastic; moreover, there is no known means of making it combine with water again. Pure silicate of alumina of the formula $Al_2O_3,2SiO_2$, representing 54 per cent. SiO_2 and 46 per cent. Al_2O_3, has a melting point of 1830° C., according to Boudouard, and, although this is the same number as he gives for pure silica, the latter is more easily obtained in a state of purity; and the impurities in the former, as acting on a silicate, have greater effect in lowering the fusion point. Recent researches are tending to make more exact our general practical knowledge of the effects of the different impurities in varying amounts on the fusibility of burnt clay, and the practical fact remains that the fire-clays obtainable will not withstand steel-melting temperatures in the open hearth furnace, and that for the roofs of all, and for the bed in acid work, nearly pure silica is used. The influence of the alkalies potash and soda is probably the most potent for evil, since, unlike the acid materials, in no case do we require the clay to be more fusible for practical work, excluding, of course, the making of more and more fusible mixtures in the manufacture of the useful Seger cones for pyrometric work. But the fear of the influence of potash and soda has led some to overstate the case, and say that quantities almost unattainably low are necessary, and should be specified, or bad bricks will result. The Glenboig bricks, which are generally acknowledged to be among the finest fire-bricks in the country, are known to contain about 0·7 per cent. of potash and soda; while in a series of preliminary tests made by an old student for the selection of one from three of the best natural clays procurable, Stourbridge, the lowest of the series, gave 0·65 per cent. of the alkalies, and samples heated in a crucible in the coke holes, and containing 2 per cent., stood well up to 1200° C., without sign of forming porcelain, and not till 3 per cent. was reached did the test entirely break down at this temperature. A minimum of these materials is desired; but as what is wanted cannot always be obtained at the price available for its purchase, it is always well to know at least the order of the quantities that would be injurious in ordinary work. Lime, and ferrous oxide, are also objectionable because of their forming fusible double silicates; but their exact influence in certain quantities is not yet sufficiently well known to enable definite pronouncements to be made, and we must obtain general ideas from the known tendencies of these materials as given here, carefully study the amounts found in clays known to give excellent results, and then set aside and rigidly investigate any case of failure or extra specially good wear. An interesting case came under notice recently of good and bad stoppers and nozzles used in a 2-ton ladle for distributing mild open hearth steel. The stopper and nozzle were found to soften sufficiently during the teeming just to stick together; consequently, before the end of the pouring, the stopper had changed in shape so much that it would no longer fit the nozzle or a piece actually pulled off the stopper end. Stopper ends from another firm were tried, but they pressed into the nozzles, and, finally, this second firm supplied nozzles also, and excellent results followed. The bad stopper was carefully analysed, and it was shown to contain SiO_2, 52·7; Al_2O_3, 35·2; Fe_2O_3, 4·4; FeO, 1·8; CaO, 1·2; MgO, 0·3; $Na_2O + K_2O$, 2·5; MnO, 0·1; P_2O_5, 0·5; loss on ignition, 0·3; showing nothing so very bad in any one item, but each deleterious impurity high, so that the total reaches 10·3 per cent. The good stopper was examined sufficiently to show that it was fairly normal with SiO_2, 54·0 ; Al_2O_3, 40 ; Fe_2O_3, 2·6 ; FeO, 0·5 ; CaO + MgO, 0·8 ; and, assuming the $Na_2O + K_2O$ to be 1 per cent., there is a total of deleterious matter of 5 per cent. These two examples are sufficiently interesting in themselves, as the bad were only sufficiently so to give a dribbling stopper, and they are also good examples of the kind of thing that should be thoroughly investigated when it arises.

It will be obvious that fire-bricks must be set in fire-clay, for, with ordinary mortar of lime and sand a fusible double silicate of lime and alumina would be formed, and their life would thus be short; the ordinary life has been known to be much reduced by the too liberal use of mortar in the red brick course behind the fire-brick lining. Common red bricks used in too hot a part of an air furnace flue were found (on inspection to find the cause of unsatisfactory working) to have formed a hanging curtain of beautiful, but draught-destroying, stalactites.

In making clay crucibles, as the plastic clay contracts very considerably on drying, generally some non-plastic material is mixed with the clay. For experimental purposes the old two-thirds burnt one-third raw formula of the Royal School of Mines answers well, but for the manufacture of crucibles to stand the highest temperatures of coke steel melting (a temperature which just softens all ordinary clays) an admixture of another of the neutral materials, carbon in the form of best quality coke dust is used; and while the clay portion of the crucible is soft, the coke being quite hard acts as a kind of framework or skeleton, and enables the crucible to keep its shape throughout the day. This is very beautifully shown, if either accidentally, or purposely, for an experiment, a little air is allowed to strike the mouth of the pot during the 12 or 14 hours annealing, so that the coke is burnt out, then that portion gets all out of shape during the working, and, if the air has entered the annealing furnace fairly freely, the usually beautifully shaped pot becomes a wretched looking object, and these shapeless portions, when broken cold, are always found to be white and porcellanous, showing that the carbon has been burnt out; while the shapely parts give a black fracture, indicating that the coke dust, the skeleton, still remains. The other neutral material of this class, namely, acid and base combined, known as chromite, or chrome iron ore, is essentially a ferrous chromate (FeO,Cr_2O_3), and, all things considered, is probably the most refractory material known. It withstands a very high temperature, is not affected by an oxidising, and not much by a reducing, atmosphere under ordinary furnace conditions; it withstands the wash of acid slags or basic oxides. Its high price and the fact that it has no binding properties are against its extended adoption; but, as an example of its special utility, it is often used as a parting between the basic hearth and the acid roof of a basic Siemens furnace.

Of carbon in its various forms as a neutral refractory material much might be said. A typical use of coke dust has already been given. Coke bricks are being used for the hearths of blast furnaces. Charcoal is made into a brasque or inside coating for experimental crucibles; and in one of its crystallised forms, plumbago, it is used in admixture with about an equal weight of good fire-clay in the manufacture of graphite or plumbago crucibles.

Plumbago in powder, or as the familiar black lead, appears as a facing for moulds. So far as its refractory properties are concerned, its melting or even softening point is outside the range of ordinary furnace operations. In the case of coke it is hard, and will stand abrasion; but, either as charcoal or plumbago, it is exceedingly soft, and, as in experimental brasques, must scarcely be touched, or, as in the plumbago crucibles, must be supported by fire-clay; and even then any necessary stirring should be done with caution. Seldom in works experience need complaint be made of articles being too good, but in their practice the authors have met something like it at least. For the making of a very special alloy, vigorous stirring was deemed necessary after the mixture was melted. Two firms were asked to quote for crucibles, and several lots ordered from each; but the crucibles of the firm with the greater name never anything like equalled those of the other in numbers of heats turned out. This curious result led us to examine the two carefully, and, while they were much the same in texture and in the nature of clay used, those which lasted the better only differed (so far as was determined) by having more than the usual 50 per cent. or so of clayey material, which is much the cheaper substance; this is another example of the fact that not the dearest, but the material best suited for its work is the best, while it also shows the saving that even firms of the highest repute may make by careful experiment.

	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric Oxide (Fe_2O_3).	Ferrous Oxide (FeO).	Lime (CaO).	Magnesia (MgO).	Alkalis ($K_2O + Na_2O$).	Combined Water.	Carbon Dioxide (CO_2).
Best Sheffield ganister (Rock), ...	98	1	0·5	...	...	...	...	...	...
White sand, . . .	96·5	2	1	...	0·5	...	...	...	...
Moulding sand, . . .	85·5	5·5	3·7	...	0·7	0·5	...	...	...
Steel Moulders' "Compo" (*Harbord*),	59·8	25·2	5·4	...	1·1	0·8	3·0	water and carbonaceous 4·7	
Chemically pure china clay, $Al_2O_3 . 2SiO_2 . 2H_2O$	47·1	39·2	...	...	..	...	...	13·7	...
Best Stourbridge fire-clay, .	62·0	23·3	3·0	..	0·7	...	0·7	...	...
Glenboig calcined or burnt clay, ...	64·0	32·0	2·0	...	0·7	0·6	0·7	...	...
Inferior fire-clay stopper, .	52·7	35·2	4·4	1·8	1·2	0·2	2·5	...	...
Superior fire-clay stopper, .	54·5	41·0	2·5	0·3	0·2	0·5	1·0	...	...
Raw dolomite (Anston Crags), ...	2·0	0·9	...	...	31·0	20·4	...	...	45·5
Calcined Steetly dolomite (*J. C. S. Armitage*),	2·1	5·4	...	...	54·0	37·5	...	(S.) 0·02	(P.) 0·03
Magnesite Raw, . .	1	1	1	...	2	45	...	...	50·0
Magnesite Calcined, .	2	1	1	...	4	92	...	...	...
Arkansas Bauxite, calcined (*A. J. Aubrey*),	6·4 TiO_2 4·0	87·3 ...	1·4 ...	... ...	... ...	... ...	... ...	0·9 ...	... ...
Graphite, ...	3·9	3·0	2·3	...	0·2	1·7	...	...	(Carbon) 86·6
Chromite, ...	7·0	12·0	...	15·0	...	10·0	...	...	(Cr_2O_3) 56·0
Common red brick, . .	78·5	13·3	4·7	...	0·4	1·1	2·0	...	...
Porcelaine de Sèvres (*Gruner*), . . .	58·0	34·5	...	...	4·5		3·0	...	...

The last two are given for comparison with really refractory materials. As showing how electrical products are coming into use, carborundum fire sand, an amorphous form of carbide of silicon, is being sold for patching and even for lining cupolas, ladles, etc.

CHAPTER XXVIII.

FUELS AND FURNACES.

VARIOUS forms of furnaces are used for preparing the metals or alloys and for raising them to a temperature sufficiently above their melting points to make it practicable to transfer them to the moulds and pour them at a temperature to permit of the making of good castings. The crucible, the reverberatory or air furnace, and the Siemens regenerative open hearth, the cupola and the Bessemer converter with its modifications the Robert and Tropenas, are the principal types of furnaces used in the foundry for the production of the molten metal. Cast-iron in its molten state, taken direct from the blast furnace or from a mixer to the foundry in a ladle, and known as direct metal, is now much used where the two plants can be placed conveniently near to one another; but the blast furnace is not yet generally claimed to belong to the foundry, and will not be considered in this work, especially as it is dealt with in detail in Prof. Turner's volume on iron in this series.

Also this chapter is only general, dealing mainly with principles, to enable those in the foundry to understand the methods by which the metals they use are produced; and varieties of each type of furnace, with elaborate details and in most cases working drawings to scale, may be found in Harbord's volume on steel in this series.

It is helpful to consider these furnaces as falling under four types:—

1. Those in which the metal or mixture of metallic substances is enclosed in a refractory vessel, as in the various kinds of crucible furnaces, the enclosing vessel or crucible being surrounded by the fuel in the coke-fired furnaces, but only by the products of combustion in the gas- or oil-fired furnaces.

2. Those furnaces in which the metals are heated on a separate hearth and only the products of combustion reach the metal or the slag floating on its surface, as in the ordinary reverberatory or air-furnace of the brass or iron foundry; or in the Siemens open hearth, used either in the place of an air furnace merely to melt the charge, with, generally, a minimum of alteration in its composition; or, as in the manufacture of steel, for melting followed by alterations in composition purposely made by the oxidising or purifying influence of additions, generally of oxide (ore) to the slag, and continued until the desired composition has been reached.

3. The cupola type, where the fuel and the metal are in contact.

4. Those furnaces in which, starting from a fairly high initial temperature, the composition of the charge is altered and the necessary additional heat is obtained by the oxidation or burning of one or more of the constituents of the

metal itself, by means of a blast of air forced through the molten metal or impinged upon its surface. This is the underlying principle of the Bessemer and such modifications as the Robert converter for side blowing and the Tropenas for surface blowing.

1. CRUCIBLE FURNACES.—Sections and a plan of different kinds of solid fuel crucible furnaces are shown. They all act on substantially the same general principles, and, in construction and working, differ only in details. In nearly all cases the draught is obtained by means of a chimney stack, only rarely supplemented by forced draught underneath the grate. The small assay furnace, fig. 186, and the one-pot hole for brass and German silver melting, fig. 187, are shown in section, while the two-pot hole for steel melting, fig. 188, is shown in section and in plan. The air drawn in by means of the chimney draught is admitted under the fire bars. This air is cold, and when it impinges on the hot fuel over the bars, although by its combination with the carbon of the coke a great quantity of heat is produced, naturally the maximum temperature is not immediately reached, and hence the first point in all crucible work is to raise the crucible above the level of the bars so that metal when melted may be within the region of maximum heat. It will also be obvious that as the air drawn in moves along the path of least resistance, the actual burning away of the fuel tends to produce vacant places and natural arches, and these again would admit comparatively cold air, which, impinging on the crucible, would lower the temperature; hence, these spaces must be broken up by poking the fuel down from above. Judgment must be gained and used in this matter, as the steady rise of temperature would be interfered with by the too frequent removal of the cover of the furnace. Another point follows from this, that the best qualities of crucible cokes for the highest temperatures, although of a considerable hardness and of a quality by analysis equal or even superior to cupola or blast furnace coke, must be more brittle and break more easily when struck with the poker. This important point may best be seen by comparing two cokes of columnar structure, one suitable for blast furnace or for cupola work and the other for crucible steel melting; the smallest columns of the former are very much larger than those of the latter. The authors have used cupola coke for crucible work during a strike, but

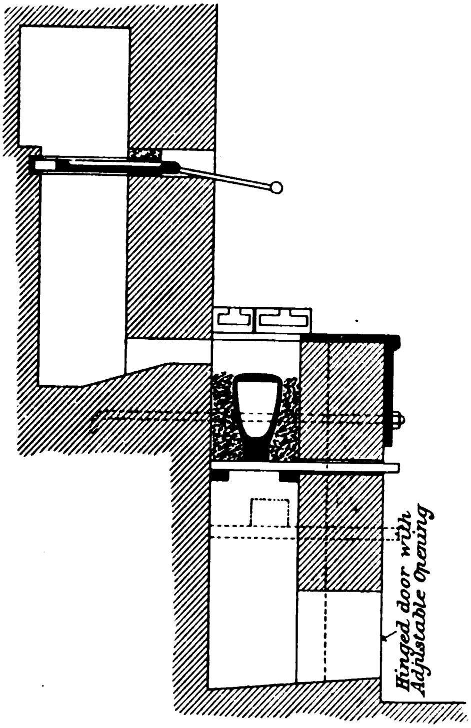

FIG. 186.

great care must be exercised with it, as, not only does it require more labour to break it to suitable sizes for charging, but when in the furnaces, instead of breaking when poked down and filling up the spaces, it has a tendency, owing to its great strength, to go through the side of the crucible.

In a small assay or experimental furnace, fig. 186, the draught is regulated by a damper in the flue above the furnace and by a door in the ashpit. In one-pot holes for brass, German silver, malleable cast-iron, etc., fig. 187, the draught, as a rule, is only regulated by the general design of the furnace, and, if too keen, eased off by having the cover of the furnace more or less open at the top by tilting by means of a fire-brick or more often a piece of coke; the loss of power thus caused by drawing air through this opening direct to the chimney through the small flue leaving less power to pull the air from below the fire bars through the cokes. As cold coke must be added on the top to replenish loss by burning, for melting processes requiring high temperatures the coke is added to several inches above the lids of the pots or crucibles, in order that it may be partly heated by the ascending gases before it reaches any metal level in the crucibles. A series of crucible furnaces may be joined up to a large stack at one end, say twelve holes in one stack, but naturally the furnace nearest the stack draws best, and the one at the tail end worst, and it is not always convenient to arrange the melting points or the weights of the charges to suit. The arrangement may thus be convenient for college assay or experimental furnaces, where different strengths of draught are desirable; but, at the best, for commercial work it is troublesome. Sometimes four or six holes have flues leading to a stack on the centre line, in plan like a runner and sprues, and this gives a more even range. The best method is, however, to have an independent flue and chimney for each hole, the several stacks being built in a general wall for say twelve or any convenient number of holes; the authors, having at different times worked holes for brass, German silver, cast-iron, and steel on all three plans, unhesitatingly recommend the last plan for particular work as the one in which the individual care necessary for the special character of crucible melting can be given to each pot with the

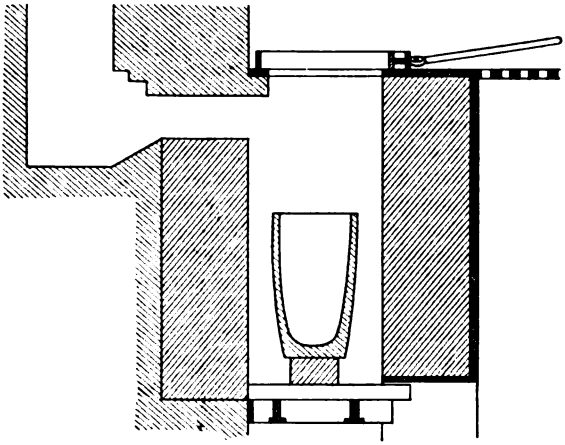
FIG. 187.—One-Pot Hole for Brass or German Silver.

least anxiety and the greatest certainty of success. The influence of the process of melting on the quality of the metal, as distinct from the influence of the chemical composition as ordinarily determined, is one of those matters of a type already mentioned that science is endeavouring to solve satisfactorily, and there is much difference of opinion, neither theoretical nor practical men being agreed among themselves. When all the processes have been considered, it will be seen that the coke crucible furnace is the only remelting furnace in which the operation is conducted under reducing conditions. As oxygen in most metal is dreaded because of its evil effect, and because of the difficulties involved in the estimation and therefore in the watching of it, the coke crucible furnace has a great advantage. This very advantage brings in its train a disadvantage, for, as all crucibles exhibit a considerable degree of porosity, if the sulphur in the coke be high, there is a decided increase of sulphur in the metal. The changes in steel in the crucibles will be dealt with in the chapter on steel, but even in German silver the same trouble is experienced. Keeping a strict watch on the sulphur in the coke, the crucible process is capable of producing metal unsurpassed where its extra cost does not debar its use; and, for special work, it is still used, as it has the further advantage that with the small charges, special compositions for series of castings can be melted and poured at their most suitable temperatures, a difficult matter to arrange for small work where a 2- to 5-ton charge is ready at one time. Crucibles for brass in one-pot holes vary from 30 lbs. to 600 lbs. per round, the larger sizes being drawn by hydraulic cranes.

The question naturally arises, "Why use coke for crucible work?" A trial in an experimental furnace with a charge requiring a high temperature to melt it, is convincing enough. Some ordinary coals, when heated, become almost semifluid and weld into one mass, and are thus known as caking coals, the variety most generally used for making coke by heating them until all volatile matter is driven off. Other coals again, when heated, have a large quantity of volatile matter driven off, but the particles do not coalesce; they remain as separate pieces. These are spoken of as dry, free burning, or non-caking coals. The caking coals are obviously unfit for crucible furnaces, as they would at once choke up the draught. Consider even the non-caking coals, and their unsuitability will be seen. When charged on the top of the fire not only must they be heated up to the required temperature, but also a certain amount of heat is used in driving off the volatile matters, and these precious volatile matters are merely sent up the flue. This very fact means also that a greater weight of coal than of coke must be used, and the simple cooling effect of this larger weight is greater. In the case of the coke, volatile matter has already been driven off, and in modern plants turned to account, and the coke only needs to be simply heated up to become active in giving out heat by combustion. The table of natural fuels indicates that anthracite might almost be looked upon as Nature's slowly formed coke, for the volatile matter is often as low as 5 per cent., and this fuel is, as a matter of experience, very useful under some circumstances for certain high temperature crucible work, and is much used in America for cupola melting. The authors have, however, used Scotch splint coal with success in the melting of such comparatively low temperature alloys as yellow brasses, because, although the cost of fuel was increased, the crucibles lasted longer with the coal than with the local coke, and the balance was found to be slightly on the right side. With the above guiding principles each case can be considered on its merits with the economic and other conditions prevailing, but it may be assumed that the highest temperatures cannot be obtained in solid fuel crucible melting with much volatile matter in the fuel.

In the assay and square built one-pot holes for brass, malleable iron, etc., the refractory lining is fire-brick set in fire-clay, with as close joints as possible. The two-pot steel melting crucible hole, fig. 188, has the outer rectangular space built in with 9-inch firestones, and then the hole is shaped round a ramming block about 2 feet × 1 foot 6 inches × 3 feet deep. The draught is regulated by taking out one or more of the loose bricks in the stack under the level of the bars, if the draught is too keen; or putting them in, if too slow; and, if the very keenest is required, then a piece of paper is quickly thrust over the loose bricks and the pull of the stack holds it there firmly. Both these last forms are shown with the top of the holes level with the floor, and this, nearly always the best and safest arrangement, is always adopted for steel melting. In the case of the other form sometimes the holes are built so that the top comes about a foot above the floor level, perhaps to save a little excavation and to enable the men more easily to lift up the grating and get down to the bars. We have, however, a very decided preference for the tops being on a level with the floor.

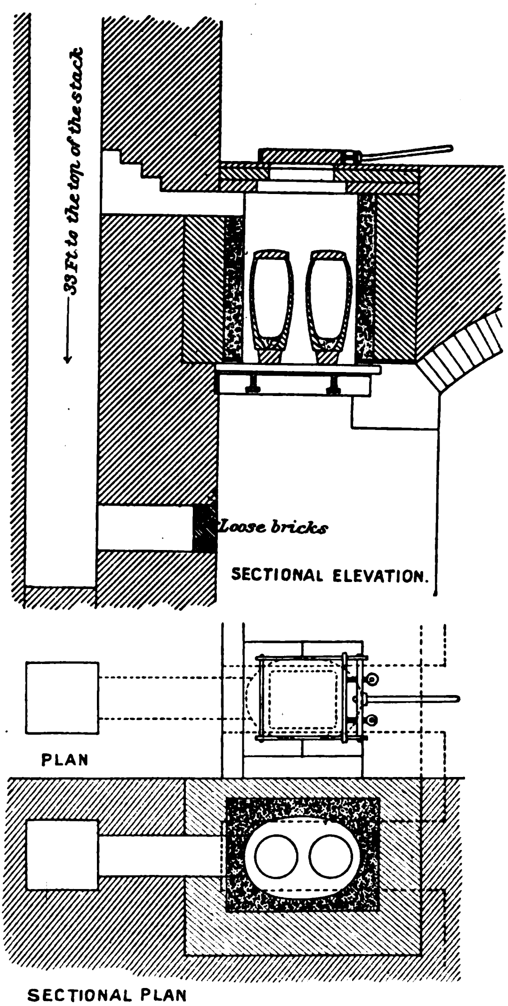

FIG. 188.

2. THE AIR FURNACE.—The general structure of the air furnace will be seen from the drawing, fig. 189. It is a reverberatory furnace, generally with a curiously double-arched roof, so that the roof dips very much in the centre. This throws the flame down on the pig and scrap, and probably tends thus to minimise the amount of oxidation in the metal. Some of the heat of the waste gases is utilised for heating the cold pig, which is placed on the gentle slope of the bed between the melting hearth and the bottom of the stack; thus the iron as it melts trickles down and forms a bath. The most suitable fuel is coal, giving a long flame and a dry ash which does not clinker the bars. It is burnt on the fire grate, and the bridge between the grate and the melting chamber enables a fairly deep fire to be kept, which prevents the entrance of excess of air to cool the melting chamber. This forms a rudimentary gas producer, the principle of which will be explained later in this chapter; and the combustible gases formed, together with the volatile matters, give a flame of almost any desired length, which, taking its direction from the roof, reverberates on or near to the surface of the charge before making its way to the base of the stack.

Air furnaces vary in capacity from ¾ cwt. upwards. As a rule, the bed, sides, bridge, and roof are built in of good fire-brick, which may be repaired with ganister or fire-clay as the furnace wears. In certain cases the bed may be formed by ramming a layer of refractory sand on the bricks. In every case the bed must drain to the tap hole.

As a melting furnace, the reverberatory is slow, and has a high fuel consumption, varying from 10 to 20 cwts. of coal per ton of iron melted; but these features are of secondary moment, for these furnaces are only used for special qualities of metal, as for the production of special quality cylinder iron, chilled rolls, and iron for malleable castings. In the brass foundry these furnaces are extensively employed for the production of larger quantities of alloys, and for this purpose are extremely satisfactory.

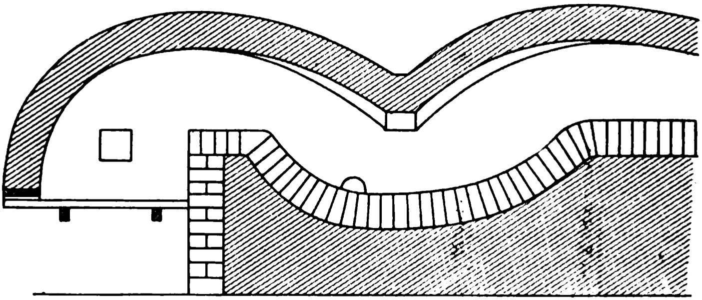

FIG. 189.—Air Furnace.

In British practice air furnaces are usually worked by natural draught, but forced draught or induced (steam jet) draught may be used, a plan followed in American malleable foundries.

With natural draught or intermittent work it follows that, as a "melter," the air furnace cannot compete with the cupola in cost, but it can and does exceed it in point of quality of product. This is due to the fact that the atmosphere of the cupola is under less control than that of the air furnace. In the latter, a neutral, oxidising, and, with careful work, even a reducing flame may be maintained, that is, from a bright, clear, and cutting flame to a smoky flame. With the former, every portion of the furnace is visible, and it indicates an excess of air which means an oxidising atmosphere. If, under these conditions, the furnace contains a bath of brass, the oxygen will actively attack the alloy, uniting in the first place with the volatile zinc, to form oxide of zinc, which is carried on with the products of combustion, and, in the second place, with copper, to form oxide of copper, which remains in solution in the bath of metal on which it has a decisive effect.

If, on the other hand, the furnace contains a bath of molten cast-iron, the effect of an oxidising flame would be in the main to oxidise silicon and manganese. The direct value of this is that the flame may be varied at will, and, in the case of iron, samples are taken, cast in chill or sand moulds, and from an examination of the fractures, further treatment is decided. Thus, if the bath is intended for a chill, and the chill on the test sample is too deep, then grey pig or ferro-silicon may be added to reduce the depth of the chill. If, as is more probable, the sample shows too little chill, the bath is held in hand until some of its silicon has been oxidised out. Similar control is offered in the case of iron for malleable castings.

With gun-metals, brasses, or bronzes the furnaces must, of necessity, be worked with a smoky flame, which means high fuel consumption. As an illustration, a charge of yellow brass can be completely "dezincified" by means of a clear flame, a bath of molten copper collecting, and the zinc being drawn up the stack, as oxide, unless means are taken to collect the white oxide in the flues. Therefore, excessive fuel economies with this class of alloys mean metal losses in the furnace, and coal is cheaper than zinc. This does not imply that one need be necessarily extravagant in the matter of fuel, but simply indicates that the atmosphere must be maintained in a condition suitable to the material being melted.

The average consumption in a series of air furnaces, varying from 2 tons up to 20 tons, is about ¾ cwt. of coal per cwt. of alloy melted under the most suitable conditions of melting. The average metallic loss cannot be exactly stated, but it is in the neighbourhood of 5 per cent. This loss is chiefly zinc, and will be referred to in detail in the chapter on alloys.

Taking the smaller furnace, 2 tons, an average of two years' intermittent working gave 81·7 lbs. of coal per cwt. of alloy, and during the period the alloys were melted at an average rate of 1 cwt. in 11½ minutes. Coke-fired crucible furnaces melting similar grades of alloys, in crucibles varying from 100 to 300 lbs. capacity, consumed 86·3 lbs. of coke per cwt. of alloy melted. Both these figures could be reduced if one type of alloy only were melted, and then always in uniform weights; but it will be noted that the crucible furnaces take 100 to 300 lb. pots, which, in the lower weight, means excess of fuel. Similarly, in the period under observation, the air furnace charges varied from 10 cwts. up to 40 cwts., the latter giving a lower ratio than the average and the former a higher one. It must also be noted that the authors' practice has always been to melt "hot," their experience leading to the conclusion that it is cheaper to regard the quality of the alloy than the amount of fuel consumed in melting it.

Under ordinary conditions, the air furnace cannot be worked continuously, for heavy chill rolls or large brass castings are only produced at intervals of days, or weeks, as the case may be. In malleable foundries, where three or four heats may be taken off each day, advantage is taken of the accumulated heat in the furnace from first heats onward, and the fuel costs correspondingly decrease. Similarly, brass foundries, working with small air furnaces of ¾ to 2 cwts. capacity, with natural draught, give fuel ratios much lower than the crucible furnace, and, in addition, there is the saving which results from the elimination of the crucibles. In this case, immediately after tapping, the furnace is recharged, and the heat of the previous charge thereby utilised. The lines of the ordinary air furnace reduced to the small capacity required give an exceedingly good melting furnace. It should, however, be noted that the shanks must be exceedingly hot.

Regulating the Draught.—Owing to the fact that an air furnace is worked with a long flame, sliding metal dampers in the flues are useless, as they inevitably warp and jam. The best method is to fit the ash-pit with doors which open outwards and can thus be readily adjusted to regulate the current of air. When working with a smoky flame, on opening the fire doors the atmosphere of the melting chamber clears, and the metal may be examined through the sight hole, a convenient sight hole being formed by a small hole through the side, plugged with a loose brick, and the joints seamed with wet sand.

The top of an air furnace may be removable in sections for introducing large waster castings or scrap difficult to break.

Charging Hot or Cold.—The authors' experience on furnaces intermittently worked is that the result for any one heat, starting with the furnace cold, is the same in either case, and it is much more convenient to charge the furnace when cold. In melting to composition, copper and any scrap are charged first, and, when nearly melted, the requisite amount of tin is added, which will quickly take the mass down to a liquid state. Zinc should never be added until the other constituents are molten, as it can then be plunged below the surface, and oxidation losses to some extent reduced.

3. THE SIEMENS FURNACE.—The Siemens open hearth furnace embodies a new principle on those already considered. It is obvious that the gaseous products of combustion leaving a furnace must be as hot as or hotter than the place they are heating up. In the crucible furnace, during a small fraction of the time of melting, a small portion of the heat of the gases is given to the cold coke added; in the air furnace the hot gases from the melting chamber are partly used to heat up cold pigs; in the cupola the hot gases from the melting zone give up some of their heat to the cold charge above before they escape; but in all these cases the gases leave the furnace at high temperatures. In the original form of the Siemens furnace used principally for steel-melting temperatures, a systematic arrangement is made for storing the heat of the furnace gases for use, in two pairs of separate chambers of refractory brick checker work, which are so built that the extremely hot gases from the melting chamber may leave their excess heat in one chamber of each pair before passing to the chimney at a temperature merely high enough to keep up the necessary draught; while from the other member of one of the pairs the cold air absorbs heat previously left by the products of combustion, and from the other member of the second pair the producer gas also absorbs heat, so that air and producer gases both enter the furnace at a high temperature. One set of checkers will thus be gradually rising in temperature, while the other is falling. By suitable valves the whole direction of these currents is reversed, and the cooler chambers are now ready to absorb heat easily from the gases, while the hotter ones are ready to heat the incoming air and gas. The most suitable length of time between reversals for a given type of work is found by experience, and for steel-melting is about twenty minutes. This is known as the Siemens regenerative principle, and the chambers of checker work are known as regenerators or recuperators, although it will be fairly clear from their action that heat accumulators would be the best, as it is certainly the most accurately descriptive term to use, for they merely act by storing up or accumulating the excess of heat between that necessarily in the gases as they come from the furnace and that required for producing the pull in the stack. Having accumulated this heat they give it up again to the comparatively cold air and gas before they enter the furnace; and thus, when these combine and convert their potential chemical energy into the heat form, the heat is not required to raise the whole of the gases from a low temperature, but only from, say, a bright orange or yellow; so that there is evidently more heat to spare for raising the charge and the furnace to the desired temperature and maintaining them at the degrees of heat required during the working of the charge. The uninitiated seem to have no difficulty in understanding the manufacture of ordinary illuminating gas where the coal is subjected to a high temperature in a closed vessel and the volatile gases driven off, cleaned, and used for illumination, while a residue of coke or "Fixed Carbon" is left, but find it not so easy to see how in a gas producer the whole of the combustible part of the fuel, volatile and fixed, may be converted into gaseous fuel. The simplest way to consider the action is to think of gas producers as being merely deep fires with more or less elaborate details for convenience and economy in working. In the Duff producer, shown in figs. 190 and 191, the draught (as is generally the case), is obtained by a high-pressure steam injector, the high-pressure steam issuing from a fine nozzle, drawing air with it; hence, it is spoken of as an induced draught. The oxygen of the air meeting the hot solid carbon above the grate combines with it to form the gas carbon dioxide, and much heat is evolved ($C + O_2 = CO_2$). This gas is not combustible, but at the high temperature produced it combines with more solid carbon to form carbon monoxide and heat is absorbed, but a combustible gas is produced which is still very hot, $CO_2 + C = 2CO$. Besides oxygen passing in we have nitrogen of the air, and the steam used for giving the pressure of air. The nitrogen is merely a carrier, and takes no part in the chemical action, but it shares the result, as the heat evolved must heat up all the gases present. The steam, however, does act on the carbon of the hot coke, and there is again an absorption of heat, but two combustible gases, carbon monoxide and hydrogen, are formed, $C + H_2O = CO + H_2$. Thus, there are carbon monoxide, hydrogen, and nitrogen still at a fairly high temperature, and these hot gases now pass through the upper layers of the fire, and meeting the undecomposed coal drive off its volatile matter, mainly complicated series of hydrocarbons, which, for simplicity, we have put down as marsh gas (CH_4). The distillation absorbs some more heat, but, again, we gain more combustible gas. Among these hydrocarbons are some which, if cooled, would produce ordinary tarry matter. In the original Siemens design the gases were purposely cooled down, and by that means the sensible heat was lost, together with the tarry matters, which, to the present day, give some little trouble by condensing in the flues and valves. In the new form, the producer gas, consisting of CO, H, N, CH_4, and

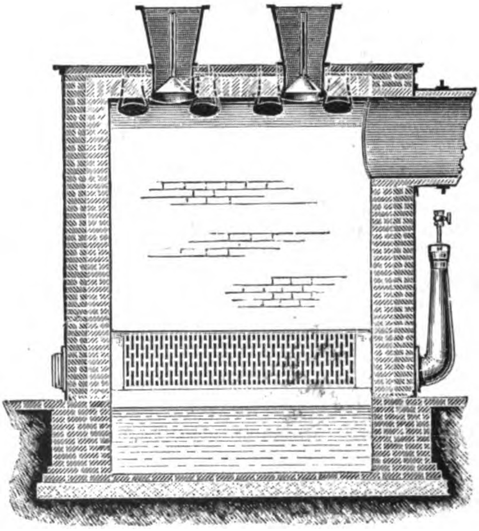
FIG. 190.—The Duff Gas Producer.

other hydrocarbons, and a small proportion of CO_2 (as the conversion to CO is never perfect), passes direct into the furnace with all its sensible heat, and holding the tarry matters in a state of vapour. It is evident that only one pair of checkers as accumulators is needed, because the gas is taken direct into the furnace, and, the steam supply being regulated to give the desired flame, the depth of the fire is so regulated that the top of the producer is kept at a nice even red (about 800° C.), as seen through the potter holes at the top; while in the old form, as the sensible heat is lost, the top of the producer is kept comparatively cool. As in crucible work, so here, the air in making its way through the fire tends to burn out cavities and form natural arches, which must be broken up by working a potter or long poker bar from above and in some cases from side potter holes also. It will thus be seen that practically all the combustible material may be converted into gas, but the ash or mineral matter remains either loose or partly fused into clinker. In some forms of producer, in which the fire rests on fire bars, the ash or clinker is removed every 24 hours or so. This is managed by stopping the blast, opening the air-tight doors near the bars, driving in flat false bars a few inches above the ordinary bars till they rest on a ledge at the back. The ordinary bars are then taken out, the ashes or clinker raked out, the ordinary bars replaced, the false bars withdrawn, the doors closed and wedged tight, the fire poked down, and the blast turned on again. The Duff producer shown in figs. 190 and 191 is what is known as a continuous form, in which the bottom of the producer is closed by a water seal formed by the water in the trough, and the ashes or clinker may be raked out from the water at any time without stopping the making of gas. The special feature of the Duff is the peculiar form of the grid used as a grate, which distributes the air and steam evenly through the mass of the fuel. Gas producers not only yield gas for melting purposes, but also for almost any other operation requiring heat, such as drying ladles and the heating of drying stoves for moulds. The section of the Siemens open hearth furnace, shown in fig. 192, is the old Sheffield Technical School furnace, designed by Mr. B. H. Thwaite, C.E., according to Prof. Arnold's general instructions, and used for the training of students. Although 20-ton charges for castings and 50 tons for ingots are common enough to-day, it will show the adaptability of the process that charges of 13 to 25 cwts. of all kinds of open hearth steel were made in it with complete success, and the three most interested spectators of its working were three

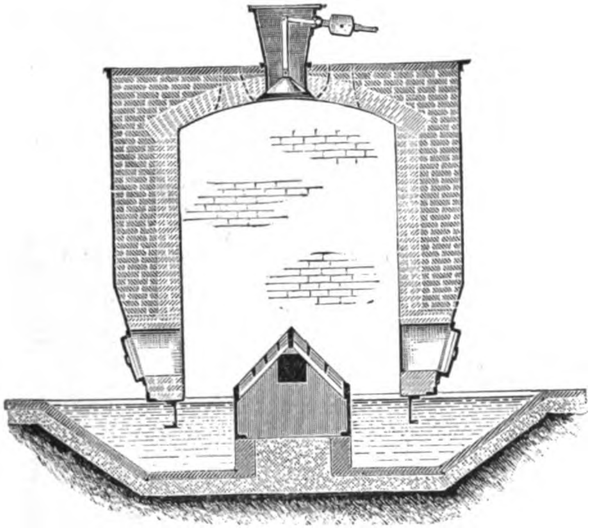

FIG. 191.—The Duff Gas Producer.

American managers of the leviathan furnaces of the day, who saw a 13-cwt. heat finished and poured. There is no doubt that the type would work well up to 5 tons at least. The producer was placed near the furnace, and worked with a hot top, like the new-form Siemens, so that only one pair of heat accumulators was needed, for, the gas being hot, only the air had to be heated. The air was brought in under pressure, as the special circumstances did not admit of a stack being erected. The section is introduced here, as the furnace gave every satisfaction in practical working, and, if carefully studied, it shows more clearly and simply than any other design what is meant by a furnace working on the Siemens regenerative principle. Anyone wishing details of the varieties of larger forms must consult special works on the subject, such as those by Harbord or Campbell.

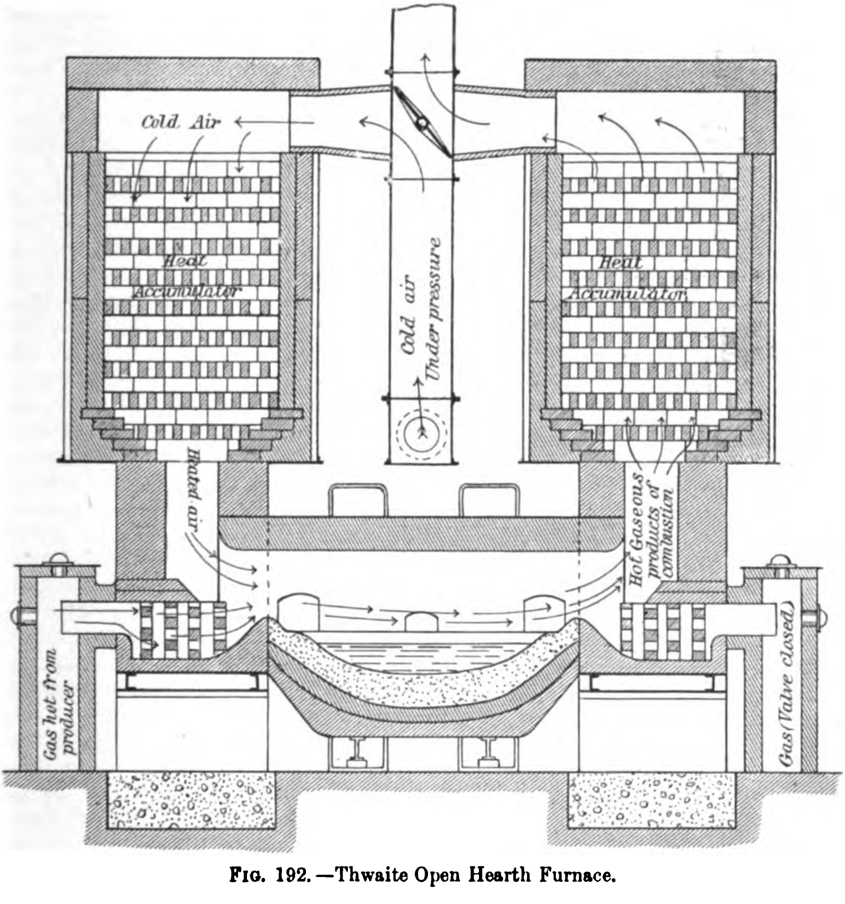

Fig. 192.—Thwaite Open Hearth Furnace.

This, and similar furnaces, may be run with an acid (silica) or a basic (calcined dolomite or magnesia) bottom as desired; and, besides its use for steel-making, may be advantageously employed for any of the ordinary purposes of an air furnace where the output is sufficient to keep it in work. When by means of suitable reversals at regular intervals a white heat is obtained, the basin-shaped acid bottom is formed by using Calais sand with about 5 per cent. of red sand mixed with it, or some mixture of a similar nature, and burning it in, in thin layers, by pouring the loose sand on and then bringing each layer to the highest temperature of the furnace. Finally, a melt of slag and, perhaps, one of pig-iron, known as the pig-wash, consolidate the bottom and leave it ready for regular work.

Gas crucible holes are worked on similar principles, only, instead of an open hearth containing a bath of molten metal and slag reacting on one another, a slightly different shape of hearth is formed; the bottom is generally made up of small coke, and crucibles are placed on these and receive the usual types of charges.

4. **THE CUPOLA.**—The cupola, in its essential features, may be considered as a vertical hollow cylinder of refractory material, suitably supported and held together, having the top end open and the bottom closed, excepting for the provision of a small tap hole. A short distance above the bottom are holes for the admission of air, which is either forced in under pressure or induced by a steam jet near the top of the stack or by other means, and about half-way up a suitable opening, for convenience in charging or throwing in the metal fuel and flux as required. The furnace being hot, the air of the blast combines with the carbon of the fuel to form carbon dioxide, and heat is given out, which is utilised for melting the metal in contact with or above the fuel. Also at the temperature produced, the flux unites with the sand of the pig and scrap and with the silica and other substances formed (which would be dry, and would deteriorate the quality of the cast-iron), and forms a fusible material or slag. Some of the carbon dioxide formed takes up more carbon to form carbon monoxide, and, as heat is thus absorbed, any of the combustible carbon monoxide that escapes at the top and burns in the air represents so much loss; for, it will be remembered, that the calorific power of carbon burned to carbon dioxide is 8134 heat units, while that of carbon to carbon monoxide is 2450, only about one-third of the maximum. When the melting begins, the tap hole is stopped up by a "bod" or conical piece of suitable plastic refractory material, and the molten metal and slag accumulate in the bottom of the cupola; the cavity between the bottom and the tuyere level represents the capacity of the cupola to hold molten material without interfering with the blast. When sufficient metal has gathered, a hole is made in the bod with a pricker bar, and the metal tapped into a ladle and taken away to the moulds. When all the metal required for the day has been run down there is always some coke, and perhaps some iron, left in the cupola. All the iron might be melted out, the coke ultimately burnt away, and the ash fluxed off, perhaps; but this method would be a great waste of time and material; hence, some comparatively large portion near the bottom is made to take off easily, or the bottom itself made in halves and hinged so that they can be held up during the heat and dropped at the end, so that the coke left and any iron that may remain is dumped on to the floor and cooled off. Any large portion of coke or slag sticking to the sides is brought off, the tuyeres cleared, and the whole left to cool. Thus the fundamentals of the cupola are remarkably simple; but, like many other things, it is not so simple as it seems, if the operations are to be carried out to the best advantage. Considerable skill must be exercised in the design, building, and working of the furnace to procure regularly the best results with the materials available, and numerous modifications have been made in the general structure, while dodges in the

working are almost as many. Much has been written on cupola practice in recent years, and one excellent work of 360 large pages is entirely devoted to it (Kirk on *The Cupola Furnace*). It is well to study the above simple principles with care, and then the idea of the various modifications will be clear, although just the measure of success to be expected, and the type of furnace or details of working to get the best results with the greatest economy, will be found quite worthy the careful thought of even the most skilful managers; for, although some claim to melt with less than 2 cwts. of coke to the ton of iron, many use 4 or even 6 cwts., and some have been known to use 10 cwts. to the ton. Many a cupola has been made by lining up an old boiler shell with fire-brick, after cutting out suitable holes for doors, etc., and many such are no doubt at work to-day; but supply firms now make a great feature of their own special design of cupola, and these are delivered all ready for erection, so that the user gains the advantage of the specialised experience in design of the particular firm with whom he elects to deal. With our primitive cupola in mind, with all its bare essentials, it will be well in a few sentences to review some of the special features of designs, illustrating only the Stewart's Rapid as a good British example, fig. 193, the Whiting cupola, fig. 194, as perhaps the best of the American designs, and fig. 195, the Greiner and Erpf, special arrangement of subsidiary tuyeres. In every cupola a space of ¾ inch should be left between the fire-brick and the shell, to allow for expansion and contraction, and the space may be loosely filled with parting sand. No definite relation can be given as to tuyere area, but, roughly, the tuyere area should be one-tenth the cross-section of the cupola in small and one-seventh in large examples. Tuyeres are, as a rule, circular, and where two only are employed are supplied directly from the blast main, but, where more than two are used, an air belt or wind chest is fitted to the cupola. The majority of tuyeres point straight in to the cupola, but the Doherty tuyeres are placed at an angle to give special motion to the blast, without, apparently, any advantage. In the Colliau design there is a double row of tuyeres, one above the other; those in the first row are from 2 inches × 6 inches to 4 inches × 14 inches horizontal, those in the second row round, 2 inches to 4 inches diameter, and entering at 45°, pointing downwards towards the centre. The Whiting tuyeres are an improvement, both rows being of similar shape and horizontal. The MacKenzie tuyere consists of a continuous opening round the circumference of the cupola, and the blast thus enters as a sheet. When a second row of tuyeres is added, as described above, the idea is to burn any carbon monoxide formed to carbon dioxide; but Greiner and Erpf claim that, only too often, with a second row of comparatively large tuyeres the burning is so concentrated, and thus the temperature maintained is so high that the carbon dioxide formed is sufficiently hot to react on hot coke and form carbon monoxide again; their cupola, therefore, has one main row of tuyeres and then a series of small tuyeres in a spiral form for a considerable distance up the cupola. They claim that, by supplying the extra air needed in small doses, they burn all the carbon monoxide to carbon dioxide without raising the temperature high enough to be followed by the reaction of the carbon dioxide on the coke again.

Blast pressure varies up to 14 or even 16 ozs. per square inch, and is generally higher the greater the diameter of the cupola; a fair average would be about 6 ozs. for small cupolas to 10 or 12 ozs. for large ones.

For raising materials to the stage, hydraulic hoists are generally used in this country.

Linings.—The lining generally consists of good fire-bricks set in fire-clay,

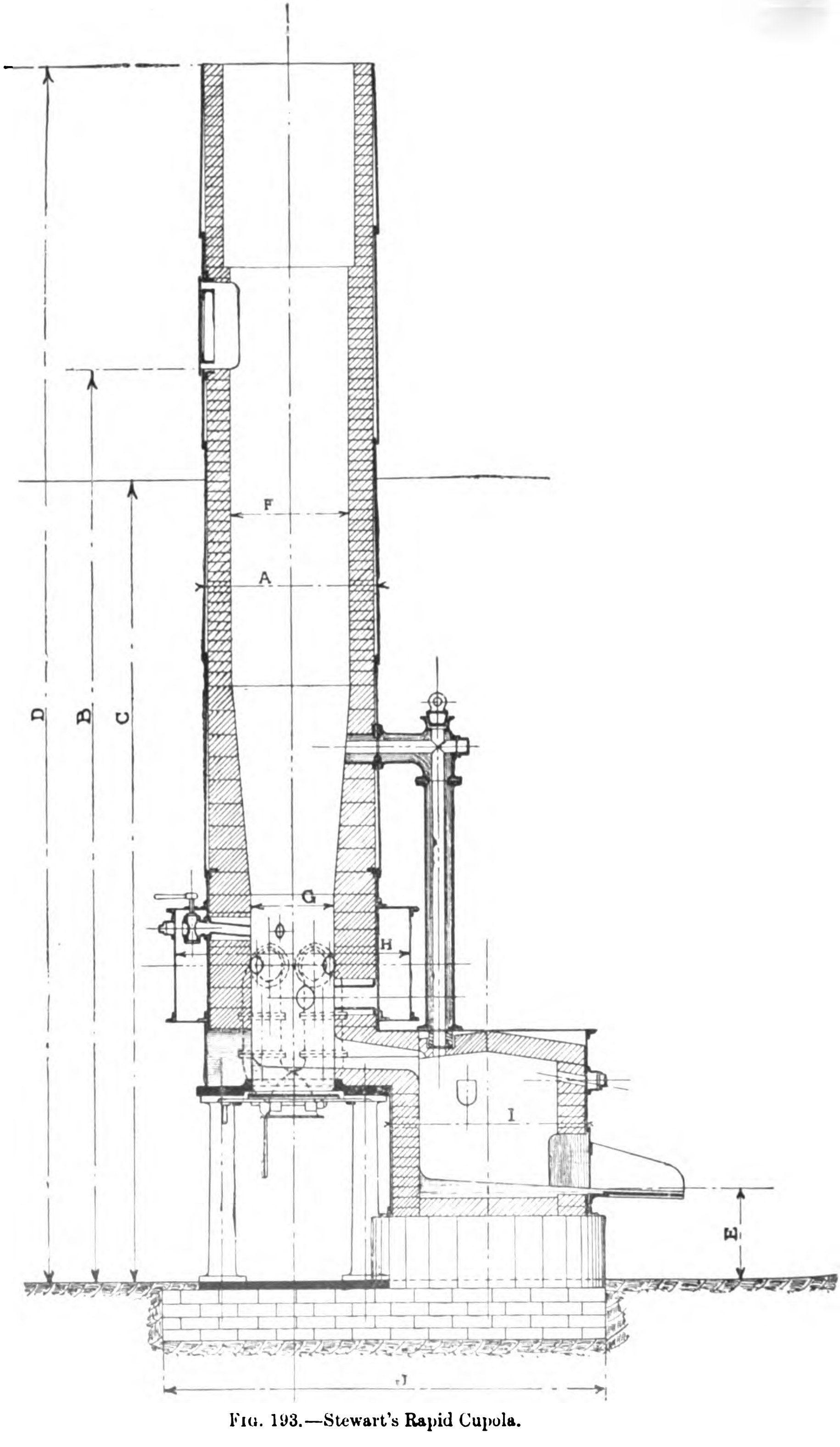

FIG. 193.—Stewart's Rapid Cupola.

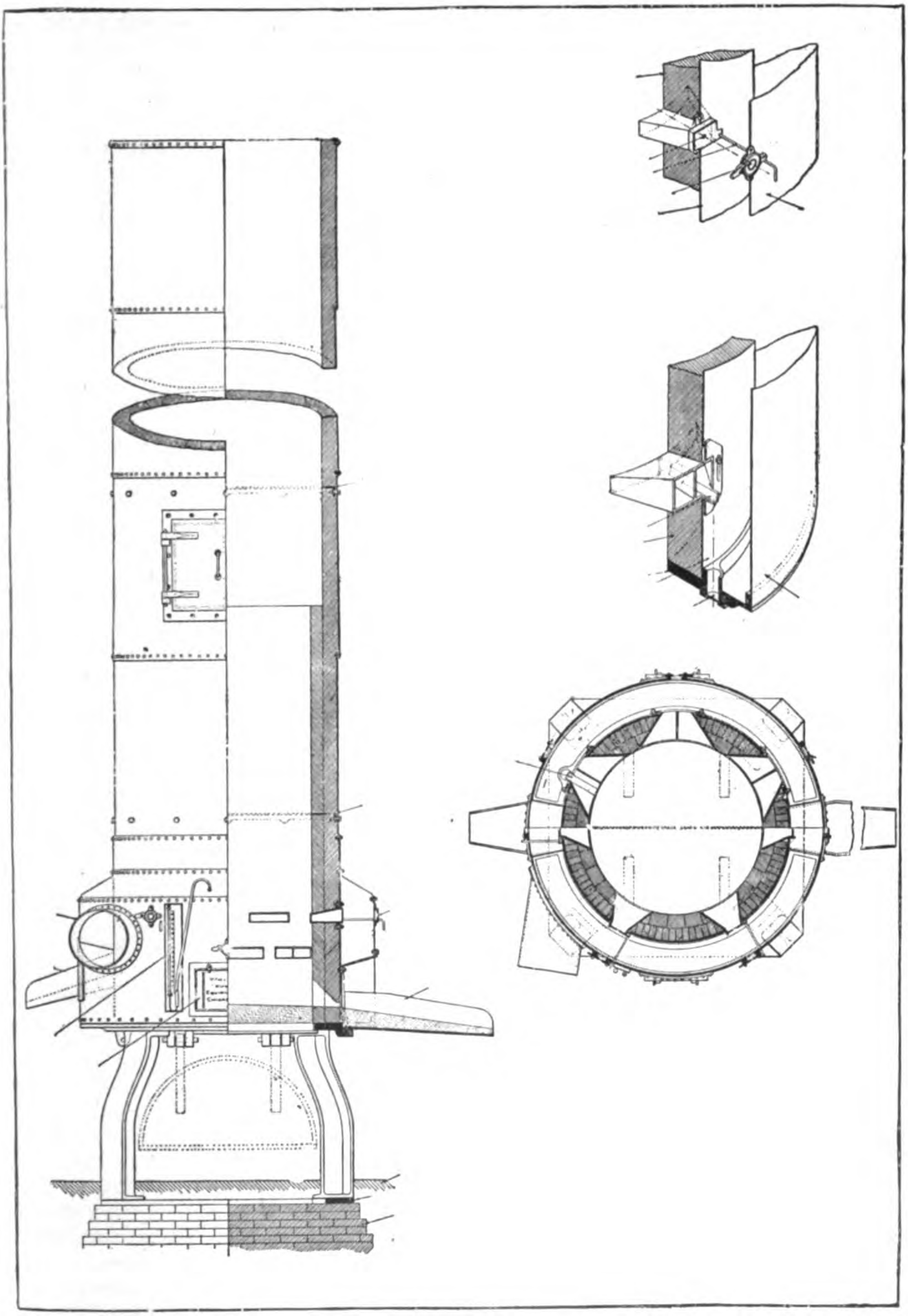

Fig. 194.—The Whiting Cupola.

the latter thin enough to allow the bricks to touch at all points, as wide joints lead to a short working life. If the cupola is lined in sections of 3 or 4 feet in depth, each section being supported on angle-iron rivetted to the inside of the shell, then any one section can be renewed without disturbing the others. For the severe work implied by long or continuous heats the cupola may be partly lined with bricks, dried with a coal fire, and then be rammed with ganister round a short wooden model, raising the model and repeating the ramming till the charging door is reached; then the ganister lining is similarly dried.

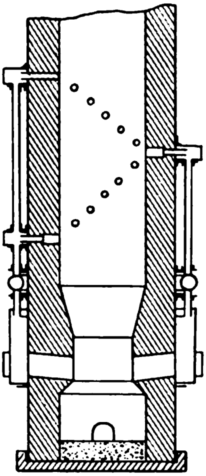
FIG. 195.—Greiner and Erpf Cupola.

The details of the cupolas selected for illustration will be well seen from figs. 193 to 195, and, as an example, the most important figures of a standard type drop bottom cupola may be taken at 44 inches diameter, 12 feet from sole to charging door; 6 tuyeres, 6 inches in diameter, 18 inches from the bottom, and run with a blast pressure of 9 ozs. Volume of blast, not pressure, is the essential point, also that the blast should reach the centre of the cupola; and as, with cupolas of more than 60 inches diameter, this is difficult to effect, the diameter is reduced at the melting zone, or some such device as West's centre blast is used.

There are many varieties of cupola other than those shown here, of which there is only space to mention the Woodward, worked with induced draught by means of a high-pressure steam jet connected with the shaft above the stock line; and the Herbertz, working similarly with induced draught, but drawing the air in through a double casing surrounding the whole of the cupola and with a slot tuyere regulated by having a movable hearth that can be moved up or down, so as to diminish or increase the width of the slot.

The mode of operating the cupola is given in the next chapter. The Stewart Rapid, shown in fig. 193, has a smaller diameter in the melting zone, is fitted with two rows of tuyeres, and has also a receiver for collecting the molten metal, thus giving some of the advantages of an air furnace. This receiver is connected by a ganister lined pipe to the body of the cupola further up, but those we have used seemed to work quite as well with this pipe removed.

CHAPTER XXIX.

MIXING BY ANALYSIS. INFLUENCE OF REMELTING. WORKING THE CUPOLA.

Mixing by analysis, tempered with judgment based on past experience, is steadily replacing mixing by fracture, by guesswork, or by trial. The calculation of mixtures by analysis, given the compositions of the pig-iron and scrap available, and of the castings required and the changes that take place in melting, becomes merely a question of arithmetic. A. M'William, in 1889, at the Sheffield Technical School, being faced by a class of students from works who had to be taught how to calculate more or less complicated mixtures for the manufacture of steel, found some members of that class not sufficiently adept in juggling with figures to make the necessary calculations, set himself to simplify the problems, and designed what has become known to more than half a generation of students as the "pound per cent." method, with its "platform" modification, a method that is still in practice at the Sheffield University, and is daily employed by many in the works. It has been found the easiest also in carat calculations for students of dental metallurgy and for other similar purposes. It should be obvious that the influence of a material in a mixture with regard to any one element is proportional to the weight of that material in the mixture and to the percentage of the particular element it contains. Also, that the combined influence is obtained by multiplying the weight of the material by the percentage of the element. Thus, if 1 lb. of a material containing 1 per cent. of silicon is used in a mixture, 2 lbs. at 1 per cent. silicon would give twice the amount of silicon to the mixture, and 3 lbs. at 1 per cent. 3 times; while 1 lb. at 2 per cent. would give twice, 2 lbs. at 2 per cent. 4 times, and, generally, the number of lbs. multiplied by the percentage they contain gives a measure of their influence on the total; for, indeed, it represents the actual amount of silicon added in hundredths of a pound. This unit is given the name of lb. per cent., to act as a guide in remembering that if the amount be spread over so many pounds, divide by the number of pounds, and the result is the percentage; or divide by the percentage required, and the number of lbs. in which it would produce that percentage is obtained, or:—

$$\text{lbs.} \times \text{per cent.} = \text{lbs. per cent.} \qquad \frac{\text{lbs. per cent.}}{\text{lbs.}} = \text{per cent.} \qquad \frac{\text{lbs. per cent.}}{\text{per cent.}} = \text{lbs.}$$

Any other unit of weight may be used as cwts. per cent. or tons per cent., and any fraction other than hundredths; thus, using carats or twenty-fourths as in jewellery; the unit carat oz. is employed. The problem that has to be faced in the foundry is not the composition of the material as charged, but what the composition will be in the casting; and in cupola work, as in all other melting operations, we are thus at once brought to consider the influence of remelting on the composition of the metal. Everyone must test this under his own conditions, but examples will show the general type of changes to expect. In remelting an ordinary grey iron mixture there is, as a rule, a loss of about 0·2 to 0·3 per cent. of silicon. Unless the total carbon be abnormal, this will not change much; but, if abnormally low, it will tend to increase to a normal amount by reason of contact with the coke, and hence very low carbon mixtures cannot be successfully melted in the cupola; a good reason why the melting of steel-casting mixtures in the cupola, as has been attempted by more than one firm, has not met with success. The manganese will decrease to a variable extent, 0·2 to 0·3 representing a typical loss if about 1 per cent. is present in the charge, while with a low manganese content (like 0·3 per cent.) the loss may be almost *nil*. The phosphorus comes out practically according to calculation; while the sulphur, again, owing to contact with the fuel, will be found to have increased, an increase seldom less than 0·02 per cent., unless with exceptionally pure coke or with a charge initially high in manganese, the manganese in the latter case apparently combining with the sulphur in the metal and taking it into the slag. An interesting article in the *Iron Age*, 19th November 1903, by J. Wangler, St Louis, summarises the experiments that have been published on the influence of the use of manganese ore as a preventive of the absorption of sulphur in cupola melting, the results being mainly those of P. Reusch and of F. Wuest, published in *Stahl und Eisen*. The latter used a 32-inch Herbertz cupola with coke from the Ruhr district, containing 0·7 to 1·3 per cent. S, and added 11 lbs. of manganese ore (91 per cent. MnO_2) and 13 lbs. of limestone to each charge of 80 lbs. of coke and 12 cwts. of pig-iron. The average of 33 tests showed Si, 2·18; Mn, 0·75; S, 0·06 per cent.; the average of 10 tests, with 5½ lbs. of ore, gave Si, 1·75; Mn, 0·65; S. 0·09 per cent.; the slag showed SiO_2, 55; Al_2O_3, 7; FeO, 15; MnO, 12; CaO, 10; MgO, 0·03; S, 0·25 per cent.; whilst during the same period (1901–3) 185 castings, made by 27 different firms, with similar coke, averaged Si, 1·66; Mn, 0·62; S, 0·11 per cent. Spiegel or ferro-manganese added to the charge has a similar effect; and Messrs. Dugald Rennie & Sons, always ready to repeat promising scientific experiments on a commercial scale, ran some special heats to test the matter for this work, and their results generally corroborate the trend of the figures given. There are obvious disadvantages for some cases, such as the scouring nature of the slag or the increase of manganese in the metal; but when the principle is established, these can be weighed up by each one for his own particular commercial conditions.

A special case of a general mixture for light foundry work is given as an example of the kind of test that should be made by the founder to obtain a measure of the changes that take place under his own conditions of working. Analyses were made of the actual consignment of each brand and of the scrap to be used, and, as the charge consisted of equal parts of these, the calculated composition is the simple mean of the results:—

	Wt.	C.C.	Gr. C.	Si.	Mn.	S.	P.
Bestwood No. 3,	1	0·12	3·34	2·78	0·50	0·08	1·20
Renishaw,	1	0·06	3·28	3·34	0·35	0·05	1·51
Parkgate,	1	0·55	2·96	1·84	1·10	0·056	1·34
Staveley,	1	0·14	3·20	3·40	1·20	0·043	1·20
Scrap.	1	0·60	2·85	2·10	0·80	0·094	1·36
Total,	5	1·47	15·63	13·46	3·95	0·323	6·61
Calculated composition,		0·29	3·13	2·69	0·79	0·065	1·32
Actual composition,		0·68	2·70	2·40	0·54	0·098	1·40

The above shows losses of 0·29 per cent. Si, 0·22 per cent. Mn, and a gain of 0·033 per cent. S, whilst phosphorus and total carbon remain practically as charged.

The Calculation of Mixtures.—*Problem* 1.—Take first an example of the simplest case in the calculation of mixtures, namely, given the weights which make up the charge and the percentage of any one element, such as silicon, that each item contains, what is the calculated percentage of silicon in the charge? Let the mixture be 5 cwts. of pig containing 1·92 per cent. Si, 2 cwts. at 2½ per cent. Si, and 3 cwts. of scrap at 1·8 per cent. Si. Multiply each weight of pig or scrap by the percentage of silicon it contains; this gives the cwts. per cent. of silicon added by each. The sum of these numbers represents the total cwts. per cent. of silicon in the charge. Divide by the total weight of the charge, and the result is the percentage of silicon in the mixture, thus:—

Cwts.	×	Per cent. of Si.	=	Cwts. per cent. of Si.
5	×	1·92	=	9·60
2	×	2·50	=	5·00
3	×	1·80	=	5·40
10	×	Per cent. Si in mix.	=	20·00

and $$\frac{20\ \cancel{\text{cwts.}}\ \text{per cent. Si}}{10\ \cancel{\text{cwts.}}} = 2 \text{ per cent. silicon.}$$

Those who do not care for calculations will find that this example, representing only the simplest multiplication, addition and division, contains all that is necessary for testing mixtures to find out what their calculated composition is; and, with the mere extension to other elements and entered in the tabular form shown later, the most complicated mixtures may be calculated without confusion. Thus, a man with good judgment in making mixtures may, with the tabular form shown and by means of the simplest calculations in the whole range of arithmetic, check his judgment by figures, and confirm his mixture or modify it if found desirable.

Problem 2.—When the compositions of the materials are given, and the weights necessary to produce a given composition of charge are required, the problem is of a more confusing type, particularly when several elements are specified, although this also may be converted into the first type by judging what would give the desired result, testing this and modifying according to the result obtained. The authors have found that in even the most complicated cases a third trial is nearly always successful in the hands of the average man. Omitting the judging method, which can be tried by anyone, calculate the weights of the above materials which would make a charge containing 2·0 per cent. of silicon. Look at these materials, not as to their actual content of silicon, but as to their positions above a percentage platform equal in height to the lowest of the three. This, obviously, eliminates the lowest from the calculation, and shows that the weight of the other pig × its height in Si above the platform must equal the weight of the mixture × its height above the same platform. Thus, 1·92 is the lowest and 2·5 is 0·58 above and 2·0 is 0·08 above the 1·92 platform. Hence, weight of 2·5 pig × 0·58 = 7 cwts. × 0·08, and weight of 2·5 pig $= \frac{0 \cdot 56}{0 \cdot 58} = 0 \cdot 97$, or, practically, 1 cwt. The weight of the 1·92 pig required is $\therefore$ 7 − 1 = 6 cwts; and the reader on checking this charge, as in problem 1, will find that it comes to 2·0 per cent.

Problem 3.—Assume that the exact reverse of No. 1 is required, namely, that 30 per cent. of 1·8 Si scrap must be used in a 10 cwts. charge. 10 cwts.

at 2 per cent. require 20 cwts. per cent. Si, but 3 cwts. at 1·8 per cent. will add 5·4 cwts. per cent. Si, leaving 20 – 5·4, or 14·6, to be found in the remaining 7 cwts., an average of $\frac{14·6}{7} = 2·09$ per cent. The lowest of the three remaining is the 1·92 pig and the other is 0·58 above, whilst the 7 cwts. will be 0·17 above; hence

$$\text{cwts. of } 2·5 \text{ pig} \times 0·58 = 7 \times 0·17 = 1·19,$$
$$\text{and cwts. of } 2·5 \text{ pig} = \frac{1·19}{0·58} = 2·05 \text{ cwts.},$$

or, practically, 2 cwts., and the weight of the other = 7 – 2 = 5 cwts.

Problem 4.—Passing to some examples of the type of No. 1, all taken from actual cases extensively used in the foundry, charges for castings which had hydraulic tests to pass, such as those applied to high-pressure valves, consisted of 6 cwts. of Stanton No. IV., 3 cwts. of Gartsherrie No. III., 1 cwt. of Warner's C.B.R. No. IV., and 5 cwts. of foundry scrap.

Material.	Cwts.	Percentage Composition.				Cwts. per cent.			
		Si.	Mn.	S.	P.	Si.	Mn.	S.	P.
Stanton IV.,	6	2·0	0·4	0·06	1·2	12·0	2·4	0·36	7·2
Gartsherrie III.,	3	2·5	1·3	0·03	0·6	7·5	3·9	0·09	1·8
Warner C.B.R. IV.,	1	1·3	0·4	0·05	0·2	1·3	0·4	0·05	0·2
Foundry scrap,	5	1·4	0·6	0·08	0·8	7·0	3·0	0·40	4·0
Mixture,	15	1·85	0·65	0·06	0·88	27·8	9·7	0·90	13·2

Rule out a form, as shown above, leaving a column for names of materials, one for weights used, one for each element to be considered, and one for a cwts. per cent. column for each of the same elements. Leave a number of lines equal to the items in the mixture and one extra for the mixture itself. Under the composition columns enter the corresponding results of analyses. Figures are given that will show the types of the pigs named; but these numbers should, wherever possible, be taken from the compositions of the actual consignments used. Taking the Stanton first, multiply the 6 cwts. in column 2 by the 2 per cent. Si in column 3, and place the result in the 7th column, representing cwts. per cent. Si. Multiply the 6 by the 0·4 Mn in column 4, and record the result in column 8 as cwts. per cent. Mn, the 6 cwts. × 0·06 per cent. S in 5, and record in 9, and the 6 cwts. × 1·2 per cent. P in 6, and enter the result 7·2 in 10 under cwts. per cent. of P. Do the same for all the other constituent parts of the mixture, add up the totals of the several cwts. per cent. columns, divide each by the total number of cwts. in the mixture, and enter in the proper composition column. Thus, the total of column 7 is 27·8 cwts. per cent. Si, and $\frac{27·8 \text{ cwts. per cent. Si}}{15 \text{ cwts.}} = 1·85$ per cent. Si, which is entered in column 3 under Si per cent. Thus, in line with, and immediately following, the total weight of the mixture is found the composition as charged. This form has been tried with success by the authors on many people who are easily confused with calculations.

Problem 5.— Another example of the type of No. 1 may be given without further explanation. The mixture is used extensively for heavy marine cylinders, and consists of 1 cwt. of No. 1 Staffordshire cold blast, 2 cwts. of No. III. West Coast hematite, 2 cwts. of Coltness No. III., and 5 cwts. of good engine scrap, averaging 2·0 per cent. Si; and it will be seen that, with the compositions given, this would calculate to Si 2·14, Mn 0·67, S 0·06, P 0·59, as charged.

Material.	Cwts.	Percentage Composition.				Cwts. per cent.			
		Si.	Mn.	S.	P.	Si.	Mn.	S.	P.
Staffs Cold Blast I., .	1	1·8	1·1	0·02	0·6	1·8	1·1	0·02	0·6
West Coast Hem. III.,	2	2·3	0·3	0·05	0·05	4·6	0·6	0·10	0·1
Coltness III., . .	2	2·5	1·0	0·03	0·6	5·0	2·0	0·06	1·2
Good engine scrap, .	5	2·0	0·6	0·08	0·8	10·0	3·0	0·40	4·0
Mixture, . . .	10	2·14	0·67	0·06	0·59	21·4	6·7	0·58	5·9

This would represent about 1·9 Si, 0·5 Mn, 0·08 S, 0·6 P in the castings.

We shall now attempt a few of the more difficult type, such as Nos. 2 and 3; all these problems have been presented from foundry sources, so that they could not, even unconsciously, have been made to suit the method of calculation.

Problem 6.—Wanted a cheap mixture for stove grate work, the limits being Si 2·4 to 2·7, P 1·0 to 1·3, S less than 0·15. The phosphorus so easily fits the pigs given, the silicon also is a common foundry one, the sulphur is easy, and the limits for a calculation are so wide that we shall not work this out, but leave it to the student for practice.

Problem 7.—The castings are required to contain 2·5 per cent. of silicon, not more than 0·6 of manganese, 0·08 of sulphur, and 1·0 of phosphorus. Previous experience shows that with our conditions of design of cupola, coke used, pressure of blast, and rate of melting, a loss of 0·2 silicon, a loss of 0·2 manganese, and a gain of 0·02 per cent. of sulphur is experienced. The mixture must, therefore, calculate as nearly as possible to 2·5 + 0·2 = 2·7 per cent. Si, 0·6 + 0·2 = 0·8 per cent. Mn, and 0·08 - 0·02 = 0·06 per cent. S.

It has already been pointed out that the first element to consider is phosphorus, as, in any one series of pigs, that element is fairly constant, and we find Holwell with over 1 per cent. P, hematite with 0·05 per cent. or so, and Scotch with 0·7 per cent P; it is obvious, then, that with the pigs shown in Chapter XXVI., either hematite or Scotch may be mixed with the foundry of the district, which we assume to be Holwell. Taking the Holwell at 1·2 per cent. P and the hematite at 0·05 per cent., and assuming that 40 per cent. of scrap from similar work and therefore of the composition desired is used, how much hematite must be added? 600 lbs. of pig are required for each 1000 lbs. charge: working from a 0·05 per cent. P platform

$$\text{lbs. of Holwell} \times 1{\cdot}15 = 600 \text{ lbs.} \times 0{\cdot}95 \text{ per cent. P.}$$

$$\text{lbs. of Holwell} = \frac{570 \text{ lbs. per cent. P}}{1{\cdot}15 \text{ per cent. P}} = 496 \text{ lbs.}$$

and the remainder 600 − 496 = 104 lbs. of hematite. The mixture would thus be 496 lbs. of Holwell, 104 lbs. of hematite, and 400 lbs. of scrap.

Proof.— 496 lbs. Holwell × 1·2 per cent. P = 595·2 lbs. per cent. P.
104 lbs. hematite × 0·05 per cent. P = 5·2 ,, ,, ,,
400 lbs. scrap × 1·0 per cent. P = 400·0 ,, ,, ,,
1000 lbs. mixture × x per cent. P = 1000·4 ,, ,, ,,
∴ x = 1·0 per cent. P.

This platform method can be amplified to almost any extent; the conditions of the work or of the district will generally fix some part of the charge. In the case thought of here the problem was:—using a 1·25 pig of the neighbourhood and our own scrap at 1·0 per cent. P, what is the amount of hematite necessary (minimum amount was the phrase used) to produce castings containing 1·0 per cent. of P?

Similarly, how much Scotch at 0·7 per cent. P would be necessary? As 0·7 is the lowest percentage, we view the others from this platform. Holwell is 0·5 above it, and the mixture must be 0·3 above that; hence

$$\text{lbs. of Holwell} \times 0{\cdot}5 = 600 \text{ lbs. of the charge} \times 0{\cdot}3.$$

$$\text{lbs. of Holwell} = \frac{180 \text{ lbs. per cent. P}}{0{\cdot}5 \text{ per cent. P}} = 360 \text{ lbs.}$$

The mixture, then, is 360 lbs. of Holwell, 240 lbs. of Scotch, and 400 lbs. of scrap, and the result can be checked, as in the other cases. Next, suppose that a charge made up of three different kinds of pig is desired; the problem is indefinite in this case, because it is evident, from the above, that either 24 per cent. of Scotch or 10 per cent. of hematite may be used, each to the exclusion of the other. Now, test the mixture with Scotch for manganese, 240 lbs. @ 1·3 per cent. Mn = 312 lbs. per cent. Mn; 360 lbs. @ 0·6 = 216; and 400 lbs. @ 0·6 = 240; a total of 768 lbs. per cent. Mn, which, divided by 1000 lbs. = 0·768 per cent. Mn. So that if you really must have 0·6 per cent. of manganese in the casting, of the two you must use this mixture, or the hematite one with ferro-manganese or spiegel added; or choose a hematite higher in manganese.

Thus, the fundamentals of the nature of the charge are chosen, and, having settled, for simplicity, on the last shown, the Holwell, Scotch, and scrap (and this part of the choosing may be done once for all, to settle the character of the mixture), then the element most changeable, and yet, probably, most important of all, comes to be dealt with, namely, the silicon. Assume the scrap at 2·5 per cent. Si, the Scotch at 3 per cent., what Si Holwell must be chosen to complete the mixture?

400 lbs. of Scrap @ 2·5 per cent. Si = 1000 lbs. per cent. Si.
240 lbs. of Scotch @ 3 per cent. Si = 720 lbs. per cent. Si.

This makes a total of 1720 lbs. per cent. Si, but 1000 lbs. must contain 2·7 per cent. Si = 2700 lbs. per cent. Si. There is ∴ a deficiency of 2700 − 1720 = 980 lbs. per cent. Si. This must be supplied by 360 lbs. Holwell; hence, the Holwell must contain $\frac{980 \text{ lbs. per cent. Si}}{360 \text{ lbs.}} = 2{\cdot}72$ per cent. Si; and this is found in your stock as Holwell No. 1 foundry. It happens that there is a pig that exactly fits; but if there did not happen to be one, then it becomes a problem of finding, say, two of these pigs that would make up a mixture of 360 lbs. containing 2·72 per cent. silicon.

This is practically the most complicated problem that can occur, and it is seen how it resolves itself into simple ones, always tempered with judgment to select from the materials those that will possibly fit the case. There is no use setting oneself the task of calculating how much mottled hematite should be added to a No. 5 ordinary foundry pig to give a 3 per cent. Si metal for small cylinders. By whatever method you may have arrived at your mixture, whether by trial, by general judgment, or by calculation, as shown here, the result should always be checked by the tabular form, a recommendation worth much when you have made out calculations for steel mixtures containing 5 special elements, as was required of the authors at one time.

Materials.	lbs.	Percentage Composition.				lbs. per cent.			
		Si.	Mn.	S.	P.	Si.	Mn.	S.	P.
Holwell No. I., .	360	2·80	0·6	0·03	1·15	1008·0	216·0	10·8	414·0
Scotch, . .	240	3·00	1·3	0·02	0·71	720·0	312·0	4·8	170·4
Scrap, . .	400	2·50	0·6	0·08	1·00	1000·0	240·0	32·0	400·0
Mixture, . .	1000	2·73	0·77	0·05	0·98	2728·0	768·0	47·6	984·4

Although these figures are as the problem was presented to us, the Holwell pig fits absolutely; but suppose that we had nothing nearer in stock than the one shown as Staveley 2·5 Si, 0·065 S, 1·1 Mn, and 1·30 P, let us see how near this would come to requirements. Form the table as before.

Materials.	lbs.	Percentage Composition.				lbs. per cent.			
		Si.	Mn.	S.	P.	Si.	Mn.	S.	P.
Staveley, .	360	2·50	1·1	0·065	1·3	900	396	23·4	468·0
Scotch, . .	240	3·00	1·3	0·02	0·71	720	312	4·8	170·4
Scrap, . .	400	2·50	0·6	0·08	1·00	1000	240	32·0	400·0
Mixture, .	1000	2·62	0·95	0·06	1·04	2620	948	60·2	1038·4

It is seen that this change gives us a mixture of 2·62 per cent. Si, 0·95 per cent. Mn, 0·06 per cent. S, and 1·04 per cent. P; the use of this tabular form for trying mixtures, either those in use now, or new ones just calculated, or for trying (as we have just done) what difference would be produced by the insertion of so much of some other pig perhaps offered at a favourable price, is very strongly recommended, as it almost prevents error by keeping the necessary figures in a compact form and very clearly defined; it shows the result of any change at once, and in the lbs. per cent. columns shows the actual influence of each item on the mixture as a whole with regard to each element in turn.

Problem 8.—Required a mixture for hydraulic castings giving in the castings 1·4 per cent. Si, 0·75 Mn, 0·6 P, and S not more than 0·08 per cent., which would mean about 1·6 per cent. Si, 0·9 Mn, 0·6 P, and not much more than 0·06 per cent. S. This constitutes a difficult problem if one must keep to cast-iron materials, for, in practically all the pigs shown and in all ordinary makes with silicon at 1·6 per cent., the sulphur is generally above the amount specified, and Swedish pig or American washed iron would be prohibitive, owing to price. One of the low silicon and low sulphur pigs shown in the table of erratic hematites and a type like the Derby brand might suit, but if the use of steel scrap is allowed then it becomes easier. Take the hematite shown as 1·4 per cent. Si, and 0·01 S, 0·02 per cent. P, a rather unusual composition, but the whole series is from careful personal analyses, doubly checked; and Derby at 1·30 per cent. P. Calculating as before, lbs. of Derby × 1·28 per cent. P = 1000 lbs. × 0·58 per cent. P. lbs. of Derby $= \frac{580}{1 \cdot 28} = 453$ lbs., and ∴ 1000 − 453 = 547 lbs. of hematite. The hematite choice in the tables is rather restricted, so 547 lbs. of this hematite is assumed. This adds 547 × 1·4 per cent. Si = 765·8 lbs. per cent. Si; but there are 1000 lbs. × 1·6 per cent. Si = 1600 lbs. per cent. Si required; hence, the 453 Derby must provide 1600 − 765·8 = 834·2 lbs. per cent. Si, and should contain $\frac{834 \cdot 2 \text{ lbs. per cent. Si}}{453 \text{ lbs.}} = 1 \cdot 84$ per cent. Si, and the nearest to this contains about 1·9 per cent. Si. Test the mixture by the form as usual :—

Material.	lbs.	Percentage Composition.				lbs. per cent.			
		Si.	Mn.	S.	P.	Si.	Mn.	S.	P.
Hematite, . .	547	1·4	0·7	0·01	0·02	765·8	382·9	5·47	10·94
Derby, . .	453	1·9	0·6	0·12	1·3	860·7	271·8	54·36	588·9
Mixture, . .	1000	1·63	0·65	0·060	0·60	1626·5	654·7	59·83	599·84

This would come very close to the requirements, only the Mn would be rather low ; and should this be rigidly required up to specification, if a suitable pig low in Si, S, and P could not be found, it would be easy to add a small proportion of ferro-manganese to the charge, the amount of which the student could now easily calculate.

Problem 9.—Take the same case as last, only allow the use of 20 per cent. of steel scrap from ship plates and 30 per cent. foundry scrap from a similar mixture, the steel scrap being taken at C 0·2, Si 0·02, Mn 0·5, S 0·05, P 0·05. This assists in lowering the silicon without raising the sulphur content ; and it is evident that, roughly, we may take this as a normal hematite phosphorus, taking the first table of hematites at 0·05 per cent. P. As before, Derby required $= \frac{700 \times 0 \cdot 55}{1 \cdot 25} = 308$ lbs. We shall try to use the Staveley shown, to help up our Mn, and first take stock of lbs. per cent. Si so far, namely, 200 steel at 0·02 = 4 (what a boon we have here at once for a low silicon mixture !), 300 scrap at 1·4 = 420, 308 Staveley at 2·5 = 770 ; total, 1194 out of a total required of 1600 ; so that the hematite must add 1600 − 1194 = 406 lbs. per cent. Si; and this from 192 lbs. hematite means that it must contain $\frac{406 \text{ lbs. per cent. Si}}{192 \text{ lbs.}} = 2{\cdot}11$ per cent. Si; thus we have our 2·1 Si, 0·72 Mn, 0·04 S, 0·04 P. What a difference this 20 per cent. steel scrap makes to a low silicon, low sulphur mixture, for, after bringing it in, we can select among the pigs containing over 2 per cent. Si for the remainder, and thus find it easier to get low sulphurs. Test as before.

Material.	lbs.	Percentage Composition.				lbs. per cent.			
		Si.	Mn.	S.	P.	Si.	Mn.	S.	P.
Staveley, . .	308	2·5	1·1	0·06	1·30	770·0	338·8	18·48	400·4
Hematite III., .	192	2·1	0·72	0·05	0·05	403·2	138·2	9·60	9·6
Steel, . . .	200	0·02	0·6	0·05	0·05	4·0	120·0	10·0	10·0
Home scrap, .	300	1·4	0·75	0·08	0·6	420·0	225·0	24·00	180·0
Mixture, . .	1000	1·60	0·82	0·062	0·60	1594·2	822·0	62·08	600·0

This should melt out as close to the specification as need be desired; which specification, from being an awkward one to fulfil with ordinary pig and cast-iron scrap, becomes easy with the use of 20 per cent. of steel scrap; the calculation also shows the nature, as to composition at any rate, of the beneficial effect of steel scrap in cupola charges.

Operating the Cupola.—Previous to a heat the cupola is chipped out, projecting knobs of slag, etc., removed, and all worn places patched with fire-clay or ganister, preferably the latter. In an iron foundry running daily heats, this is usually done the first thing in the morning. The next stage is to fix the bottom doors in position. Cupolas of small sizes have the bottom doors supported by means of a bolt, with a ring head, into which a hooked bar can be inserted for withdrawing the bolt and dropping the bottom. Cupolas of larger size, however, must have the additional support of props between the foundation plate and the under side of the door. The necessity for this will be seen when it is recognised that the bottom doors have to carry the full weight of the charge. After hooking and propping the bottom doors, the sand bottom is put in. For this purpose the foundry floor sand or black sand is used. It should be passed through a ¼-inch riddle, and be of the same degree of dampness as is usual for moulding, that is, the sand should be sufficiently damp to cohere when pressed together, but not actually wet. The doors are brushed over with water or clay-water, the sand spread on them and evenly rammed. The best plan is to ram, in courses of 2 inches deep, and tuck the sand into the interspaces between the fire-brick lining and the doors, by means of the fingers. The whole of this bottom must be perfectly solid without being dead hard. If too hard or wet, the molten iron will blister or scab the sand, thereby leading to leakage. In this respect precisely similar conditions hold as in the case of a sand mould. The requisite slope to the bottom is given, and should be such as completely to drain the metal to the tap hole. The surface of the bottom is then carefully traversed by the fingers in order to detect any soft places, which should be made good. The face of the sand bottom may then be brushed over with clay-water or blackwash. In the case of a cupola not fitted with a drop bottom, the foregoing procedure is, of course, omitted. Such a bottom may be put in to last over a number of heats, but the breast and tap hole have to be made up each heat. To effect this, a piece of round iron of the diameter required in the tap hole is laid in position and a wall of coke built level with the inside of the cupola lining. The front of this coke is rammed with sand level with the casing; the breast plate placed in position over the sand, and wedged between snugs fixed in the casing. The tap hole and spout leading from it are then made up with moulding sand. The spout should have a fall of about 1 inch per foot in order to drain. On completing the heat the breast plate is removed, the sand broken away, and the cupola raked out by means of a long-handled rake. Solid bottoms, though largely used in Britain, are not nearly so convenient as drop bottoms. The latter are in general use in the United States of America, and within the last few years have been largely adopted in Britain. Generally, drop bottom cupolas have a fettling door opposite the spout; therefore, after the bottom is put in, the door must be made up. A wall of coke is built in level with the lining, and the fire kindled in the cupola. Air is drawn through the fettling door until the fire is well started, the door is then made up precisely as in the case of a draw front cupola, except that no tap hole is required in it. One tap hole is ample for any cupola, but, in certain cases, two are provided, one being fixed for crane ladles. The size of a tap varies with the size of the cupola. In some instances the tap hole is left open throughout the heat, while in others the hole is plugged and opened again when the required quantity of the metal has accumulated. When stopping a tap hole a mixture of clay and sand is pressed in the form of a cone on to an iron bar, termed a bod stick, and this forced into the tap hole. If clay is used alone, it is apt to bake hard, and the next tap will be difficult. A mixture of one-third sand and two-thirds clay will not bake hard, and is easily opened out again by a tapping bar. Slag holes, when fitted to a cupola, are made up in similar manner to the tap holes. These holes are placed just below the tuyeres, and, when it is required to draw off the slag, metal is accumulated in the cupola until it reaches the bottom of the slag hole, which is then opened by a tapping bar and the slag runs out.

In charging a cupola it is always advisable to weigh all materials entering the furnace. This practice is now almost universal, and the plan of mixing by analysis is also being adopted by the more progressive firms. The first step is to determine the height of the coke bed, which can only be done by actual trial. In starting a new furnace it is well to start with a comparatively high bed, and gradually to decrease it until the right height is found. With the bed too high melting is slow, and with the bed too low the iron is dull and lifeless. Just as no rule can be given for the amount of the bed coke, neither can one be given for the subsequent charges of iron and coke. These features can only be determined in practice; but, as with the bed so with the charges, it is better to err on the safe side by commencing with comparatively light charges of iron to rather heavier charges of coke, until the conditions most suitable to the cupola are found. Special attention is drawn to this aspect of trial, because experience with many types of cupola is convincing that no set of advantageous rules can be given. At the best, the cupola is an empirical apparatus, and the conditions most suitable to each particular furnace must be ascertained by trial and then rigidly adhered to. Similar remarks hold good for the fuel ratio, and many published figures are truly misleading. On paper, pig-iron may be melted with very little coke. In practice, 2 cwts. per ton, or a 1 to 10 ratio, represents excellent work. The ratio will, however, vary according to the class of casting. Thus, while 1 to 10 represents excellent practice for large work, 1 to 8 may be necessary for light or thin castings. Melting ratios are expressed in two ways: in Britain, usually as so many cwts. of coke per ton of iron melted; and in the United States, more generally as 1 to some number, thus 1 to 8, meaning that one part by weight of coke has been used in melting 8 parts by weight of metal. There are many difficulties in the way of settling what is good practice with regard to coke consumption, and this cannot be done by merely stating the melting ratio, for, not only must due consideration be given to the types of castings made, but also to the total weight melted at each run and its duration in time for the cupola in use. In West's moulder's text-book details are recorded of 47 different heats from 46 firms, and the average consumption of coke works out at 2·7, or, practically, 2¾ cwts. per ton, a 1 to 7½ ratio; although for one run, in which 70,000 lbs., or a little over 31 tons, were melted, a ratio of 1 to 11 is shown. Kirk says that a 1 to 8 ratio with Connelsville coke is good melting. R. Buchanan, in a paper on "The Foundry Cupola and How to Manage it," read before the Staffs I.S.I. in 1901, gives his ratio, over 1 month, when with Messrs. W. & T. Avery, as 1 to 10 for heavy castings, 1 to 7·87 for light castings, with an average of 1 to 8·49 for the month; and sets out details of a typical run as under:—

Inside diameter of cupola 36 inches, contracted to 19 inches at bottom; two rows of tuyeres 78 square inches total area; melts over 4 tons per hour, and 20½ tons have been melted in one afternoon; height from bottom plate to charging door 15 feet, cupola full to charging door when 50 cwts. of iron in; blast pressure 8 to 10 ozs., and 24 to 28 lbs. limestone put on top of each charge of coke.

SYSTEM OF CHARGING.

1.	Bed coke,	5 cwts.	7.	Coke,	1½ cwts.
2.	Iron,	10 ,,	8.	Iron,	10 ,,
3.	Coke,	1½ ,,	9.	Coke,	1½ ,,
4.	Iron,	10 ,,	10.	Iron,	10 ,,
5.	Coke,	1½ ,,	11.	Coke,	1 ,,
6.	Iron,	10 ,,	12.	Iron,	10 ,,

and so on; until after the second last charge, when only 56 lbs. of coke is put on. Metal appears in about eight minutes after the blast is put on, and is hot enough to run castings sometimes under ⅛-inch in thickness.

It is well worth while making a few calculations on this record, for it is obvious that, if stopped at 3 tons, it gives 3·83 cwts. per ton, or a 1 to 5·2 ratio; if at 10 tons, then 2·55 cwts., or a 1 to 7·8 ratio; if at 15 tons, 2·37 cwts., or a 1 to 8·4 ratio (practically Mr. Buchanan's mean); and, taking the afternoon on which the cupola melted 20 tons, it is 2·28 cwts. per ton, or a 1 to 8·7 ratio.

Another series of heats before us is worked on a system of 7 cwts. of bed coke and charges of 10 cwts. of iron to 1 cwt. of coke; but, after every third cwt. of coke, a double weight of iron is charged, and generally a 1½ weight of iron for the final charge of the run, the metal being used for light work. Owing to the necessities of the melting, as a rule this system has to be stopped after running down about 3¼ tons, and hence shows a consumption of 3·38 cwts. per ton, a ratio of 1 to 6; whilst, when it is possible to run on to 7¼ tons, the same system shows 2·34 cwts., or a 1 to 8·53 ratio. A careful consideration of the essentials indicated in these or any similar reliable records, from the points of view given here, will enable anyone to make a just comparison between them and his own practice; but melting ratios obtained by experiment should at least occasionally be checked by comparison with a half-yearly or other balance sheet, the only true judge; and in all contemplated change in practice it must ever be kept in mind that not melting ratios, but the providing of metal in its best state for pouring into the moulds prepared, is the aim and object of the cupola, and that a small saving in coke, which produced an increase in wasters, would be but doubtful economy.

CHAPTER XXX.

FURTHER TREATMENT OF CAST-IRON.

ANNEALED METAL—BLACKHEART AND MALLEABLE CAST-IRON.

THE varieties of cast-iron have already been dealt with, and there remains the further treatment of cast-iron castings as distinct from castings in general. This further treatment is a heat treatment, and it may be necessitated either by the casting being harder than desired, or it may be an essential part of the process designed from the start, as in the making of malleable cast-iron. There are thus two distinct classes—(A) Cast-irons pure and simple, made and sold as such; (B) Malleable cast-irons.

Annealed Metal.—The material coming under section A consists of ordinary grey or mottled iron castings, some of which, owing to their configuration, are liable to have serious internal stresses, which are apt at any time to cause the fracture of the casting. Again, these castings may be hard to machine, and particularly so on the skin, owing to the chilling action of the sand on metal within certain limits of composition. Judicious heat treatment will not only render the hard places soft, but will also diminish or remove the internal stresses. The treatment is simple, for, by heating to a good red heat and cooling slowly, a new crystalline formation is given to the iron, which relieves the stress; and the carbides of iron, which were the cause of the hardness, are decomposed into free carbon and iron.

Certain small intricate castings also, such as are used for textile machinery, table forks, harness fittings, etc. (which are so thin that they are apt to be chilled), are subjected to this simple annealing to soften them, and they are then sometimes called black metal castings.

It must, however, be remembered that annealing grey iron greatly reduces its strength, often to about half of what it was before annealing. Tests carried out by P. Longmuir showed that a cast-iron, with its carbon mainly graphitic, and of 11·4 tons tenacity, stood only 6·7 tons after annealing for four days; a loss in strength of 4·7 tons per square inch. W. H. Hatfield, in his memoir, cited later, shows three cast-irons (Si 2·5, Gr.C. 2·4, C.C. 0·8) which stood an average of 8·5 tons per square inch as cast; but, when annealed, had Gr.C. 3·24, C.C. 0·06, and only stood 4·5 tons per square inch. It is also worth noting that annealed grey irons have a coarse open grain.

Blackheart and Malleable Cast-Iron.—With regard to section B, malleable castings, there are two distinct varieties, namely, blackheart and ordinary malleable. Both these varieties are malleable, and possessed of considerable strength when properly made. The fracture of the blackheart consists of a black inside and a silvery outside, and in a good specimen the black "heart" has a silky lustre. The fracture of ordinary malleable is similar to a close-grained mild steel, and has a distinctly steely appearance. The difference between the two varieties is due to the different principle involved in their manufacture. In each case, before annealing, the castings consist of hard white iron, containing 3 to 4 per cent. of carbon as hard carbide of iron. In the blackheart process, the object of the manufacturer is to decompose the carbide of iron into free carbon (amorphous or annealing carbon) and iron, thus obtaining a soft malleable product, which still contains practically the whole of the initial carbon, only as free carbon merely intermixed with the iron, instead of as combined carbon, hard carbide of iron. In the ordinary malleable (Réaumur) process, the idea is to eliminate the carbon by packing the hard white castings in some oxidising substance, thus producing material similar to wrought-iron; in fact, where pure iron is used, a well-made malleable casting is similar in analysis to wrought-iron. The Réaumur malleable is the variety which, up to the present, has been principally made in this country, whilst blackheart is almost the only product of the American malleable foundries. This seems mainly due to the local conditions and to the composition of the irons at the disposal of the manufacturers in the respective countries. It is well known that sulphur is not injurious to the typical malleable castings of this country, the authors having come across a sample containing 0·5 per cent. which still bent double. It has already been pointed out that white irons produced by the English hematite blast furnaces are high in sulphur, but they are suitable for the manufacture of Réaumur malleable. In blackheart malleable, sulphur has a deadly influence, in some way preventing the precipitation of the free or annealing carbon. The low silicon irons of America, being generally lower in sulphur, it seemed a natural consequence that blackheart should be manufactured there, as the operation of changing the condition of the carbon requires much less time than the elimination of the carbon.

The Production of Ordinary (Réaumur) Malleable Cast-Iron.—The iron used is generally a mottled white of the following composition:—Total carbon, 3½ per cent.; manganese, 0·1 to 0·2; silicon, 0·5 to 0·9; sulphur, 0·25 to 0·35; and phosphorus, 0·05 to 0·08.

This iron is melted in the crucible, in the cupola, in the air furnace, or, in rare cases, in the Siemens furnace, but the cupola is the furnace most generally used in this country. Below is appended an interesting series of analyses, showing approximately the influence of remelting by the several processes. The rather large increase in sulphur by the crucible process is due to the fact that for producing malleable cast-iron the crucible is not a closed vessel, no lid being used, the charge when put in coming above the top of the crucible, and thus being in contact with coke.

Original Pig-iron.	Crucible.	Cupola.	Reverb.	Siemens.
C 3·5	3·4	3·4	3·2	3·2
Si 0·85	0·82	0·75	0·65	0·70
Mn 0·20	0·10	0·10	0·10	0·10
S 0·25	0·30	0·31	0·27	0·26
P 0·05	0·05	0·054	0·052	0·05

Whatever furnace is used, it is necessary to have the metal fluid enough to fill the most intricate parts of the moulds to be poured in any one batch. Moulding operations are similar to those of the grey iron foundry, provision being made for the narrow range of fluidity and the high contraction of white iron, about $\frac{1}{4}$ inch to the foot, although as the blackheart castings during annealing expand $\frac{1}{8}$ inch per foot, for these the same shrinkage allowance on the pattern as for ordinary grey iron is given. The castings are allowed to set, and then the runners are either knocked off when the casting has just set, or, after it has gone cold, according to the nature of the casting, remembering always that this type of iron, when just set, is more than ordinarily weak. The amount of feeder necessary to make a solid casting is very variable, and may range from 25 per cent. to 125 per cent. of the weight of the casting. One strong feature of the skill of the moulder is brought out in being able to make a solid casting with a minimum weight of metal.

Having obtained the castings as hard brittle white iron, they are next barrelled or otherwise dressed to remove the sand, and they are then ready for annealing. The annealing ovens, of which a simple type is shown in fig. 196, are built to contain one to eight tons of malleable castings, and are generally heated with coal, although many are now to be found gas-fired. A common type of oven consists of a rectangular chamber, with fire grates at each corner placed below the floor level. The flames enter the chamber at the floor level, pass towards the middle, and are drawn out at the roof by means of a flue running down the centre.

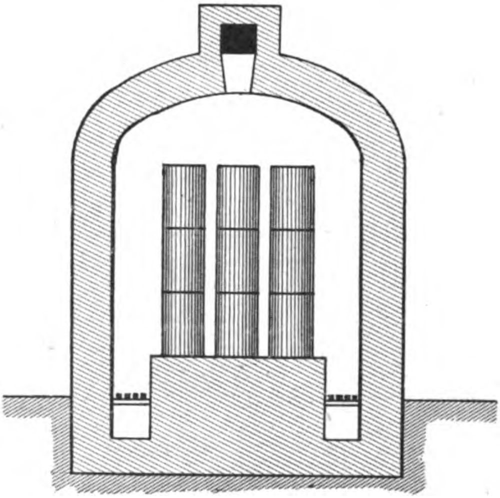

FIG. 196.—Annealing Oven.

In many cases the products of combustion from the fires are conducted through series of flues somewhat analogous to the most modern coke ovens, or to the Clinch-Jones furnace, shown in fig. 197, the object being, in each case, to give a uniform heat to the whole of the oven. The dimensions of ovens vary with the output; an oven capable of holding a large number of pots would measure internally 12 feet × 15 feet × 6 feet in height. The castings are packed in "pots" or pans with iron ore, stacked in the ovens, and raised to the necessary heat. The pans, which may be round, square, or rectangular, as most suited to the forms of the castings, are generally made of cast-iron, and are used over and over again. An average size of pot for small castings would be 15 inches diameter × 23 inches in depth. The ore used is red hematite, broken up finely, but never used all new, as it seems to act too energetically as an oxidiser, and, generally, one part new ore is added to several parts of ore that has been used before, the two thoroughly mixed, and the castings carefully packed so that no two castings are in contact. The oxygen from this ore oxidises the carbon in the castings, and thus gradually eliminates that element. The ore previous to use is red oxide of iron (Fe_2O_3), but after the

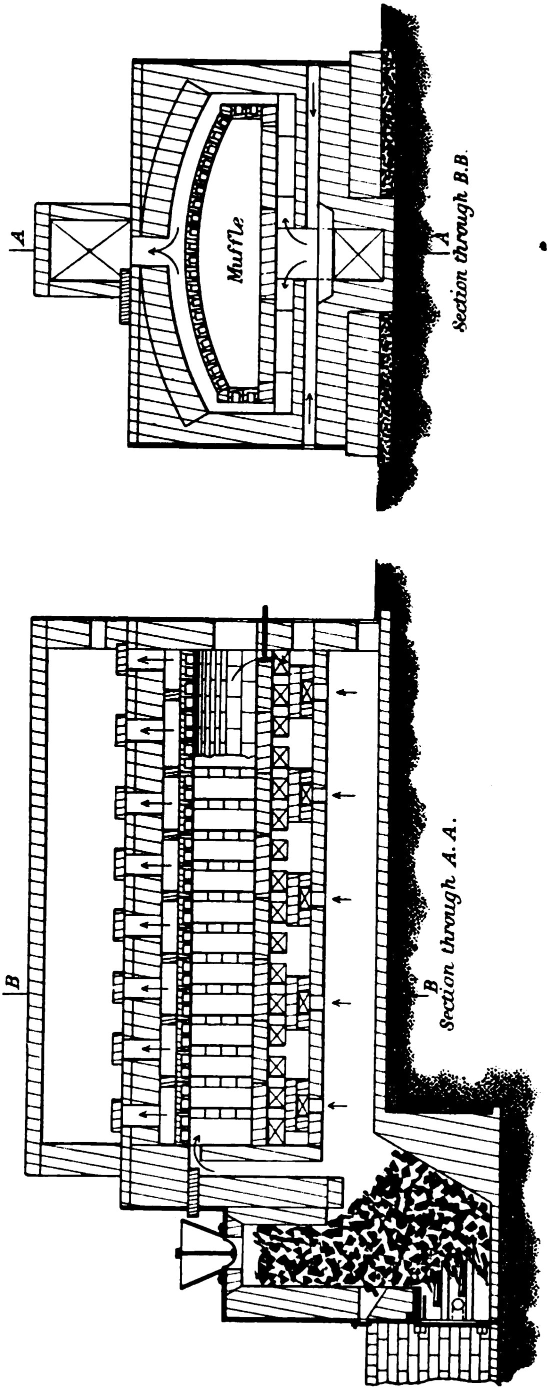

Fig. 197.—Clinch-Jones Patent Heat-Treatment Muffle.

annealing process it is found to be black, and to correspond to the formula Fe_3O_4; but amongst this are frequently found particles of metallic iron which have been reduced from the ore, presumably by the carbon monoxide produced during the annealing. With regard to the height and duration of temperature for annealing, as the process is broadly intended to remove the carbon, it will be evident that thin castings will be more quickly annealed than thicker ones; the time for very light work is generally about two to three days heating to the temperature, twelve to twenty-four hours at the temperature, and two to three days cooling. For thicker work the heating up and letting down occupy about the same time, but the heat is maintained for a period increasing with the thickness of the castings up to about four days.

Naturally, these times will also vary somewhat with the size of the oven, and, as a rule, it will be found that the larger ovens produce the best work. The temperature curve of one of these ovens would be of the order of fig. 198, although some makers anneal at as low a temperature as 850° C.

Within reasonable limits the chemical composition of the castings in this process has little bearing on the result, provided they are white iron as cast. The carbon at the commencement should be 3 per cent. or upwards, the silicon may be anything from 0·3 to 0·9, the sulphur from 0·05 to 0·5, and the phosphorus should be under 0·1. Manganese is the evil genius of the process, and causes trouble if in excess, say more than 0·5 per cent.

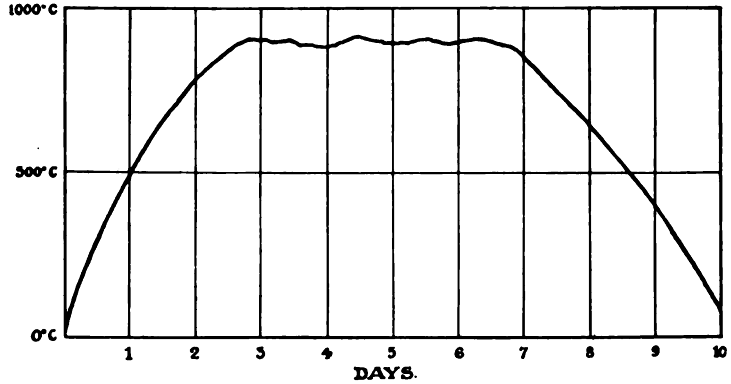

FIG. 198.—Temperature Curve of Annealing Oven.

Castings made by this process give on the testing machine a maximum stress of 18 to 22 tons, with an elongation of 2½ to 6 per cent. on 2 inches, and a reduction in area of 3 to 8 per cent., with a cold bend on ½-inch square of 45 to 90°, although special samples give higher results; and one commercial casting, tested and analysed by P. Longmuir, gave 27 tons M.S., 5·7 per cent. elongation on 2 inches, and 10 per cent. reduction in area; it contained 0·65 per cent. Si, 0·15 per cent. Mn, 0·3 per cent. S. and 0·04 per cent. P.

With regard to chemical composition, the carbon only is affected by the annealing, being considerably reduced in amount, and what remains is partly free and partly combined. A good sample showed combined carbon 0·4 per cent. and free carbon 0·6 per cent.

Blackheart.—The production of blackheart requires greater skill in manipulation and more scientific knowledge than is required for the production of

Réaumur metal. The iron used is of a somewhat different type. It must be low in silicon, but need not necessarily be a white iron, its chemical composition being the necessary feature. The analysis should approximate to carbon 3 per cent., silicon 0·5 to 1 per cent., sulphur 0·05 as a maximum, phosphorus 0·1 as a maximum, and manganese not exceeding 0·5 per cent. The principle involved is the making of a white iron casting of a suitable composition, heating it to a high temperature, and thus converting the iron to the malleable condition by precipitating the carbon in a fine state of division as annealing carbon. The higher the temperature, the shorter the anneal; but it has been found in practice more reliable to use a lower heat and a longer anneal, as the change can thus be made more certain. The process is similar to the other in its general aspects, excepting that it is usual to pack in scale instead of in ore; and, as an oxidising medium is not necessary in this case, bone dust, sand, and even fire-clay are sometimes used.

The composition of the casting after annealing is only altered in the carbon, the total content being somewhat lower and practically all present in the free state; the composition and tests of a sample by one of the largest makers in the kingdom being Si 0·50, Mn 0·4, S 0·04, P 0·07, Gr.C. 2·5, C.C., 0·05 per cent.; a test piece of section ½-inch square, bent through 180° cold, and the tensile test registered M.S. 20 tons per square inch, elongation 6 per cent. on 2 inches, and reduction in area 9 per cent.

Blackheart is not so reliable for heavy work as for light; and, to avoid the introduction of sulphur, it is usual to melt the pig-iron in the air furnace.

An important point to remember is that the shrinkage in the finished casting is only half that in the Réaumur process, owing to the expansion produced by the precipitation of the annealing carbon.

Those who wish to go further into detail with regard to the changes underlying these processes are recommended to digest the following papers:— G. P. Royston on "Malleable Cast-Iron" and on "The Relation of Carbon to Iron at High Temperatures" (*Iron and Steel Inst. Journ.*, 1897, I., pp. 154–190); G. Charpy and L. Grenet on "The Equilibrium of Iron-Carbon Systems" (*Bull. Soc. d'Enc. l'Industrie Nat.*, Mar. 1902); P. Longmuir on "The Influence of Varying Casting Temperature on the Properties of Steel and Iron Castings" (*Iron and Steel Inst. Journ.*, 1904, I., pp. 420–436, which is summarised with other matter in Chap. XXXVII.; and W. H. Hatfield on "The Influence of the Condition of the Carbon on the Strength of Cast-Iron as Cast and Heat-Treated" (*Iron and Steel Inst. Journ.*, 1906, II., pp. 157–188).

Special attention should be paid to some of Charpy and Grenet's conclusions, noting well, before attempting to apply them, the particular conditions under which the experiments were made. The compositions of the irons used are shown in the following table; practically the only element which was varied in amount was the silicon:—

No.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.
1	3·60	0·07	0·03	0·01	traces
2	3·40	0·27	traces	0·02	0·02
3	3·25	0·80	traces	0·02	0·03
4	3·20	1·25	0·12	0·01	0·01
5	3·30	2·10	0·12	0·02	0·01

These irons were poured into cold water, and (excepting the last, which had 0·20 per cent.) contained no appreciable amount of graphite. Samples of these were subjected to various reheatings; and, to ascertain as nearly as practicable the condition at any one temperature, the samples were quenched at that temperature and then analysed. Some of their conclusions are as follows:—

1. The temperature at which the separation of graphite begins is lower the higher the silicon content. Thus, No. 1 heated to 1100° C. or any lower temperature for long periods gave no graphitic carbon, but at 1150° C. the separation of graphitic carbon was produced. No. 2, heated for four hours each at 700°, 800°, 900°, and 1000° C., showed no free carbon; but it appeared on heating to 1100° C. No. 3 showed traces at 800°, Nos. 4 and 5 at 650°; and in the case of No. 5, after heating at 650° for six hours, the content of graphitic carbon had increased from 0·10 to 2·83 per cent.

2. The separation of graphite, once commenced, continues at temperatures inferior to those at which the action begins. Thus, a sample of No. 1, heated to 1170° and quenched, contained only 0·50 Gr.C. and 2·6 C.C.; while another sample of the same cast-iron, heated at the same time to 1170°, cooled slowly to 700°, and then quenched, contained 1·87 Gr.C. and 0·43 C.C. Again, a fragment of No. 3, heated to 1170° and quenched, contained 1·42 Gr.C. and 1·69 C.C.; while another fragment, heated to 1170°, cooled slowly to 700°, and then quenched, contained 2·56 Gr.C. and 0·38 C.C.

3. At a constant temperature the separation of the graphite is effected progressively at a rate that is the more gradual the lower the temperature or the less the silicon content.

These authors also show, with regard to critical points, that their cast-irons have the usual carbon change point about 700°, but that there is another well-marked arrest in heating at 1140°, 1165°, 1137°, 1165°, and 1165° C. for Nos. 1, 2, 3, 4, and 5 respectively, and similarly in cooling at 1120°, 1145°, 1130°, 1137°, and 1145° C.

In W. H. Hatfield's important memoir there are many points of interest, but specially noteworthy are the results on the 6 bars, all of composition C.C. 0·08, Gr.C. 2·83, Mn 0·22, Si 1·0, S 0·04, P 0·04 per cent., which were all white irons as cast, but were variously heat-treated, so as to give the same composition to analysis, but to have the free carbon in all states of division from fine in No. 1 to coarse in No. 6. Bars 1 inch square × 18 inches long were tested transversely on knife edges 12 inches apart, and gave No. 1, $2\frac{1}{4}$ inches; No. 2, $1\frac{5}{8}$ inch; No. 3, $1\frac{9}{16}$ inch; No. 4, $1\frac{5}{16}$ inch; No. 5, $\frac{13}{16}$ inch; No. 6, $\frac{5}{8}$ inch deflection before fracture, the gradually decreasing deflections given being due entirely to the increasing coarseness of the free carbon. Another set of 4 test bars, containing 0·45, 0·90, 1·10, and 1·88 per cent. of silicon, but otherwise similar in composition to the above, and then heat-treated, so that all should have the same type of free or annealing carbon, gave practically the same numbers, namely, 95°, 98°, 94°, and 89° respectively, when subjected to the ordinary bending test. The microstructure of these bars consisted of ferrite, or silicon ferrite, speckled with annealing carbon, which, if kept of suitable structure, affects the malleability little more than does the slag in the case of wrought-iron. He also shows that pearlite, when present, after heat-treating white irons, greatly increases the tenacity; one sample had a tenacity of 32·6 tons per square inch, with an elongation of 6·0 per cent. on 2 inches and a bending angle of 90° when treated so as to leave 0·35 per cent. of carbon in the combined form and present as pearlite in the structure; while another sample, of the same general composition, but treated to leave only 0·06 per cent. as combined carbon, had a tenacity of 21·2 tons per square inch, with an elongation of 11 per cent. on 2 inches and a bending angle of 180° unbroken. These results have been obtained at Messrs. Crowley & Co.'s, under works conditions, by Mr. W. H. Hatfield, an old student of the Sheffield University, and they show what can be done by the application of the methods of science to ordinary works practice.

CHAPTER XXXI.

HIGH TEMPERATURE MEASUREMENT.

ONE of the most noticeable features of recent years is the way in which pyrometers, or instruments for measuring comparatively high temperatures, have won their way into the most conservative works. For every inquiry about pyrometers and their application to metallurgical manufacturing purposes received fifteen years ago, there are fifty such to-day, and a like proportion seems to exist with regard to the numbers of actual applications of pyrometers to manufacturing processes. The history of the development of apparatus for measuring temperatures higher than those that can be conveniently registered by the mercurial thermometer is one of absorbing interest, but to deal with it fairly would require too much space, and demand a very considerable degree of attainment in mathematics and physics. Happily, no more than a short summary need be given here, because the subject is very thoroughly treated in *High Temperature Measurement*, by Le Chatelier and Boudouard, translated into English, with additions, by Burgess; and all interested in the more theoretical points are advised to study that work. In this chapter only such expositions will be given of the underlying principles on which the different pyrometers are based, as seem desirable for the intelligent application of the various types to industrial work. Also, only those examples that have come within the authors' own experience, and that seem to give promise of being of practical use in the foundry, will be described.

It can hardly be doubted that the oldest pyrometer of all is an optical one, namely, the human eye, and one can have very little notion of the antiquity of its use to measure the temperatures of bodies by the colour of the light they emit; and probably, at the present day, it is the pyrometer that is most extensively used. How early such precautions to attain a greater degree of accuracy as doing work in a semi-dark place, or at least taking care that the tell-tale light from the article is not asked to compete with direct sunlight, cannot even be surmised. The errors of this instrument, apart from any inherent structural defects, come mainly from lack of the training of experience or of temporary aberration in the brain to which it is attached, or from the variation of the surrounding or competing light, so that on a dull or foggy day the light at one temperature seems much brighter than it would appear on a clear and sunny day and of a different colour; and an important drawback also lies in the fact that no permanent numerical record of temperatures can be made from its observations. A fairly good judgment of temperatures by colour to the eye is attained, especially when one is constantly experimenting with pyrometers. The following shows the colours as observed in a dull light, and as given by different authorities; they may be taken as a rough guide, until opportunity arises for comparing the colours observed with the readings of a pyrometer. We have often tested several different people on the same furnace, and it is rather surprising to find how much they differ in naming the colour—much more so than in estimating the temperature in °C. :—

Temperature.	Pouillet.	Otto Thallner.	Authors (with a Le Chatelier Pyrometer).
1500 to 1600° C., . .	Dazzling white	Bright white	Moonlight white
1400, . . .	Welding white	...	...
1300, . . .	White	...	...
1200, . . .	Clear orange	Dull white	...
1100, . . .	Orange	Bright yellow	Clear yellow
1000, . .	Bright cherry red	Yellow	Orange yellow
900, . . .	Cherry red	Yellow red	Orange
800, . . .	First cherry red	Bright red	Bright cherry red
700, . .	Dark red	Cherry red (750°)	Dark red
	First red (525°)	Brown red (550°)	...

About 1782 Josiah Wedgwood, the famous potter, evidently felt the need of some apparatus that would yield a measure of the temperature his kilns had reached, and he conceived the idea of making standard pieces of clay mixture in a mould, drying them, and burning them at the temperature of the kiln. Then, as the higher the temperature reached, the greater was the contraction of the standard piece, by fitting the burnt piece into a sloping scale, he had a measure of the temperature which could be recorded. The temptation to mention this simple historical instrument cannot be resisted, although the authors have never used it.

The Murrie pyrometer had a vessel of mercury which, as the temperature of the furnace in which it was placed was higher, gave a higher reading on an ordinary pressure gauge. The Bailey gave direct readings on a scale by means of the relative expansions of metal rods.

The Siemens water pyrometer, familiarly known as the copper ball pyrometer, is shown in cross-section in the accompanying sketches (fig. 199), and relies for its indications on the method of mixtures which seems to have been used first by T. Wilson and the present form designed by Mr. Cowper. It consists of a cylindrical copper vessel, provided with a handle, and containing a second smaller copper vessel. An air space (*a*) separates the two vessels, and a layer of felt surrounds the inner one, in order to retard the exchange of temperature with the surroundings. The capacity of the inner vessel is a little more than a pint. A mercury thermometer (*b*) is fixed close to the wall of the inner vessel, its lower part being protected by a perforated brass tube, whilst the upper projects above the vessel and is divided as usual on the stem into degrees, Fahrenheit or Centigrade, as desired. At the side of the thermometer there is a small brass scale (*c*), which slides up and down, on which the high temperatures are marked in the same degrees as those in which the mercury thermometer is divided; on a level with the zero division of the brass scale a small pointer is fixed, which traverses the scale of the thermometer. Short cylinders (*d*) of copper, iron, nickel, or platinum, which are so adjusted that their heat capacity at ordinary temperature is equal to one-fiftieth of that of the copper vessel filled with one pint of water, are supplied with the pyrometer.

The water pyrometer is used as follows:—

Exactly 1 pint (0·568 litre) of clean water, preferably distilled or rain water, is poured into the copper vessel, and the pyrometer is left for a few minutes, to allow the thermometer to attain the temperature of the water. The brass scale (*c*) is then set with its pointer opposite the temperature of the water, as shown by the thermometer. Meanwhile, one of the metal cylinders has been exposed to the high temperature which is to be measured, and, after allowing sufficient time for it to acquire that temperature, it is rapidly withdrawn and dropped into the pyrometer vessel without splashing any water over. The temperature of the water then rises, and when the mercury of the thermometer has become stationary, the degrees are read off, as well as those on the brass scale opposite the top of the mercury. The sum of these last two gives the temperature required.

With the copper ball, temperatures up to 1000° C. may be measured, and this simple instrument holds its own in some works for special purposes. In the determination of the correct temperature for the quenching of armour plates, it is still in favour with some of the largest producers.

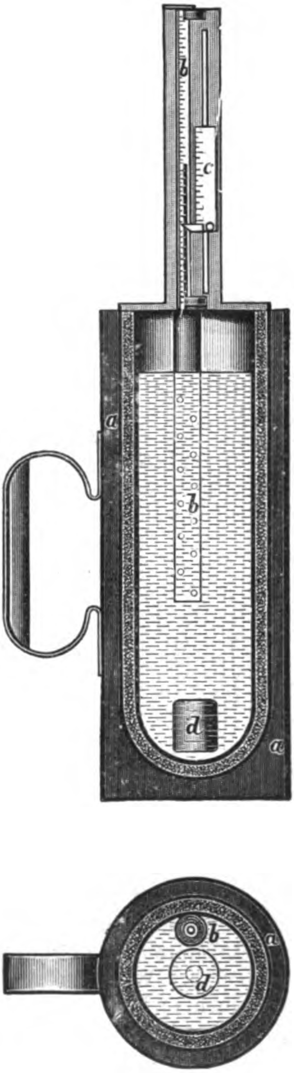

FIG. 199.—Siemens Water Pyrometer.

Thermo-Electric Pyrometers.

After the discovery of thermo-electricity many kinds of thermo-couples were tried, but the germ of a great advance was given life when, in 1873, Professor Tait of Edinburgh made the suggestion that the current from a thermo-couple, using metals of high melting points (such as platinum and an alloy of platinum and iridium), might be used for the measurement of high temperatures. This idea awaited the introduction of the D'Arsonval deadbeat galvanometer, and, after various trials, Mr. H. Le Chatelier of Paris brought the matter to a successful issue for scientific and industrial purposes, and the peculiar adaptability of this most successful instrument gave the investigation of the properties of metals and alloys a new and very powerful impetus. So important in itself, and because it is the parent of many of the best-known pyrometers of to-day (the Roberts-Austen, the Baird and Tatlock, the R. W. Paul, etc.), we shall consider in some detail the principles underlying its construction and use, and then, merely alluding to the special points of difference in the other three mentioned, endeavour to indicate how they may be made useful in foundry practice.

First, the facts about a thermo-couple must be noted, and these are that if two dissimilar metals are joined so as to make a complete circuit, there must be two junctions; and if one junction is made hotter than the other, a current of electricity, due to the electromotive force produced by the difference in temperature, will pass round the circuit. This current is called a thermo-electric current, and the two dissimilar metal wires thus used are called a thermocouple, short for thermo-electric couple. For every difference in temperature between the two junctions there is a corresponding difference in electromotive force (E.M.F.), and as the current in a circuit = the E.M.F ÷ the resistance of the circuit, or $C = \frac{E}{R}$ then, if the same couple and circuit be used, for each difference in temperature there is a corresponding strength of current passing round the circuit. It is evident that if we measure either the E.M.F., or the strength of the current, under known conditions which can be repeated, we have a measure of the temperature required. The current is conveniently measured on a D'Arsonval dead-beat galvanometer, which will give a steady reading from zero in about five seconds.

Suitable dissimilar metals for pyrometry are platinum and platinum alloyed with 10 per cent. of rhodium; or platinum alloyed with 10 per cent. of iridium.

If it were necessary to have the galvanometer in the Pt, Pt-Rd, or in the Pt, Pt-Ir circuit, the cost would be prohibitive for general purposes; but it is found that if the ends of the wires forming the cold junction, instead of being joined together, be each soldered to a copper wire, these two junctions kept at the same temperature, and the circuit completed, then the two junctions become the cold junction, and sufficient copper wire may be used to form leading lines from any required number of furnaces to one galvanometer, which, by the aid of a switch placed near the scale, may be used for any of these furnaces in turn, provided that wherever dissimilar metals touch, as at terminals, etc., the two junctions be kept at the same temperature. It is therefore advisable to have such junctions near together and enclosed in a wooden box. To form the hot junction the wires need not be either fused or soldered together, but only closely twisted round each other as at *b*, fig. 200; not one round the other as at *c*; when they are twisted in this manner they are apt to come apart on heating. This point must be carefully watched, as the platinum-rhodium wire being stronger than the pure platinum wire, there is a tendency for the latter to twist round the former, and this tendency should be counteracted by handicapping the platinum-rhodium wire by bending it back before each twist is made. Two or, at most, three twists will generally be enough. When properly done, this will be quite efficient for laboratory experiments; but, where a couple is to be left in a furnace for an indefinite period, it will be safer just to fuse the ends of the wires together by placing them for an instant in an oxyhydrogen flame (see *a*, fig. 200).

The wires should be protected from contact with metals which would alloy with the platinum, and from such substances as hot magnetic oxide, or reducing gases, which render them brittle.

The pyrometer may be installed to read the temperatures of two or indeed almost any number of furnaces in succession on the same scale with only one galvanometer. A wire joins the + or platinum-rhodium terminal of the galvanometer to the centre of a switchboard placed under the scale. The movable contact arm is in electrical contact with the centre, and several brass pieces are insulated from the arm and from one another, but joined to the wires from their respective furnaces. A common wire is carried from the—or Pt terminal of the galvanometer, and is connected to the—terminals throughout the system. The direction of the current is from Pt to Pt-Rd, through the hot junctions. It will be seen, by making a diagram and following the wires round the only possible circuit, that if the arm be turned to No. 1 brass, the reading will be that of No. 1 furnace; if to No. 2, that of No. 2 furnace; and so on. In ordinary furnace work the cold junction is contained in a hinged wooden casing, preferably with a thermometer bulb inside and the scale outside to read the temperature of the cold junction, as in the Baird and Tatlock form.

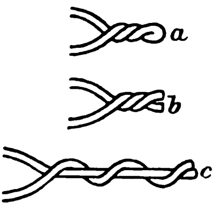

FIG. 200.—Thermo-Couple Twists.

For experimental work the cold junction is better to be kept in cold water, which can be maintained at a fairly constant and easily determined temperature. For very special research the cold junction is often kept at one of the fixed points, as when immersed in melting ice or even boiling water, as used by Dr. Stansfield.

Calibration of the Pyrometer.—It must be carefully noted that as it is the E.M.F. produced that, for a given thermo-couple, corresponds with any given difference of temperature between the junctions, the current will only give a true measure of temperature when the resistance of the circuit is kept constant or within the limits of accuracy required. The next point is, that having obtained a measure of the temperature it will be desirable to convert that into degrees Centigrade or Fahrenheit, as the most convenient way of expressing temperatures. This is done by calibrating the instrument, using, as standards, known fixed points, generally the melting points or boiling points of pure substances which have been determined with great care by comparison with the great standard of temperatures, the air or the nitrogen thermometer. Such are the melting points of tin (232° C.), lead (327° C.), silver (962° C.), and copper (1084° C.), or potassium sulphate (1060° C.), and the boiling points of water (100° C.), sulphur (445° C.), and selenium (680° C.). The hot junction is placed so that it may attain to each of these in turn. The current due to these temperatures, *minus* the temperature of the cold junction, is passed through the galvanometer, and the reading on the scale (of millimetres with the Le Chatelier) is taken. There is no necessity to consider the strength of current that the reading represents, for by taking these observations through the required range of temperature, plotting temperatures as ordinates, millimetres or other readings of the galvanometer as abscissæ, and drawing a fair curve through the points obtained, a calibration curve is made from which an unknown difference of temperature between the hot and the cold junctions is obtained.

The zero of the instrument is noted by bringing the two junctions to the same temperature; generally, for furnace work, by leaving the encased couple in the air in such a position that the two junctions will reach as nearly as possible the same temperature and taking the reading on the scale when constant. If this is not easy, the zero may be obtained by breaking the circuit, but, whenever possible, should be checked by the other method in case of any small current being in the circuit. In all experiments it is necessary to arrange that the wires shall not touch unless at the hot junction, and they must therefore always be suitably insulated, as by running one or both through quill glass, or porcelain tubing, or thin pipe stems, or two-hole pipe-clay or porcelain tubing manufactured for the purpose. The reading for boiling water can be taken with an ordinary wash bottle, the jet tube being replaced by a closed glass tube and the water allowed to boil till the reading is constant, as in all the other boiling-point determinations. To ensure a correct reading for boiling points, the couple should not be in the liquid but in the vapour immediately above the liquid. For lead and tin small fireclay crucibles holding a few ounces are used; and after melting the metal over a Bunsen burner, and inserting the couple (protected by a closed hard glass tube, closed as thin as possible) into the molten metal, the flame is removed and the spot of light on the scale is watched. It generally rises a little, owing to the excess heat in the bottom of the crucible, then turns and begins to fall steadily, becomes stationary when the metal begins to solidify, remains so till the metal is solid, and then begins to move steadily down again. The exact point is thus easily determined. Similarly, the point for pure copper is obtained, only the copper is melted in a coke crucible furnace in a plumbago crucible, with a good covering of charcoal or borax on the top, and the protecting tube must be porcelain or a similar refractory material as thin as possible. If the copper be melted in an oxidising atmosphere, it may solidify at as low a temperature as 1065° C. instead of at 1084° C., when proper precautions are taken to keep the conditions reducing. We have recently been using pure silver under similar conditions with very satisfactory results when the melting is done under glass and the wires are protected with thin hard glass tubing. One oz. of this silver, which can be obtained for 3s. or 4s., is sufficient, and lasts indefinitely. The sulphur point is most conveniently taken in a 6-inch × ¾-inch test tube, with an asbestos jacket which may be made by wetting thin asbestos millboard, rolling it on the tube, and tying it on till thoroughly dry. This jacket, which will last out many test tubes, should come to within about 1 inch of the bottom of the tube, and is necessary in order to obtain the true reading from the sulphur vapour, by preventing the cooling effects of currents of air on the one hand and the superheating effect of the flame on the other. A Bunsen burner answers admirably as a source of heat. Similarly, the boiling point of selenium may be taken as a calibration point, using a hard glass or "oxygen" test tube as the containing vessel and an ordinary gas and air blowpipe as the source of heat. In the last two cases (for a stopper) the protecting tube and two open tubes are packed in the mouth of the vessel with asbestos, which is soon bound into a solid mass by the condensation of vapour among the fibres.

For rough practical purposes a near approximation is obtained for the temperatures included by taking the reading for sulphur and for silver and joining these by a straight line, which may be produced even up to 1200° C. without being more than 15° or 20° from the true line at any one point.

The above details, if carefully studied, will make clear the principles on which thermo-couple pyrometers are based, and enable them to be more efficiently handled. Thus, the Roberts-Austen is practically a Le Chatelier, with a spot of light recording the temperature on a sheet of bromide paper stretched on a revolving drum driven by clockwork, while part of the light is also reflected on to a scale so that it can be read at any instant. It is made by Mr. J. Pitkin, 36 Red Lion Street, Clerkenwell, London, E.C. Pattern 1, at about £33, giving a record from any one of six furnaces by means of a switch. Pattern 2, about £35, giving two continuous and simultaneous records. Pattern 3, about £38, taking three continuous and simultaneous records.

The Baird and Tatlock portable pyrometer is also on a similar principle, only the galvanometer readings are given by a pointer, and the scale is marked off in degrees. It is obvious that the cold junction temperature must be added to the reading on the scale for accurate work. There is one stationary form, for which a fairly level surface must be found ; and another set on gimbals like a mariner's compass. This firm also supply a direct reading form, with photographic recorder attachment, which they call a pyrograph (see fig. 201). In this instrument a band of photographic paper is drawn at a suitable rate under a very fine slit in the dial, the record running for 24 hours. The face being illuminated by an 8-volt electric lamp, the needle of the pyrometer moving over the dial casts a shadow through the slit on to the photographic paper, and when this is developed the record is seen as a white line. The same clockwork which draws the paper also switches off the lamp for one minute every hour, and this marks white hour lines across the record. The scale can be seen while the diagram is being made, the records can be inserted and withdrawn in daylight, and the temperature lines are ruled off by means of a gauge supplied. The portable form costs about £12, mounted on gimbals about £14, and the pyrograph form about £24.

Fig. 201.—Baird and Tatlock's Pyrograph.

R. W. Paul has elected to use the platinum and platinum with 10 per cent. iridium couple, and has attached these to his well-known single pivot portable galvanometer, with scale marked in degrees and in millivolts. This is an extremely convenient and portable instrument, and the mere act of lifting the galvanometer fixes the bearing ready for carrying about, while the placing of it down pushes in a little pin which frees it again for taking readings. It is also wound with special wire of low temperature coefficient, so that the variation in the readings due to change of resistance in the galvanometer as its temperature varies, is reduced to a minimum.

The R. W. Paul single pivot moving coil galvanometer, 230 ohms resistance, with wall plate for wall, shelf, or tables, costs about £7 ; it is graduated to read in degrees and also in millivolts if required. Thermo-couples, etc., cost about £3. It is one of the cheapest and remarkably portable and efficient.

Electric Resistance Pyrometers.

In these the increase in the resistance of a platinum wire with increase of temperature is the feature used for measuring temperatures, a principle first proposed by Sir Wm. Siemens in 1871. The Callendar and Griffiths is a well-known pyrometer of this type in which a fine platinum wire is wound on a mica frame, in section that of a cross with equal arms, which gives perfect insulation without causing any alteration in resistance of the wire, the principal defect in the Siemens form with the platinum wire wound on porcelain. The platinum wire is connected by means of stout copper or platinum leads to terminals in the head of the pyrometer. Two similar leads, but unconnected with the coil, pass through the whole length of the pyrometer and act as compensating leads. By this means no error is introduced by the variation of the temperature of the wires connecting the thermometer with the indicator or the recorder. For recording temperatures by means of an electric resistance pyrometer a Callendar recorder is employed. This instrument consists of a Wheatstone bridge or potentiometer, in which the movements of the slider along the bridge wire is automatically effected by relays worked by the current passing through the galvanometer between the bridge arms. According as the moving coil of this galvanometer is deflected in one direction or the other, a relay circuit is connected through one or the other of two electro magnets. Each of these magnets is mounted on a clock, the movement of which is prevented by a brake. When a current passes through a magnet this brake is lifted, allowing the clockwork to revolve. These clocks are connected by differential gearing with a recording pen, which is pulled in one direction or the other when the brake is lifted from the corresponding clock. The bridge slider moves with the pen, and tends to restore the balance. Cambridge Scientific Instrument Co.'s pyrometer costs about £8 to £10; the Whipple indicator for taking readings, £20; or the Callendar recorder for continuous readings for one week, £43; the record is made in ink, and can be read at any time.

The Seger Cones are made of mixtures of silicates which melt at certain fixed points. The temperatures at which the several cones will melt begin with cone No. 022, melting at 590° C., to No. 010, melting at 950° C., with intervals of 30° C.; and from No. 09, melting at 970° C., to No. 36, melting at 1850° C., with increments of 20° C.

In fig. 202, cones 9, 8, 7 and 6 are shown protected from the action of live flame by a little fire-brick erection, and as they would appear after being withdrawn from a furnace of approximately temperature 7 or 1270° C., No. 6 having practically melted, while 7 comes nearest to the condition under which they have been made to indicate the temperatures in the table, namely, that the cone has bent over until the apex has nearly touched the base, Nos. 8 and 9 are as sharp on the edges as when put in, so the furnace reached over 1250° C., did not reach 1290° C., and was somewhere very near 1270° C. The applications of these, with their advantages and disadvantages, are obvious.

The cones are imported and sold at about 13s. 6d. per 100 by Messrs. S. G. Bailey & Co., Ltd., Stroud, Glos.

Melting Points of Seger Cones.

Cone No.	Cent.	Fahr.	Cone No.	Cent.	Fahr.	Cone No.	Cent.	Fahr.	Cone No.	Cent.	Fahr.
022	590	1094	07	1010	1850	9	1310	2390	24	1610	2930
021	620	1148	06	1030	1886	10	1330	2426	25	1630	2966
020	650	1302	05	1050	1922	11	1350	2462	26	1650	3002
019	680	1256	04	1070	1958	12	1370	2498	27	1670	3038
018	710	1310	03	1090	1994	13	1390	2534	28	1690	3074
017	740	1364	02	1110	2030	14	1410	2570	29	1710	3110
016	773	1423	01	1130	2066	15	1430	2606	30	1730	3146
015	800	1472	1	1150	2102	16	1450	2642	31	1750	3182
014	830	1526	2	1170	2138	17	1470	2678	32	1770	3218
013	860	1580	3	1190	2174	18	1490	2714	33	1790	3254
012	890	1634	4	1210	2210	19	1510	2750	34	1810	3290
011	920	1688	5	1230	2246	20	1530	2786	35	1830	3326
010	950	1742	6	1250	2282	21	1550	2822	36	1850	3362
09	970	1778	7	1270	2318	22	1570	2858			
08	990	1814	8	1290	2354	23	1590	2894			

The Wiborgh Thermophones consist of small calcined cylinders, enclosing some explosive material. When placed in a furnace or space, the temperature of which is required, after an interval corresponding with the temperature of the blast, molten metal, or hot space, as the case may be, the cylinder explodes with a sharp crack. They must be deposited in the place where the temperature is to be measured, and at the exact moment a stop watch started. The watch is stopped at the moment the thermophone explodes, the reading taken to the fifth of a second, and the corresponding temperature is found by reference to a table supplied with each box of cylinders. With proper care and a little practice it is really surprising how nearly the results agree with the readings of a standard Le Chatelier pyrometer.

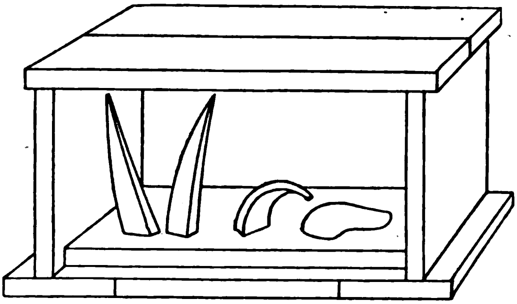

Fig. 202.—Seger Cones, and Method of Protecting.

The Sentinel Pyrometers have just been put on the market, and, from preliminary tests made, they bid fair to take a prominent place amongst this class. They consist of cylinders about $\frac{7}{8}$-inch long × $\frac{1}{2}$-inch diameter, and are made of mixtures of oxy-salts, protected from the moisture in the air by a thin coating of paraffin wax. These salts are so compounded that the cylinders melt sharply at certain intervals in a wide range of temperature; their uses will easily be gathered from what has already been said.

Optical Pyrometers.

For the daily determination of very high temperatures with the methods given, and particularly in those cases where the manipulation of molten metal is included, difficulties increase until the methods become impracticable. Consider two typical cases. It would be of great interest, and no doubt ultimately of great value in open hearth steel making, to be able to give, with some fair degree of reliability, the temperatures of the furnace, the slag, and the metal at different stages of the heat, and the temperature of the metal as tapped from the furnace or as run into the moulds; but thermo-couples need efficient protection, such as it is almost impossible at present to find for them for application to this case industrially, and resistance pyrometers break down before this temperature is reached. Again, there are cases where, owing to the necessities of output, etc., the reader of temperatures must not disturb the rhythm of the work, even for short periods, and his instrument must not stop, say, the pouring of castings. For these and similar reasons, advantage has been taken of the radiation from the hot body whose temperature is to be measured. These radiations will come through space to the instrument without the aid of wires, and the observer may take his readings without disturbing the ordinary routine of the foundry. The eye has already been given as an example of an optical pyrometer which is used for determining temperatures by judging of the colour and brightness of the light given off by the body. Even here, when very high temperatures are reached, artificial help is called in, as, in open hearth practice, the judging of the heat of the furnace through blue glasses of a standard tint, the colour of the bubbles as they break, or the thickness (viscosity) of a slag judged to be of a given composition, or, again, the appearance of some part of the furnace as seen through the glasses.

The Mesuré & Nouel Pyrometer.—One of the simplest optical pyrometers is that of Mesuré & Nouel, the principle of which will be sketched as simply as possible, as, although optical pyrometers have been so much improved recently, this one is still much used, and serves well as an introduction to the others. The pyrometer is in the form of a telescope, and consists, essentially (fig. 203), of a polariser, P, and an analyser, A, of which the position of extinction is the zero of the graduation on the divided circle, C.C. This circle is divided into degrees, and is movable in front of the fixed index, I. Between the two Nicols, P and A, is a quartz plate, Q, of convenient thickness and rotation, carefully calibrated. The lens L faces the opening G, which is furnished with plate-glass, or, if required, with ground glass of very fine grain, and, in certain cases, with a special additional lens system in order to gather in a greater amount of light when observing

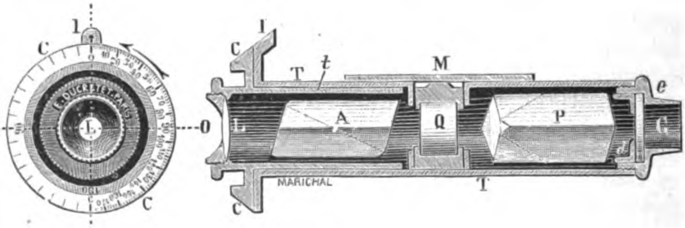

FIG. 203.—Mesuré & Nouel Optical Pyrometer.

temperatures below 900° C. The light emitted by incandescent bodies is not homogeneous. Its spectrum contains, for the temperature corresponding to dark red, only the least refrangible rays. In proportion as the temperature rises, the series of more and more refrangible rays appear and augment in intensity until all the colours of the spectrum of white light are represented. Applied to composite light the preceding system cannot, in any position of the analyser, determine the extinction of the emergent pencil; but the rotation of the analyser causes a series of tints of varying colours and intensities to appear. In the case of white light one of the tints is specially noticeable. It is called the "Sensitive Tint," because it changes more quickly than any of the others. It is greyish-violet, and turns to blue or to red for a very small rotation of the analyser in one or the other direction. The light from incandescent bodies also gives a sensitive tint, and the angle of rotation which causes it to appear varies with the composition of the light and therefore with the temperature of the bodies. It is so much less as the temperature is lower, and hence the measure of the angle serves to define the temperature.

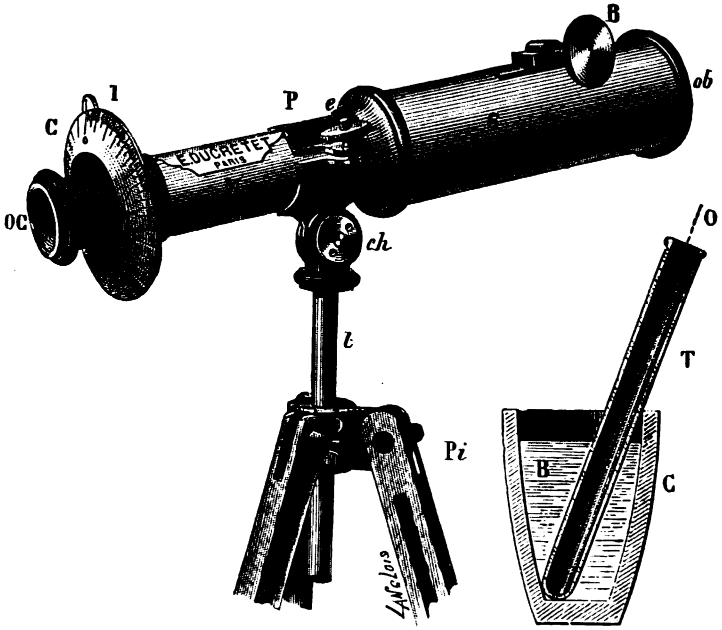

Fig. 204.—Mesuré & Nouel Optical Pyrometer.

For extremely high temperatures the sensitive tint approaches that of sunlight, is of a greyish-purple, and turns from red to blue. For lower temperatures, the blue rays being feebler or wanting in the spectrum, the sensitive tint passes from red to green, and is of a greyish-yellow colour. For still lower temperatures only the passage of the red to the greenish-yellow is obtained, and, finally, merely the simple extinction of the red rays. The reading on the circle when this sensitive or transition tint is observed defines the temperature of the incandescent body, and, although there is no standard for comparison, considerable skill in obtaining concordant results is acquired by practice. Particularly for repeating a certain temperature day after day it is used with success, and its easy portability is greatly in its favour for positions not easily accessible. For metals giving off coloured vapours while fused, a tube of iron closed at one end may be forced into the bath or into the hearth to be observed and the reading obtained by looking into the open end of the tube with the pyrometer. This is made by Ducretet, Paris, and costs about 130 francs; the lens system for temperatures below 900° C. is 45 francs extra; and the very useful stand shown (fig. 204) is another 32 francs.

The Wanner Optical Pyrometer serves for measuring temperatures from 900° C. upwards. It is very convenient for the measurement of the temperatures of molten iron or steel, of other very high temperatures, and of the temperatures of places that are inaccessible or where machinery or workmen would be interrupted by the use of instruments, part of which must touch the sample or be in the actual space, the temperature of which is to be measured. The light from the hot body or place enters the apparatus through a slit, and, after traversing a direct vision prism, forms a spectrum from which, by means of a screen, light of definite wave length is cut off and the intensity of the light measured by polarisation. The part of the apparatus facing the radiation to be measured is fitted with a small 6-volt electric incandescent lamp, the light from which also passes through the apparatus and is used as a standard for comparison with the intensity to be measured, the lamp being worked by an accumulator which must be kept at a fairly constant voltage. On looking through the apparatus, the circular field of view is seen to be divided into two semi-circles, one of which is illuminated by the little electric light and the other by the body under observation, the colour being red, as the light selected is that corresponding to the Frauenhofer line C. By adjusting a rotating eyepiece containing a Nicol prism, the halves of the field of view can easily be brought to equal intensity, as, when they are even slightly different, there is a distinct line across the diameter, which just disappears when they are equalised. The angle of rotation is measured on a circular scale, and, by reading the angle, the temperature corresponding to it is found in the table sent out with each instrument. The method simply consists in comparing the rays of a known temperature emitted by the electric lamp with the rays of an unknown temperature, and the operation is a very simple one. The whole apparatus is about 12 inches long, and is made in the form of a telescope. Consequently, it can be manipulated with ease, and the distance from the object to be measured is of little importance, so long as the field of vision is fairly filled with the light to be measured; and, with practice, when this is not feasible, as in taking the temperature of a thin stream of metal, fairly concordant results can be attained. It is essential that the filament of the little electric lamp should always have the same temperature, and as this may vary as the accumulator runs down, or as the lamp deteriorates with use, the electric light is periodically compared with a standard light, namely, the flame of a standard amyl acetate lamp, burning steadily, protected from draught, and with its flame of definite height as measured by the metal gauge supplied with the instrument (see fig. 205).

The underlying principle is, that if the light from a hot body is passed through a prism, and light of certain wave length selected from its spectrum (in this case the red) as the temperature of the hot body increases, the intensity of any portion, and, therefore, of this red portion of the spectrum increases, and herein is obtained a measure of the temperature of the hot body.

This is only strictly true, however, for the theoretically black body (like lampblack) which absorbs all rays that fall on it, and hence can radiate light of any colour or wave length. Lampblack is almost perfect; iron and black slags are nearly so, while bright platinum is far removed; copper also, owing to its own red colour, appearing hotter in a muffle side by side with iron and brick.

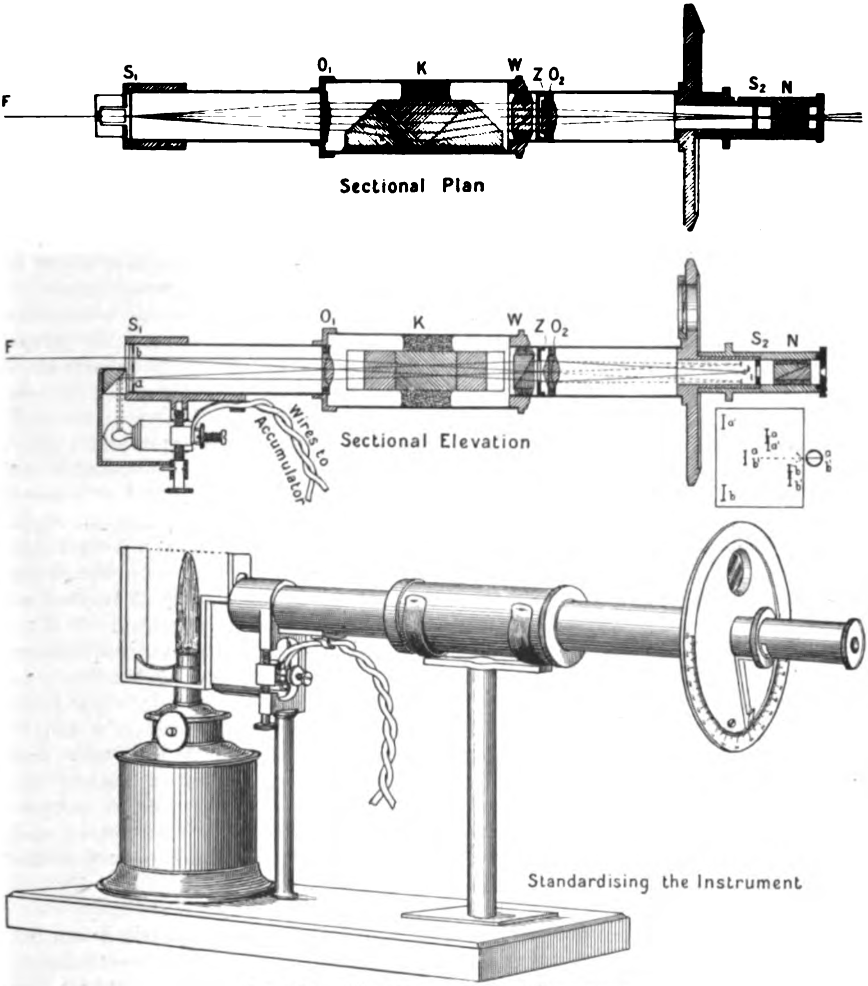

Fig. 205.—The Wanner Optical Pyrometer.

According to Kirchhoff, a hollow space, surrounded by walls that are impervious to heat and perfect reflectors, is a theoretically black body; and practically the same effect would be attained if the walls, instead of being reflecting, have the same constant temperature as the hollow space. Closed furnaces at high temperatures thus approximate to this condition, and it is encouraging to be told by the physicist that any deviation from perfection decreases as the temperature increases.

At S_1 there are two vertical slits, *a* and *b*, vertically above one another, the lower, *a*, illuminated by the little electric lamp through a right-angled or totally reflecting prism, ground on the face next the lamp to diffuse the light from the lamp filament. The upper slit, *b*, is illuminated by the light from the furnace walls or other hot body. O_1 is a lens which, placed at its focal length from S_1, transmits the two sets of rays as parallel beams. K is a direct vision prism which forms the continuous spectra of the beams. Through the polariser W, each pencil from *a* and *b* is resolved into two polarised parts, called the ordinary and extraordinary rays, vibrating in directions at right angles to each other, and having different directions. There are now four series of spectra, and the lens O_2 would focus these four spectra over the surface of S_2, but the pencils have to pass through the double prism Z, which deviates them towards the axis, meanwhile making eight spectra. Z is so proportioned that only one from *a* (ordinary rays) and one from *b* (extraordinary rays) are focussed in one plane exactly in front of the slit S_2, the diaphragm of which cuts off all the others, and all but the red rays of these two, so that there is now in the field of view of the analyser N, two half fields, which are polarised in directions at right angles to one another, the lower illuminated from *b* alone and the upper from *a* alone. If the slits be equally illuminated, and the plane of the analyser midway between or at 45° to the plane of the polarisation of each beam, the two semi-circles will be equally illuminated and appear as one complete circular field; if they do not, then, by turning the analyser, one will become brighter and the other darker, so that they may be equalised. The angle may be read from a scale, and the temperature calculated or taken from a table made by calculation or by calibration. This table is supplied with each instrument. Townson and Mercer are the agents, and the price is about £22.

With these optical pyrometers strong reflected light from an external source must be avoided where possible, and the atmosphere between the body at the required temperature and the observer must be reasonably clear, that is, free from much smoke, or coloured fumes, or clouds of dust or steam.

The Féry Radiation Pyrometer.—This recently introduced and convenient form of pyrometer uses the heat radiation from the furnace or hot body to measure the temperature, and is thus suitable for dealing with very high temperatures. The complete outfit consists of a short telescope on a tripod stand and a Meylan-D'Arsonval galvanometer graduated in millivolts and ° C. The radiation from the hot body falls on a concave mirror within the telescope and is brought to a focus on a copper-constantan thermo-couple. The hotter the body the greater the rise in temperature of the couple, and the stronger the current produced; thus a measure of the temperature of the body is obtained.

The Uehling Pneumatic Pyrometer and **Steinbart Automatic Recorder** form one complete instrument, the former registering the temperatures attained, and the latter, at the same moment, legibly recording them in ink. The pyrometer is based upon the laws governing the flow of air through small apertures, and, although the instrument is wonderfully ingenious, and has so far given satisfactory results for annealing furnace temperature, we cannot afford the space to describe it in detail. It has been carefully described by its inventors before the Cleveland engineers and later by Mr. J. H. Harrison, M.Inst.C.E., before the Iron and Steel Institute (*Journ.*, 1904, I.). Suction is maintained by a steam aspirator, and is kept constant by drawing air in through a tube in a deep water vessel. Specially purified air which has attained the temperature of the space enters one small aperture in a platinum tube, is drawn along to a second, where it is also reduced to a constant temperature (100° C). As there is a constant suction behind the second aperture, and all air passing in at the first is reduced to a constant temperature, if the air passing in at the first is of a high temperature and a given volume passes through the first aperture the amount that reaches the second will be less than if the temperature were lower; hence, the pressure will be less the higher the temperature, and the water in a manometer tube attached will rise, while, when the temperature is less, the water will fall; hence, the height of this water gives a measure of the temperature. This varying pressure is transmitted to a float, so that as the pressure varies the float has a corresponding movement, and, by means of a special pen attached, records the temperature on paper moved by clockwork. The price is about £100 for each furnace.

Choosing a Pyrometer.—The starting point is, the purpose for which the instrument is required, whether merely to take the temperature of a space or to record the delicate changes in the rate of cooling of a piece of iron, steel, or alloy; to determine the temperature of an oven or an annealing furnace; or to take that of a mass of metal at any given moment; to regulate the performance of a given operation, such as quenching, so that it shall always be done at the same temperature; or merely to ensure that a kiln shall have attained to a certain high temperature before it is allowed to cool down again. Next must be settled whether a reading at any desired moment will do, or a continuous record must be kept; if the latter, whether the record need be visible while being made, or if it will suffice to be traced photographically so that one day's record can only be examined when it is completed and the plate or paper developed. Then comes the price that would give a reasonable expectation of return; or what smaller amount is the maximum those in authority may be induced to expend; and, lastly, what instruments are available, at what price, and where they may be purchased. For taking the temperature of a space, such as an oven or a muffle, almost any of the pyrometers are available when used with knowledge and care. To read off the heat at a certain spot quickly, or to obtain the temperature of a piece of metal for experimental purposes, or to follow the faintest of the changes in the rate of cooling of, say, a piece of pure iron, the thermo-couple stands easily first, and, with regard to its indication changing with use, thermo-couples have been in use for two and three years at a time for experimental work from 0° to 1000° C., gradually becoming shorter and shorter through small pieces being cut off; but their calibration curve has hardly altered; if protected with double-glazed porcelain tubes (as resistance pyrometers must be), their life would probably have been much further prolonged, although their indications would not be so promptly defined. Such pyrometers as thermophones, Seger cones and sentinels, are cheap at first, and are convenient as checks, where others cannot be bought; but it must be remembered that each time a reading is required one thermophone is gone or several cones are destroyed; if few readings are required, these may do; but if many are needed the cost mounts up. The simple ball pyrometer still holds in certain large furnaces where the length of the thermo-couple, always exposed to a considerable temperature, is an objection, and, as in the case of a large plate, the small ball attached to asbestos-covered wires can be laid on the plate and covered with asbestos or sand, thus taking the temperature of the face; the instrument, though cheap, is also capable of giving many readings at a small cost; but it is mainly used for such work as taking a large plate or furnace to a given temperature. With a nickel cylinder this may be dipped into metals or alloys of low melting point, such as white metals or antifriction alloys, and thus their best casting temperature arrived at. Where the length of couple-wire required is not excessive, and the wires can be protected from oxide of iron or reducing gases, then the thermo-couple gives readings at any moment and will take the temperature of the place where the couple is, in a few seconds. They are thus in constant use for steel casting and other annealing furnaces, for malleable annealing ovens, for taking the temperatures of chimney gases, etc. These are of the Le Chatelier type ; the R. W. Paul is one of the cheapest and most portable, but does not record ; the Baird and Tatlock is another, their pyrograph records photographically, and the record can only be seen after development, as is the case with the Roberts-Austen. With the platinum resistance type the platinum must be protected by a double-glazed porcelain tube, which is rather tender and causes lag, a matter of little importance in recording a temperature for twenty-four hours, and with proper precautions the reliability of the indications is a great point, and the record made by the Callendar & Griffiths type is in ink and can be seen at any time. If in either of these types, thermo-couple or resistance, the poker has to be thrust into a furnace above a dark red, the metal tube is soon eaten through, and, for continuous work, must either be replaced by a kind of fire-clay tube now being made, or the tube must be water-cooled up to the part that is recording the temperature. The Uehling is a good example of a water-cooled tube arrangement with a visible record in ink, the last six or seven hours of which can be read without disturbing anything, and, on the whole, it is a marvel of ingenuity ; the only points against it are its price, the fact that it cannot be moved from one part of a works to another, and that, practically, a new pyrometer is required for every furnace. Finally, as the authors have found by experience that they are as often asked for prices and name of maker or supply-house as for the principle on which that pyrometer acts, the names of the makers and approximate prices have been given, merely as a guide ; and when some idea has been formed of the most suitable kind available, the firms mentioned, or almost any of the usual houses who supply chemicals and apparatus, will give a proper quotation for specified wants. Thermo-couples may be used for temperatures near to the melting point of platinum, but if required for extended periods to read above 1100° C., the wires soon deteriorate and recourse must be had to an optical form : for cheapness, the Mesuré and Nouel is with practice good for deciding when a certain fixed temperature is reached, as it needs no standard and storage battery, and is easy to take to places difficult of access ; but only with long practice is it of much use in varying temperatures, as the sensitive tint is different for every temperature. The Wanner optical is much dearer ; but since it has been available as a matter of personal experience, even the 1½-lb. Wanner, with its 18-lb. accumulator to haul about instead of the Mesuré and Nouel weighing 2 lbs. in all, the Wanner is the one now used for taking the temperature of Siemens bath, tapping the Siemens, hot end of the checkers, molten cast-iron, special experimental steels, and the like. Then, it must be remembered, that several others of importance have not been described ; but as the authors have not yet used them, the reader will obtain as reliable information as they could get here from their respective catalogues. It should be observed that it is not so much an instrument that is said to read to a fraction of a degree, and may not be giving the real temperature at all, as one that will give, with reasonable accuracy, the actual temperature of the space or metal required, with the greatest facility and the least interference with work, that contains the essentials of a pyrometer for practical purposes.

CHAPTER XXXII.

STEEL.

THERE is a wealth of information on the influence of composition on steel generally, both in the form of the tests given by many varied compositions and by tables of results of special experiments, showing the effect of gradually increasing the amount of one element present, keeping the others in fairly constant proportions. The great majority of these tests have, unfortunately for our present purpose, been made on forged materials, and, probably because the composition of the great bulk of steel castings came, until recently, within comparatively narrow limits, the tests on materials as cast or annealed, but without work on them, have been by comparison but few. Another reason for the paucity of results on castings of varying compositions may be that with castings there are so many influences, other than composition, that affect the tests, the effect of which is nearly eliminated by always casting in an ingot mould and subsequently forging; hence, probably, the greater attraction of forged material for experimenters.

Influence of Carbon.—The influence of carbon on iron, whether in cast or in forged material, is of such immense importance that, in this case, we shall consider, briefly, both the cast and the forged materials. Fortunately for the purposes of comparison, the best results on the purest materials are, in both cases, by the same experimenter, Prof. Arnold. In all these results N means normalised, that is, heated up to about 950° C. to 1000° C., and cooled in air; A (annealed) means that the specimen was maintained for about 70 hours near 950° C., and cooled in the furnace in about 100 hours; and U means unbroken.

The table on page 288 is worthy of careful study, as it shows the influence of carbon on steel in castings, and it also shows that, although the pure iron and carbon steels may be ideal for certain forged or hardened materials, they are not suitable for the general run of commercial steel castings; as, when the tenacity has been sufficiently raised, the ductility has fallen off to an extent that would ensure their rejection, a common specification being 28 to 30 tons maximum stress, 20 per cent. elongation on 2 inches, and 90° bend on 1-inch square bar over a radius of not more than 1½ inch. It may be mentioned here that, although the drastic or long annealing improves the quality of the steel castings, it injures forgings of a similar composition, and one is often asked why this should be so. The answer seems fairly clear, for a casting, as cast, is in its least reliable state for its composition, and it requires long annealing to give it the opportunity not merely to eliminate internal stresses, but also to repack itself and remodel its whole constitution, as will be seen from the photo-micrographs shown; while a forging has already had a compulsory remodelling with a very severe artificial closing up of its ranks, until distances

Treatment.	Specific Gravity.	Elastic Limit. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 ins.	Reduction of Area per cent.	Bending Angle 1 in. sq. round ⅛-inch radius.	Compression per cent. at 100 tons per square inch.	Combined Carbon per cent.
Crucible Casting, FeB, Si ·02, Mn ·05, S ·02, P ·01, Al ·02. Forging, Si ·03, Mn ·02, P ·02, S ·03, Al ·02.								
As cast . . .	7·916	10·7	19·8	30·0	38·7	180° U	62·3	0·07
Annealed A .	7·925	9·1	19·2	46·0	65·1	180° U	63·0	0·07
Forged N .	...	12·2	21·4	46·6	74·8	...	61·9	0·08
Forged A .	...	8·8	18·3	52·7	76·7	...	64·4	0·08
Casting, Si ·01, Mn ·09, S ·03, P ·01, Al ·02. Forging, Si ·05, Mn ·05, S ·03, P ·02, Al ·02.								
As cast . . .	7·887	11·9	19·9	19·5	29·1	180° U	61·8	0·18
Annealed A .	8·014	9·4	19·5	31·0	47·0	180° U	61·9	0·16
Forged N .	...	17·1	25·4	42·1	67·8	...	57·5	0·21
Forged A .	...	9·0	21·3	42 3	65·7	...	61·5	0·21
Casting, Si ·04, Mn ·06, S ·02, P ·01, Al . Forging, Si ·03, Mn ·08, S 02, P ·02, Al ·03.								
As cast . . .	7·851	17·2	23·4	6·5	8·4	90°	45·7	0·42
Annealed A .	7·865	10·1	24·0	24·5	29·0	180° U	50·0	0·40
Forged N .	...	18·0	30·0	34·5	56·3	...	53·4	0·38
Forged A .	...	9·6	25·0	35·0	50·6	...	58·4	0·38
Casting, Si ·06, Mn ·03, S ·025, P ·02, Al ·03. Forging, Si ·03, Mn ·09, S ·02, P ·02, Al ·03.								
As cast . . .	7·905	22·3	32·4	2 0	1·8	8°	Sheared at 90·4 tons per sq. in.	0·97
Annealed A .	7·960	18·5	29·0	4·0	1·7	50°	50·7	0·83
Forged N .	...	24·8	52·4	13·0	15·4	...	28·9	0·89
Forged A .	...	16·8	36·7	4·5	4·2	...	41·4	0·89
Casting, Si ·1, Mn ·28, S ·02, P ·02, Al ·04. Forging, Si ·07, Mn ·15, S ·02, P ·02, Al ·03.								
As cast . . .	7·879	22·3	22·3	0·0	0·0	0°	33·1	1·29
Annealed A .	7·854	16·6	29·9	2·5	3·5	20°	40·7	1·10
Forged N .	...	35·7	61·7	8·0	7·8	...	28·4	1·20
Forged A .	...	16·2	32·9	6·0	4·9	...	46·3	0·92 Gr. ·28

between crystals must have been brought down very nearly to ordinary molecular distances, and a long annealing only allows these to become greater again where they have that tendency.

The following tests on carbon-silicon, carbon-manganese, and the remarkably high tensile crucible-melted carbon-, silicon-, manganese-steel castings respectively are selected from an unpublished research of Prof. Arnold's, and given here by his special permission. They should be compared with the pure iron and carbon series, and with the several tests of carbon-, silicon-, and manganese-steel castings given in the table and in the text, and also with the curious nickel steel casting result and with the one marked W and B, made by Messrs. A. B. Winder and J. D. Brunton, in 1892, in the small open hearth furnace, fig. 192.

Mark.	Treatment.	Chemical Composition.						Elastic Limit. Tons per square inch.	Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.	Reduction of Area per cent.	Bending Angle 1 in. sq. round ⅝-in. Radius.	Compression per cent. at 100 Tons per sq. in.
		C.C.	Si.	Mn.	S.	P.							
Si 3	As cast,	0·35	0·51	...	...	...	...	6·4	6·4	0	0	0	50 2
Si 3A	Annealed,	...	...	...	...	...	...	16·5	23·1	4	5	117°	54·1
Si 1	As cast,	0·41	0·23	0·13	0·02	0·01	...	16·6	16·6	0	2	0	50·7
Si 1A	Annealed,	...	...	...	...	...	...	11·9	28·9	16	17·3	33°	...
Mn 1	As cast,	0·35	0·08	1·34	0·03	0·02	...	22·7	39·0	4	4	13°	42·3
Mn 1A	Annealed,	...	...	...	...	...	...	23·6	37·9	18	25	150°	52·4
403	As cast,	0·34	0·15	1·58	0·06	0·06	...	23·1	35·8	8	9	33°	41·7
403 A	Annealed,	...	...	...	...	...	...	17·3	32·1	21	28	180°	...
	Annealed,	0·27	0·20	0·90	0·04	0·04	...	...	30·0	32·0	50·0	...	...
	As cast,	0·39	0·58	1·42	0·03	0·02	...	29·6	39·1	3	2	10°	41·7
	Annealed,	...	...	...	...	...	...	22·6	39·1	16	20·5	135°	44·1
W. & B.	As cast,	...	...	...	...	...	Cr	...	31·5	13·0	13·8	50°	...
W. & B. A	Annealed,	0·3	0·1	0·53	0·05	0·07	0·19	...	32·7	15·0	22·5	120°	...
	Forged,	...	...	...	...	...	...	...	34·2	29 0	46·7	180° U	...
Ni B.	As cast,	...	...	...	...	...	Ni	18·0	23·1	24·4	62·2	180°	...
Ni B. A	Annealed,	Nil	...	...	...	...	0·95	13·9	21·6	17·5	33·2	180°	...

The Annealing of Steel Castings.—Steel castings are still sometimes annealed in ordinary reverberatory furnaces of the coal-fired type designed with the proportion of grate area to that of the bed to give a temperature of 1000° C. with comparative ease. They are, however, more frequently annealed in a reverberatory type of furnace, but gas-fired with gas from the ordinary producers. The annealing recommended by Prof. Arnold for general work, in his paper already quoted, is to heat the castings up to about 950° C., keep them there for about 70 hours, and (luting up the furnace) cool as slowly as practicable, generally taking about another 100 hours.

One objection to the long annealing is the very considerable scaling of the castings, and, for small experimental work, to minimise this Prof. Arnold recommends that the castings should be packed in lime in covered cast-iron boxes. The old annealing furnace of the Sheffield University is a coal-fired reverberatory type; but recently a Clinch-Jones patent heat treatment furnace, embodying a simple but ingenious feature, has been installed with an idea of testing its capabilities for several types of heat treatment. Pressure of organisation and other experimental work has prevented its being thoroughly tested, but preliminary trials, and the experience of Mr. Clinch-Jones himself, show that scaling is reduced to a minimum. Fig. 197 is from a drawing the patentee has specially prepared for this work, and represents his latest type, excepting that sloping wrought-iron fire-bars have been substituted for the rather troublesome step grate, and a water bosh now forms the bottom of the ash-pit. The fundamental idea is that while the materials are heated in a muffle by keen flames outside the walls of the muffle, virgin gas from the producer is allowed to come into the muffle and combine with all the oxygen that may enter, thus preventing it getting to the castings to scale them by oxidising them at their surfaces.

FIG. 206.—Structure of Steel Casting. × 66.

The principal constitutional changes that take place during annealing may be illustrated by the following micrographs:—Fig. 206, representing an unusually perfect example of the triangular structure of this type of steel as cast, was first published by Arnold & M'William in *Nature*, 10th November 1904, page 32, to show that the triangular markings found in meteorites, and known as Widmannstätten figures, may also be found in many castings, and, in this case, they are very perfectly exhibited. The microstructure of the same casting, after annealing, is shown in the lower half circle, and the great change produced by this treatment is obvious. The straight-line triangular structure is generally typical of one kind of brittle casting, and the fact that a ¾-inch round bar bent over a ⅜-inch radius broke at 43° when of the upper pattern, and, when of the lower, bent double without fracture, shows clearly how this change in structure has produced a very marked change in the mechanical properties. Fig. 207 shows the structure of a portion of a large commercial open hearth casting, which had originally a similar structure to the above, and was insufficiently annealed, part of the bad structure being retained and part altered, with the result that a 1-inch square test-piece from this casting (C.C. 0·24,

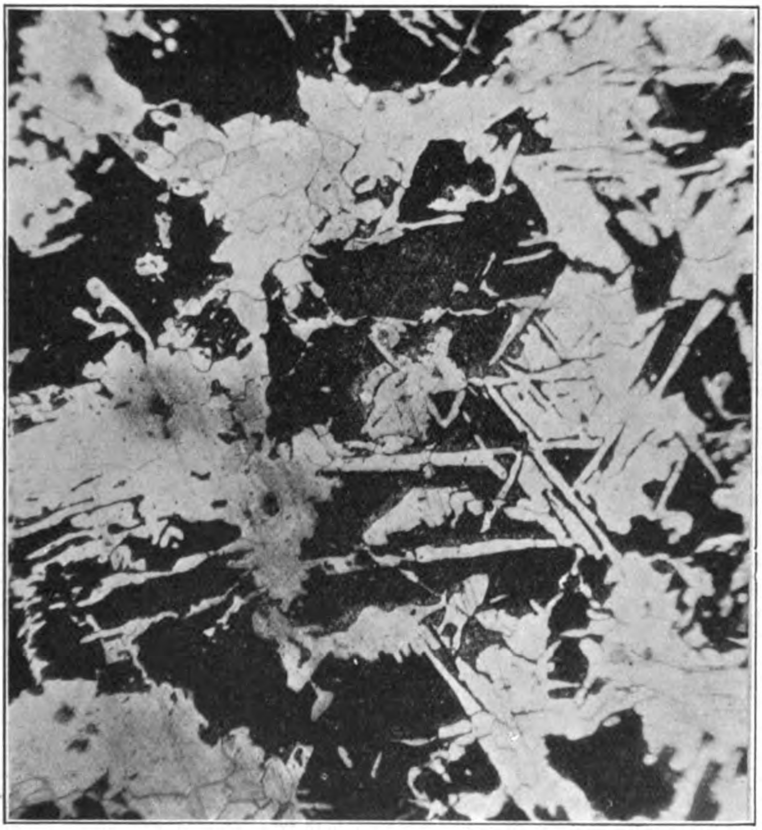

FIG. 207.—Structure of Steel Casting (Insufficiently Annealed). × 45.

Si 0·15, Mn 0·8, P 0·04, S 0·05) gave only a 40° bend and broke; while, after thorough annealing, its structure was represented by fig. 208, and it gave a bend of 101° without fracture, with a tensile test of 33 tons per square inch maximum stress, 30 per cent. elongation on 2 inches, and a reduction in area of 41 per cent. Sometimes the original brittle casting has a structure like fig. 209 (also from a large commercial open hearth casting of C.C. 0·3, Si 0·28, Mn 0·8, P 0·04, S 0·04), which gave a very poor bend, due, in this case, to the weakening influence of the sulpho-films in the ferrite rivers. Fig. 210, again, is from a similar casting (C.C. 0·27, Si 0·2, Mn 0·9, P 0·04, S 0·04), giving in tension a maximum stress of 30 tons, 32 per cent. elongation on 2 inches, 50 per cent. reduction in area, and a bend of 100° without sign of fracture. In this case it is important to notice that all trace of the triangular structure has gone, and the sulpho-films are balled up into the practically harmless form of little blebs. Unfortunately, with this type also, annealing does not always ball up these films, and fig. 211 represents the structure of a casting of general composition, C.C. 0·23, Si 0·2, Mn 1·0, P 0·04, S 0·05, which very stubbornly resisted balling up by ordinary annealing; for, after the usual process, the sulpho-films can be seen to retain their continuity in some

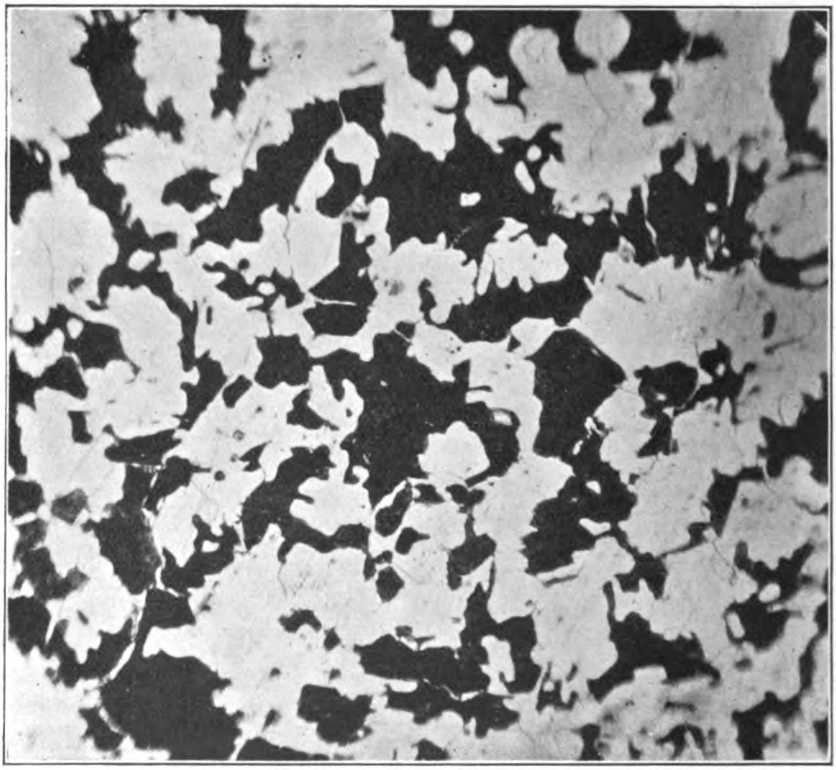

FIG. 208.—Same Specimen as shown in fig. 207 after Thorough Annealing. × 45.

cases, while in others they are balled up, and in yet other cases, all in the same field, they have merely segregated sufficiently to break the continuity by forming little elliptical masses with, however, their longer axes still in line, so that the bend was only 49°. Fig. 212, C.C. 0·6, Si 0·27, Mn 0·7, S 0·06, P 0·06, shows large groupings of ferrite and pearlite individually small, with large divisions of ferrite between ; but with an evil-looking sulphide villain at the cross roads resulting in the inferior tensile test of elastic limit 20 tons, maximum stress 31 tons, elongation 6 per cent. on 2 inches, reduction in area 7 per cent., and a bend not even worthy of being recorded. Fig. 213 is also of interest, as showing a similar case in a high carbon casting of C.C. 0·5, Si 0·25, Mn 1·0, P 0·06, S 0·05, with an elastic limit of 25 tons, a maximum stress of 43 tons, elongation and reduction in area each 10 per cent. and a bend of 25°. Only three examples of the good to several of the diseased have been given, as, although the former might be multiplied indefinitely from everyday work, it is when the latter are found that a study of their present state, and the conditions under which they have been formed, are of the greatest value to those who would produce the best, and it is a necessary study, for it is only in works in fairy-tales that such examples never occur in connection with the extremely difficult but fascinating art of producing first-class steel castings.

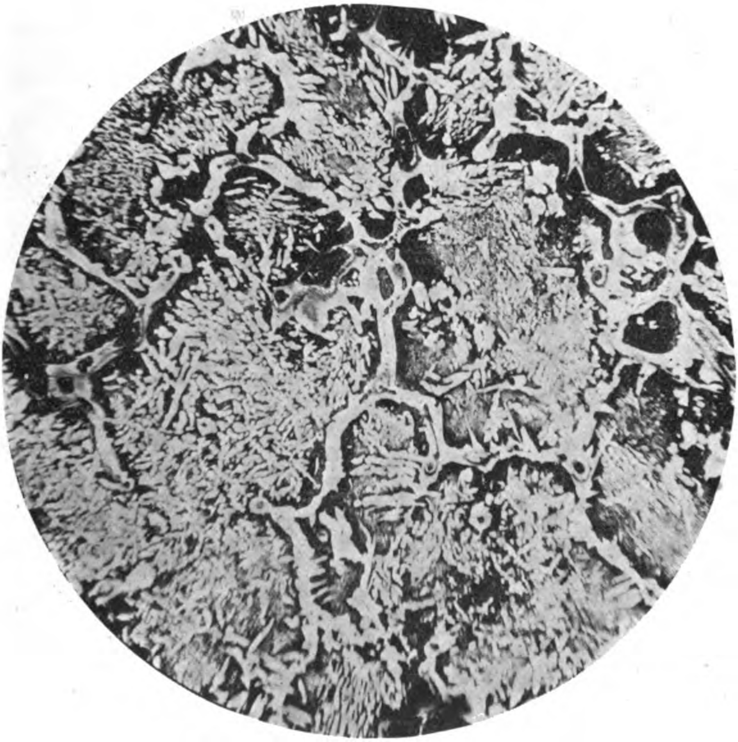

FIG. 209.—Structure of Steel Casting with Rivers of Ferrite and Sulpho-films. × 45.

Not only is there this general change in the form and grouping of the constituents, but the pearlite is different in itself, long annealing generally causing its striæ to become better defined. This change is in many cases beneficial, but in others it may be harmful, as in castings of saturated steel, and therefore entirely composed of pearlite. While eliminating internal stresses, and readjusting crystallisation, it may cause a new brittleness due to the lamination of the constituents of the pearlite (see fig. 232), but this may be removed, without reintroducing the other evils, by heating the casting to a fair red heat above Ac1 (about 730° C.) and cooling in the air, as, usually, they are not large castings (see fig. 233).

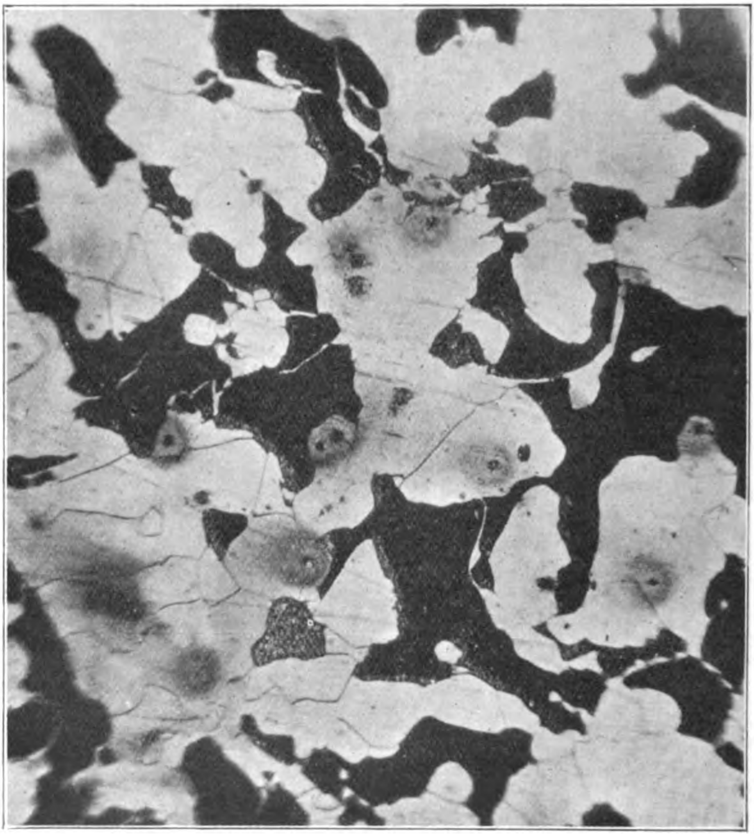

FIG. 210.—Structure of Steel Casting with Sulpho-films Balled up. × 45.

The authors have made castings for the market of an ordinary turning tool mixture, free from blowholes, by the use of aluminium; these were used without annealing, as, having only to stand being pressed through thin material, annealing would have deteriorated them for their work. Also castings of self-hard mixtures, such as the Martino steel castings, will obviously not require the customary treatment of ordinary steel castings which are annealed to give them ductility, but must be treated according to the usual well-known needs of self-hard steels. If such castings are to be tooled, they must be annealed to soften them, as they are dead hard when they cool from the mould; but a twelve hours' annealing should generally suffice, remembering never to draw the castings until they are cold enough to handle quite comfortably, or they will sensibly harden to the tool. After tooling, they may be re-hardened by suitably heating the cutting parts, or the parts required hard, to a temperature depending on the nature of the steel, and cooling again as directed by the makers, say, in a blast of air, in hot water, or in a moderately thick (viscous) oil.

Crucible Process.—In the manufacture of steel for castings by the crucible process, roughly, the resulting steel (as poured into the mould) has the mean composition of the material charged. There are, however, certain small changes during the process, which are important when making to a specification between narrow limits, and, without doubt, important also in their influence on the steel itself. There may be either an increase or a decrease in the percentage of carbon over the calculated composition, and the amount of this variation must be found for the particular circumstances. If melting is effected in a plumbago crucible, the carbon will increase, and the

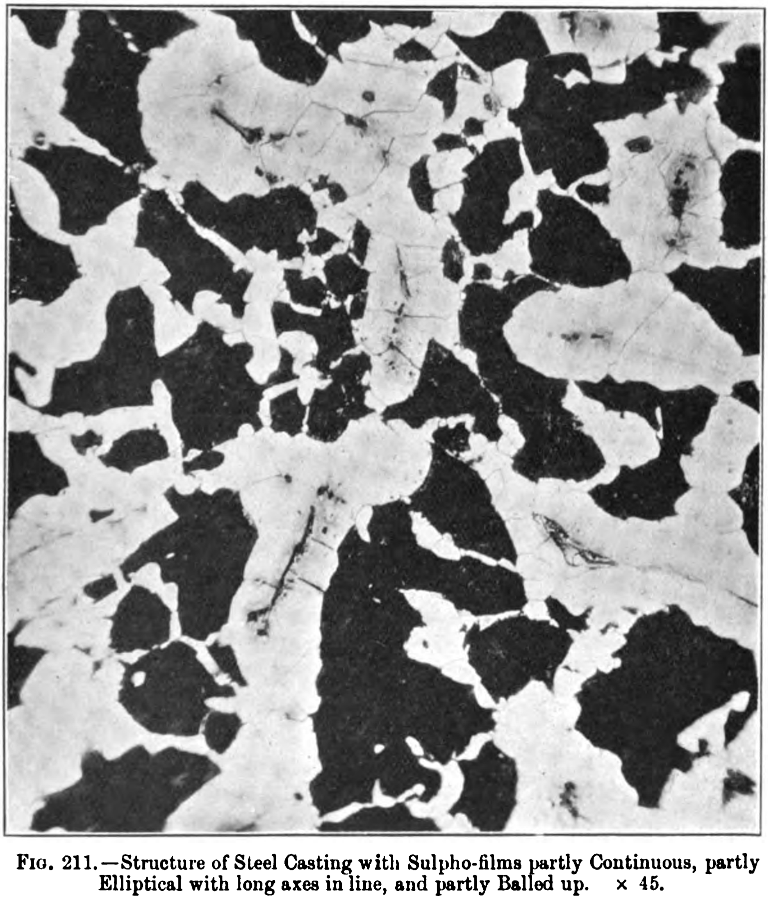

FIG. 211.—Structure of Steel Casting with Sulpho-films partly Continuous, partly Elliptical with long axes in line, and partly Balled up. × 45.

probability is that the increase will be less from the new crucible onwards during successive meltings. With the ordinary Sheffield pot, and materials free from rust, the carbon comes practically to calculation, with, perhaps, a slight increase in the first round and decrease in the third, but for the general run of casting specifications practically negligible. The silicon and manganese are subject to important variations. As an example, a mixture calculating to ·06 per cent. silicon and 0·6 per cent. manganese as charged, when melted with care by a good melter and killed by fire, that is, left in the hole for 30 minutes or so after being thoroughly fluid, will analyse in the casting about 0·12 per cent. of silicon and about 0·35 per cent. of manganese, taking actual figures. The manganese most probably decomposes some silica, in the form of a silicate borrowed from the crucible round the ring at the surface of the molten metal, and throws silicon into the steel, while the manganese itself suffers oxidation. Thus,

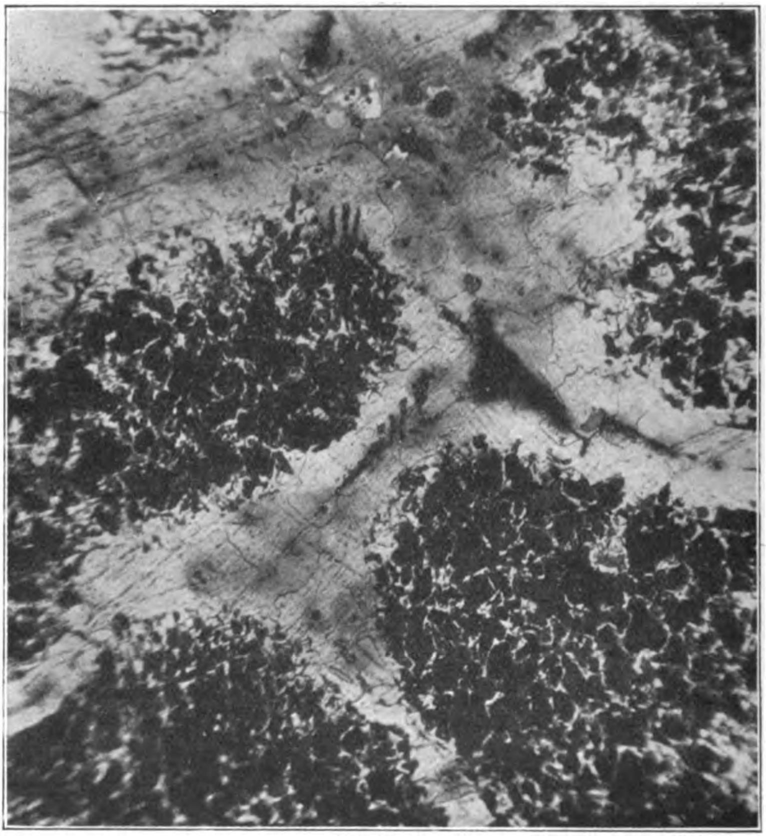

FIG. 212.—Structure of Steel Casting showing Ferrite, Pearlite, and Sulpho-films and masses. × 45.

$$2SiO_2 + \underset{110}{Mn_2} = 2MnO,\ SiO_2 + \underset{28}{Si}.$$

If this be the reaction, then the ·06 of silicon added must have been the cause of 0·24 per cent. of manganese being oxidised, and it will be seen that 0·60 – 0·35 = 0·25 per cent. Mn has gone. Any oxygen that may be present in the steel, or that has been admitted while the lid was off for inspection, may be taken up either by the silicon or the manganese; but it will be seen later that, even in the open hearth, Si and Mn may be reduced from the slag by carbon from the molten steel. Another explanation is that the Mn is oxidised to MnO, which attacks the crucible, forming manganous silicate, and that the carbon of the steel reduces silicon from this slag. Whichever be the true explanation, the facts are clear, for the longer the molten steel is kept in the crucible the more manganese is eliminated and the higher the silicon becomes. During the process of melting, the sulphur invariably increases, with ordinary commercial cokes containing from ·75 to over 1 per cent. of sulphur, and, as a guide, with coke about 1 per cent., the increase in sulphur will run to something like 0·015 per cent., while a particularly bad

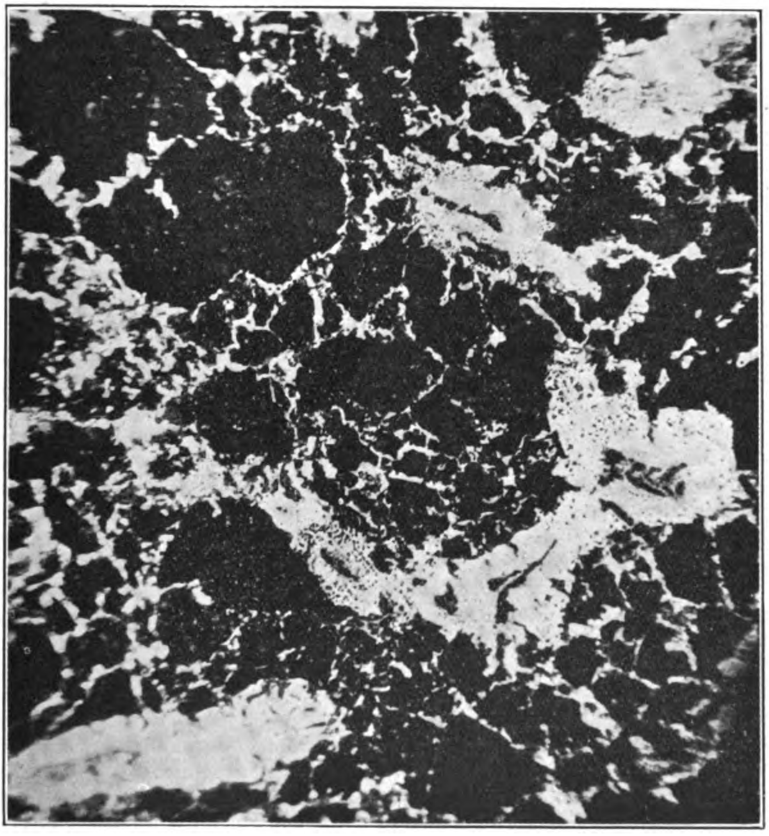

FIG. 213.—Structure of Steel Casting showing Ferrite and Pearlite. × 45.

coke of 1·75 per cent. sulphur has given an increase of over 0·02 per cent. sulphur. Also, when inferior coke dust high in sulphur is used in making the crucibles some of its sulphur is taken up by the charge. The phosphorus in the casting will be practically the same as by calculation from the mixture. To sum up, under normal conditions, with a clay crucible, the carbon shows little and the phosphorus no variation from the calculation, the sulphur and silicon an increase and the manganese a decrease. While the figures give an idea of the respective magnitudes of the differences and an insight into the nature of the changes in crucible melting sufficient to make a very good first trial for a casting to specification, they should be taken mainly as a warning of the changes that do take place; and as the amounts vary with the varying conditions of melting, and, for the same conditions of melting, with charges of varying compositions, the alterations for the special case in hand should be determined by trial charges.

The crucibles for steel melting are made of a mixture of the best fire-clays, with a small proportion of coke dust from the best quality melting coke; after the required amount of water is added, they are well mixed, and, finally, systematically trodden by the bare feet in a way that produces a quality of crucible that has not yet been produced at the same cost by any mechanical process. The clay is then divided with the spade into lumps suitable for one pot each, and these are carefully adjusted to weight, so that the exact amount necessary for one pot may be worked on a table until the potmaker satisfies himself that he has released all entrapped air. The ball is then thrown into a well-oiled flask, oiled with a kind of crude petroleum, and the plug is forced down into the clay until the guide pin of the plug enters the hole in the bottom of the flask, when the plug is driven home by blows from a heavy wooden mallet. The plug is withdrawn, the top of the crucible shaped with a hand tool, the flask lifted on to a stand, eased and then dropped, leaving the crucible standing clear. The crucible is lifted on to a board holding two, and these are taken away to air-dry. They should be allowed to dry for several weeks, and then, the night before they are required, they are placed mouth down in an annealing grate, a rectangular cavity of suitable grate area to pack the desired number of pots side by side with a slight clearance between them and a few inches deeper than the pot, while the bars are set as close as rough-cut 1½-inch square wrought-iron bars will go. This grate is started with a thin layer of small cold coke on the bars, a thin layer of hot on that, a thin layer of cold, the pots laid on mouth down, filled up with small coke to a few inches above the pots and left, when it will be at a red heat in about twenty hours or so. It is obvious that the pots made by the plug and flask worked by hand have a hole in the bottom; but sometimes, although the refractory mixture is trodden by foot, it is shaped by machines, and then there is no hole in the bottom. This latter is the type used for gas crucible holes.

In the morning a coal fire is made on a special grate, two stands carefully placed on the bars in each hole, some red-hot fuel from the grate put in, and coal on the top. When the fires have fairly started, the stands are cleared with a scraper, a sprinkling of sand thrown on, the crucibles drawn from the annealing furnace and placed on the stands, the lid put on, a little more coal added, the fire allowed to burn up for about five minutes, and then steel-melting coke thrown in till level with the lids. If the pots have a hole in the bottom, when they have attained a good heat, a generous double handful of a fairly refractory red sand is thrown in to make a solid bottom to the crucible, while the sprinkling on the stand cements the crucible and the stand together. A firing of coke is put on, and when the sand is set hard and the crucibles have attained a good heat the mixture is charged into them, the lid put on, and cokes added to well above the lids. If the steel is to be killed by fire, one firing will be required after the mixture is clear melted; but if by aluminium, then about 0·03 per cent. Al, or ¼ oz. to 50 lbs., may be added to the charge whenever it is clear melted, and the charge poured as soon as possible. By this process about 2½ to 3 tons of coke are required to melt 1 ton of steel, but the steel is the whole time surrounded by a reducing atmosphere. An ordinary casting mixture will take about four hours in the first round and three-and-a-half in the second. In the gas crucible process, the ordinary Siemens regenerative principle is adopted, and, instead of an open hearth, crucibles are used to hold the charges. The temperatures of individual charges are not under such good control as with the coke crucible, and the melting is done in a distinctly oxidising atmosphere, as seen from the extra slag produced in melting and the fact that crucibles from the same mixture are black through in fracture after use in the coke holes, while the fracture is partly white when they are used in the gas holes. Whether this has any deleterious influence on the properties of the castings is not yet known. The fuel consumption with gas holes is about 22 cwts. of coal per ton of steel melted.

The crucible is always cut away at the surface of the liquid metal, and hence the desirability of reducing the weights for each successive charge by 4 to 6 lbs. Thus, if 56 lbs. be the weight for the first round, 52 lbs. would be advisable for the second and 48 for the third, so as to have the cutting action on the crucible at a different level in each round. The life of a plumbago crucible is very variable, but the Sheffield crucible cracks in cooling, and lasts the three rounds of one day's work, or occasionally, in times of stress, even four rounds. The kind of materials suitable for steel casting mixtures is obvious. They must calculate out to the carbon required, to not more than the phosphorus, and rather less than the sulphur in the specification. The silicon is generally added by using high silicon pig or ferro-silicon, the manganese by the use of ferro-manganese or spiegel, and the charges are calculated as already shown in the case of cupola charges.

Acid Open Hearth Process.—For the acid open hearth process of steel making in the Siemens regenerative furnace, Siemens originally proposed melting on the hearth of the furnace pig-iron of suitable composition, having a covering of slag and gradually eliminating the carbon, silicon, and manganese by the oxidising action of ore (Fe_2O_3) added to the slag. Martin used a mixture of pig-iron and scrap, and the method almost universally employed to-day is a combination of these, the Siemens-Martin or pig, scrap, and ore process, in which a mixture of pig and scrap, in proportions generally somewhere between 65 per cent. pig to 35 per cent. scrap and 30 per cent. pig to 70 per cent. scrap, is charged, melted with a covering of slag, and purified by the addition of ore to the slag.

The general features of the process are, that, after melting down, the bath being well covered with slag, if not from materials formed during the melting, then by the addition of some slag from a former heat, the slag is brought into a fluid and (for the acid process) a basic condition by the addition of a comparatively large proportion of ore. The fining of the charge takes place at this stage; and the silicon and with it the manganese are oxidised into silica (SiO_2) and manganous oxide (MnO) which pass into the slag, while but a little of the carbon is removed. Then continuing suitable additions of ore to keep the slag in a thin or limpid and basic condition, the carbon begins to be attacked, and, coming off in the form of carbon monoxide, produces a bubbling action in the slag, when the bath is said to have come "on the boil." The carbon monoxide gas may often be seen burning to carbon dioxide as the bubbles break. At a stage of the boil dictated by experience, or, if there has been no experience, early enough in the process, after well rabbling, spoon samples well covered with slag are taken out, cooled slowly to below the carbon change point, then cooled off more rapidly, and either broken to judge the carbon by the fracture, or drilled for its estimation by the colour test. If the last few samples showed that the carbon is going down at the rate of, say, 0·15 per cent. C. per hour, and a carbon report 0·35 per cent. is handed in 15 minutes after the sample was taken, allowing another 5 minutes before the ferromanganese could be added, making 20 minutes or one-third of the hour, the bath would now probably be one-third of 0·15, or 0·05 lower in carbon, or $0·35 - 0·05 = 0·30$ per cent. The ferro will, however, add some carbon to the bath, and the amount should be calculated as already shown. Say it comes to about 0·1 per cent., this would make the bath $0·30 + 0·1$, or 0·4 per cent. C., as tapped. Again, taking the problem the usual way it occurs, required the carbon the last sample should show if the bath is to be tapped at 0·45 per cent. It is obvious that the carbon in the deciding sample should be equal to the carbon desired in the castings – the carbon added by the ferro + the probable fall during the time from taking the sample to reporting and adding the ferro. The ferro may be added either in the furnace or in the ladle. If in the furnace a loss of 40 per cent. may be allowed for, and finishing with a good quiet acid slag the loss to a great extent depends on the time between adding the ferro and tapping. If the ferro be added to the ladle as the stream runs in, the loss of manganese may be even less than 20 per cent.; but here, again, only a general idea from one's own experience can be given, and for striking a particular composition in the casting each one should determine the amount of the loss under his own working conditions.

The steel is then tapped by breaking through the tap hole in the fixed form or by partly rotating the hearth in the tilting form; it runs down the spout or lander into the ladle, from which it is transferred to the moulds by bottom pouring by means of the swan neck and stopper, as shown in fig. 27. A mean normal loss in the process may be taken at about 5 per cent. on the metallic charge.

In considering the reactions in the acid process it must be remembered that a quiet slag is mainly ferrous and manganous oxides, with something like 50 per cent. silica, and the ore added will soon dissolve in the slag, probably as magnetic oxide (Fe_3O_4). This may attack silicon in the bath; thus,

$$\begin{array}{ccc} \mathrm{Si_2 + Fe_3O_4} & = & \mathrm{Fe_3 + 2SiO_2} \\ 28 \times 2 = 56 & & 56 \times 3 \end{array}$$

in which case it is evident that the removal of one part of silicon from the bath would add three of iron to it, and thus be a good exchange. The reaction may also stop thus, however, $\mathrm{Si + 2Fe_3O_4 = SiO_2 + 6FeO}$, and silicon from the bath may merely reduce the magnetic to ferrous oxide, when the ferrous oxide will join with the silica formed and some from the furnace or in the slag and give rise to ferrous silicate. The one reaction obviously tends to make the slag more acid, while the other leaves it basic, and it is probable that both reactions actually take place. Generally, the carbon is very little attacked until the silicon and manganese are much reduced in amount; while, after this, the carbon is also gradually eliminated, although sometimes it was found that the steel at the end was much higher in silicon than in others. This point was very fully investigated by A. M'William and W. H. Hatfield, who gave some of their results in their paper, "The Elimination of Silicon in the Acid Open Hearth," *Iron and Steel Inst. Journ.*, 1902, No. 1, pp. 54 to 78, in which they show that, although the above generally accepted explanation is true when the slag is kept sufficiently basic, if the slag be allowed to become acid the carbon may still continue to be removed; but that, instead of being removed by reduction of oxide of iron, part of it at least reduces not only silica but also manganous oxide from the slag; so that, while the carbon still continues to fall, silicon, and even manganese, are thrown back into the bath, a discovery sufficiently startling to draw from Prof. Ledebur of Freiberg the remark "that manganese could be reduced from a slag so rich in silica was scarcely to be imagined, especially under the oxidising influences of the open hearth." The result, however, was fully confirmed by Mr. Lange of Gorton, after receipt of the usual advance copy of the paper mentioned, and has since been many times repeated. Full details are given in the paper; but it may be said that, after the fining stage was over and under their conditions of working, a slag containing 51 per cent. of silica was thin and active and kept the silicon and manganese low; while with 57 per cent. of silica it was thick, and silicon and manganese were both increasing in the bath, while somewhere near 54 per cent. of silica was about the balance point between the two. The following table and curves, taken from the same paper, are worthy of careful study, and in connection with it the authors remark: "It is interesting to note that, about an hour after melting, the carbon is 1·55 per cent., the manganese 0·1, and the silicon 0·05. At 1.30, when the thinnest slag has had a short time to act, and is just beginning to thicken again, the analysis is C.C. 0·86, Mn 0·04, Si 0·02. The slag is now allowed to thicken for two and a half hours quietly and steadily from reduction of base, and the analysis of the sample then shows C.C. 0·38, Mn 0·1, and Si 0·09 per cent.; then, with the suitable thinning of the slag again, all three elements are steadily eliminated until the final sample, just before adding the manganese, contains C.C. 0·14, Mn 0·065, Si 0·025 per cent. The percentages of silica in the slags corresponding to the last three samples are 53, 57, and 53 respectively."

DETAILS OF SPECIAL CHARGE NO. 1.

Time.		Composition of Bath.			Additions.		Consistency of Slag.	Composition of Slag.		
Hr.	Min.	C.C.	Si.	Mn.	Material.	Cwts.		FeO.	Fe_2O_3.	SiO_2.
		P. cent.	P. cent.	P. cent.				P.cent.	P.cent.	P.cent.
11	10	1·60	0·78	0·48	(Melted)	...	Thin	...	...	...
11	12	...	...	...	Ore	10	...	...	...	...
11	30	...	...	...	,,	4	...	...	...	...
11	45	1·54	0·35	0·20	(Boil)	...	Thin	30·8	7·1	45·0
12	15	1·55	0·047	0·11	...	...	,,	...	...	...
12	20	.	...	...	Ore	2	...	...	..	...
12	45	1·22	0·045	0·09	...	..	Thin	...	...	...
12	50	...	...	...	Ore	3	..	...	.	...
1	0	...	..	...	,,	1½	...	...	...	...
1	15	0·94	0·028	0·042	...	...	Very thin	24·1	2·5	52·8
1	16	...	...	...	Ore Lime	1 ¾	...	...	...	...
1	30	0·86	0·018	0·018	...	...	Thin	...	...	...

Details of Special Charge No. 1—*continued.*

Time.		Composition of Bath.			Additions.		Consistency of Slag.	Composition of Slag.		
Hr.	Min.	C.C.	Si.	Mn.	Material.	Cwts.		FeO.	Fe_2O_3.	SiO_2.
		P. cent.	P. cent.	P. cent.				P.cent.	P.cent.	P.cent.
2	0	0·73	0·022	...	...	...	Becoming thicker	...	...	...
2	30	0·65	0·034	0·056	...	...	Fairly thick	...	...	...
3	0	0·55	0·061	0·068	...	...	Thick	...	...	...
3	30	0·40	0·078	0·08	...	...	,,	...	...	...
3	50	0·38	0·088	0·095	...	...	Thickest	20·8	1·1	56·8
3	55	...	...	...	Ore	1	...	...	...	...
4	5	...	...	...	Ore Lime	¾ ½	...	...	...	...
4	25	0·26	0·031	0·072	...	...	Becoming thinner	...	...	...
4	30	...	...	...	Ore	1	...	...	...	...
4	35	...	...	...	Lime	⅛	...	...	...	...
4	45	...	...	...	Ore	½	...	...	...	...
4	50	0·16	0·024	0·065	...	...	Fairly thin	...	...	...
4	55	...	...	...	Ore	¼	...	...	...	...
5	13	0·14	0·025	0·065	...	...	Fairly thin	21·9	0·57	53·4

Finished steel, C.C. 0·31 ; Si 0·045 ; Mn 0·58.

Tensile Test.—Maximum stress, 35 tons per square inch ; elongation, 28 per cent. in 2 inches ; reduction in area, 49 per cent. on the forged sample.

Specification.—Maximum stress, 33 tons per square inch ; elongation, 25 per cent. in 2 inches ; reduction in area, 40 to 45 per cent.

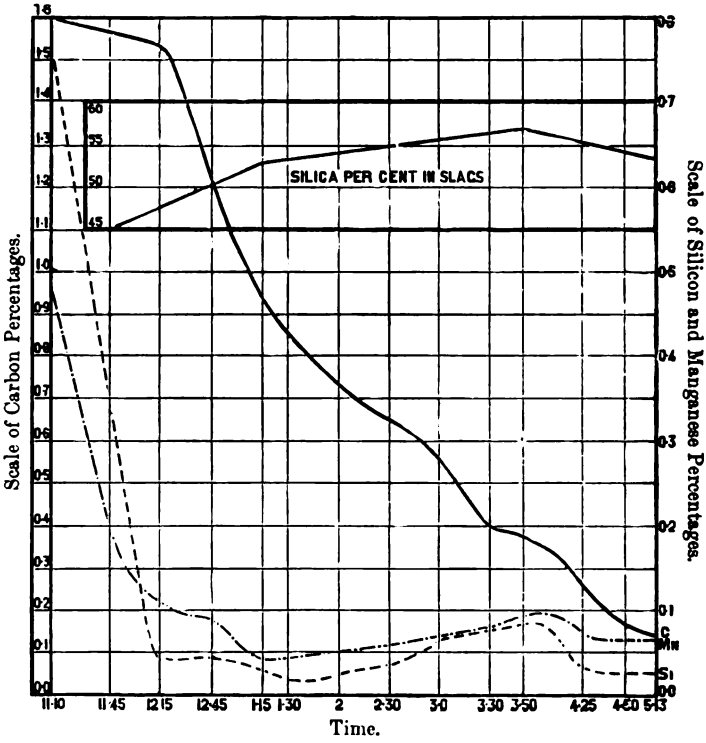

Fig. 214.

Steel of almost any desired carbon content for castings may be made by running down to dead mild and bringing the carbon up by adding a calculated quantity of pig of known composition, a process known as pigging back; but to stop the process at any desired percentage of carbon, a slowing down of the elimination process is necessary to obtain a quiet metal with the carbon within fine limits. The slag is thus allowed to exhaust itself of ore sufficiently, and thus to become comparatively acid, which, if the balance point be passed, results in a slight gradual increase in silicon; this, although it must be kept low for some forged material specifications, is not at all undesirable for metal for the great majority of steel castings, as it helps to give a quiet metal and to prevent the formation of blowholes in the castings.

Mr. Brinell, the great Swedish metallurgist, has published the results of his extended researches on "The Influence of Chemical Composition on Soundness of Steel Ingots," which ingots are, after all, steel castings cast in chills. He showed that in his practice, as a preventive of blowholes, taking the elements as found in the steel, and using manganese as his standard, silicon is 5·2 times, and aluminium, if any present, is 90 times as powerful. Hence, multiplying the percentage of silicon by 5·2, and that of aluminium in the steel by 90, and adding the results to the manganese present, he obtained a number which he called the density quotient, of such a nature that for the same density quotient he obtained the same type of ingot; for a lower quotient one with more blowholes; for a higher, one with fewer blowholes. A. M'William and W. H. Hatfield, in a paper given to the *Iron and Steel Inst. Journ.*, 1904, No. 11., pp. 206 to 220, on "Acid Open Hearth Manipulation," state that their "general experience had corroborated that of Brinell; but during the progress of their research they made the interesting discovery that those charges treated to one hour's thickening of the slag required a lower density quotient than that for normal heats to give a certain type of ingot; charges treated to two hours' thickening required a lower number still; while in a heat run specially fast, and finished with a much higher density quotient, the ingots corresponded to a lower number. The following figures are given tentatively as a matter of interest, for they appeal to the writers as being of considerable importance, and they are engaged in following the matter up through this and other channels:—

Treatment of Charge.	Density Quotient.	Type of Ingots.
Thickening, 2½ hours, .	0·814	good
Thickening, 1½ hours, .	1·000	good
Ordinary, . . .	1·35	good

The matter is quoted here, as it seems to give another point in the clearing of open hearth practice, and shows that all does not depend on the final composition as given in a 'complete ordinary' analysis, but that there is importance in the history of the charge before it has attained to that composition. Also it might perhaps become of interest if sound castings were wanted with smaller amounts of silicon and manganese and without the use of aluminium."

It is evident that, as the nearer the bath of metal comes to pure iron the higher is its melting point, the temperature must be kept up to suit the composition of the bath. The fuel consumption runs from about 7 to 12½ cwts. of coal per ton of steel melted, and the average loss is about 3 to 5 per cent. on the metallic charge; for, although a suitable pig may only contain 93 per cent. of iron, or a 2 to 1 mixture 95 per cent. of iron, and some must be oxidised during melting down, there is undoubtedly some exchange of iron from the slag for silicon or manganese or carbon, when the molten material is under its covering of slag. When considering suitable metal for the process, the mixture of pig and scrap must be as low in sulphur and phosphorus as the requirements of the specification; but otherwise there is a great freedom of choice, although, if the sulphur be low, this generally means fairly high silicon in the pig, which will then carry a good proportion of scrap. The ordinary English Siemens pig is generally mixed Bessemer numbers (see table on p. 227), running over 2 per cent. Si, under 1 per cent. manganese, with sulphur and phosphorus, say, about 0·06, but depending on the specification for the castings.

Basic Open Hearth Process.—The basic open hearth process is worked in a similar furnace to the acid, only the bottom is made of some basic material, as already described. Suitable pig and scrap are melted, or, in some cases, direct metal is charged on to the hearth, and lime and ore are added, for in this case a highly basic slag is maintained, and ultimately the carbon, silicon, manganese, and phosphorus are oxidised, and sometimes also a proportion of the sulphur is removed. As before, there is a fining stage, and then the boil, when practically all the carbon and phosphorus are eliminated by additions of ore and lime; and, during the process, if the ore be low in sulphur, and fluor spar be used to thin the slag, a proportion of the sulphur may be removed. 20,000 tons of fluor are said to have been used for steel-making purposes in U.S.A. in 1905. It will be seen that as the phosphorus must be brought low, and, if present in quantity, it is the last to go, all the elements, carbon, silicon, manganese, sulphur, and phosphorus, must be brought low, and if carburising material be added in presence of the slag, some of the phosphorus is apt to return to the metal; hence, the steel must be tapped to separate the slag, or, in the tilting form, the slag is poured off and the carbon raised to the desired extent by adding ferro or spiegel or by the Darby process of passing into the metal a known weight of charcoal.

For the basic process it is obvious that the charge should be low in silicon, for this forms the acid oxide, silica, which would either attack the bed or banks or require a large amount of added lime to keep the slag sufficiently basic. Sulphur, nearly as low as specified for the castings, is also required, as sulphur elimination is not very reliable, is expensive, and bad for the banks. The phosphorus may be almost anything in reason, only the higher the phosphorus, the longer the purifying process is said to take. Manganese is usually high in the real basic pigs, owing to the needs of the blast furnace in making low silicon pig, with low sulphur and coke as fuel; but the manganese helps the elimination of sulphur, although excess is wasteful, as it is oxidised and passes into the slag, the amount present generally being 1½ to 2 per cent. As an example, a common specification is silicon less than 0·9, and sulphur not more than 0·06. Talbot, in his basic continuous process, claims a yield of 105 per cent. on the metallic charge.

The Bessemer Process and its Modifications.—There only remains the Bessemer process in which pig-iron is purified by a blast of air, and, with an acid or a basic lining respectively, the same elements are eliminated as in the corresponding open hearth processes. Molten pig-iron, either direct from the blast furnace, or after remelting in a cupola, is delivered into the hot vessel, hot from a previous blow or heated by a fire or by a gas or an oil flame. Air is made to act upon the liquid pig-iron by being blown from underneath (ordinary Bessemer), from the side (Robert), or along the surface (Tropenas); and the air in oxidising carbon, silicon, and manganese with an acid, and carbon, silicon, manganese, and phosphorus with a basic lining, at one and the same time purifies the metal and raises its temperature to the desired extent. In the acid process, the sulphur and the phosphorus in the pig must be slightly less than in the specification, for as, in this case, the oxygen in the air merely combines with the impurities and carries them off or leaves them in the slag, there is no exchange of iron for impurity, as in the open hearth process; and, although the impurities oxidised supply the necessary heat, they are a dead loss in weight, the loss amounting in some cases to as much as 20 per cent. Hence, as there is no elimination of sulphur and phosphorus, and the amount present is concentrated in a smaller total, the sulphur and phosphorus in the pig must be less than required in the casting. The skill in the working of this process, then, is addressed to charging a composition of metal, which, under the special circumstances, shall bring the bath to the temperature required for the sizes, number, and types of castings to be made, when the proper degree of purification is reached. Ledebur has calculated that the rise in temperature of the bath, due to the combustion of 1 per cent. of each of the constituents, is as under:—silicon, 300° C.; phosphorus, 183° C.; manganese, 69° C.; iron, 44° C.; carbon, 6° C. It will be seen that silicon is of the chief importance; and generally, in the acid process, it is mainly to the alteration of this element, the others remaining approximately constant, that change of composition for different conditions is directed, except in Swedish practice, in which a considerable proportion of the heat is supplied by the oxidation of manganese. In ordinary English Bessemer practice, 2½ per cent. silicon is a fair average with ½ to 1 per cent. manganese; in American, with very hot fluid metal and quick working, 1½ per cent. silicon would be nearer the average; while in Sweden, for many purposes, as much as 2 per cent. manganese is used with a comparatively low silicon.

In the basic process, a minimum of silicon is desirable, because of the slagging effect of the acid oxide, silica, on the basic lining, and therefore only sufficient is used, with the manganese also present, to keep the bath in good condition until the carbon has all gone, when, during the after-blow, the period of the blow after the flame has dropped, the phosphorus is oxidised, and, if the right amount be present, the bath is thus brought to a temperature suitable for finishing the heat and pouring the necessary castings.

The authors are fortunate in obtaining from the well-known American Tropenas expert, Mr. Arthur Simonson, the following detailed description of the Tropenas process. Mr. Simonson is a son of Sheffield, was trained in its Technical College, and took his first practical steps in its works:—

The Tropenas Process. By ARTHUR SIMONSON, Philadelphia, U.S.A.—**Historical.**—The Tropenas process was patented by Alexandre Tropenas of Paris, France, in the beginning of 1891; and the first converter, having a capacity of 800 pounds, was erected at the works of Edgar Allen & Co., Ltd., in Sheffield. Results obtained from this baby converter, under the most trying circumstances of inexperience, smallness of the apparatus, etc., were so encouraging that a larger vessel, of two tons capacity, was very shortly erected, and the process at once became a commercial success. Since that time, by virtue of its intrinsic merits, it has progressed, until, at the present time, outside of the open hearth and Standard Bessemer processes, it is, probably, the largest producer of steel. About 1898 it was introduced into the United States, where it has met with great success, having been adopted by the Government, and used in two navy yards and one arsenal. Altogether, in the United States at this time there are over twenty converters in use in about fifteen plants.

Object and Scope of the Process.—The object of the Tropenas process is to fill a field left vacant by the other processes in use. To ascertain what this field is it will be necessary to look at the other processes and see what are their limitations. First, we have the open hearth process, supreme for the manufacture of large castings and heavy tonnage, but, needing to be kept going continuously night and day; the plant is very costly, and it is but ill suited to the fluctuations of trade. On the other hand, it is probably the cheapest process to operate when installed on a large scale and operated to its full capacity. The crucible process, while it makes the very highest grade of steel, has a very small capacity and very great cost of production. The Tropenas process occupies an intermediate position, and while it necessarily has its limitations it fills a wide and increasingly large field. It is exceedingly elastic, accommodating itself to changes in the volume of business with great economy. It produces hotter steel than any other process, gives great facility in handling, and produces small quantities at a time—two tons being the standard capacity—making it unnecessary to have a great quantity of moulds ready at one time, and thus reducing the amount of floor space required. The steel may be carried long distances in hand ladles or shanks, and poured into small and complicated castings, which replace forgings, malleable and grey iron castings. The development of automobiles, motor boats, and other enterprises calling for immense power to be developed in engines of small size and weight, has largely been made possible by the aid given to the designer by the Tropenas process.

Description of Plant and Process.—The Tropenas process consists, essentially, in the melting of a chemically calculated mixture of pig-iron and scrap in a cupola, the transference of the molten material to a special type of converter and its conversion to steel therein. The reactions of the process are identical with those of the Bessemer and open hearth processes; it is only in the manner of producing the reactions that there is any difference. The object being to produce very hot steel, as nearly free from occluded gases as possible, the converter is designed to conserve and increase the heat as much as possible, and, by preventing ebullition of the bath, to keep out any gases not necessary for or not caused by the decarburisation. In this, in particular, lies the fundamental difference between the Tropenas and all other pneumatic processes; mechanical disturbance, gyration or ebullition of the bath is reduced to the minimum. In all the other processes the aim is to cause as much disturbance of the bath as possible, allowing the air to penetrate to every part of the mass. Tropenas found this was not necessary, and that better steel was produced by its omittance. The converter in general shape is similar to a Bessemer converter, the main difference being in the location and description of the tuyeres. A good general idea of the shape of the converter is given by the illustrations, figs. 215 and 216. Fig. 215 is a photograph of the converter, and fig. 216 shows a horizontal and vertical section, giving the disposition of the tuyeres and the approximate angle at which blowing takes place. The operation is somewhat as follows:—

The cupola practice is exactly the same as grey iron foundry practice, except that the slag hole is fixed at such a height that the necessary amount of iron is contained in the cupola when melted up to that height; this is found by one or two experiments. The requisite amount of iron being melted, it is transferred to the converter and skimmed clean of slag. The position of the converter is then adjusted so that on looking through the tuyeres the metal is seen to reach exactly to the lower edge of the circular bottom tuyeres. It must not run into the tuyeres ever so slightly, but must at the same time be well up, so that the blast entering will skim along the exact surface. At this stage the vertical axis of the converter should make an angle of from five to eight degrees with the vertical. A little iron should be put in, or taken out, till this angle is reached. Blast from a blowing engine or rotary positive pressure blower is then turned on through the lower tuyeres only, the upper ones remaining closed at this time. The pressure is about three pounds. At the commencement, sparks and smoke are emitted from the mouth of the converter for about four minutes, if the composition of the iron is correct and it has been melted hot in the cupola. At the end of this time, the temperature having risen, a flame appears, which gradually increases in size and brilliance until, after about ten minutes' blowing, we have what is known as the boil. After a few minutes this dies down considerably, and the blow remains quiescent for a time. Then the flame increases in size once more, attains the maximum brilliance, and, finally, dies down for the last time. This is the end of the blow, the carbon, silicon, and manganese being reduced to their lowest limit. The converter is turned down, the blast shut off, and a weighed amount of ferro-

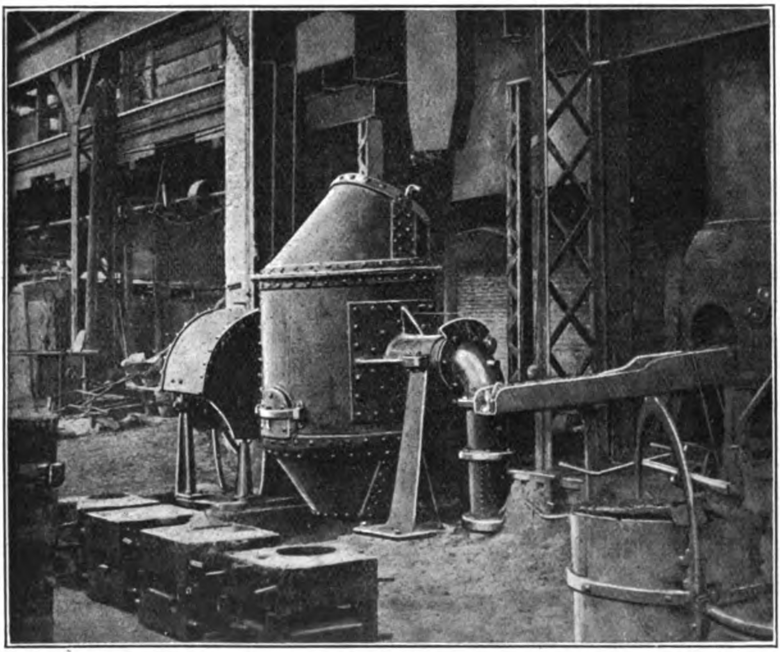

FIG. 215.—Tropenas Plant.

silicon, ferro-manganese, or silicon-spiegel added to recarburise the steel to the desired point. This is, properly speaking, the end of the Tropenas process.

Handling of the Product.—On account of the high temperature of Tropenas steel there is great latitude in its manipulation. Its freedom from thin, watery slag, and its great fluidity, enable it to be poured over the lip of the ladle, instead of having to use bottom pouring ladles. This gives great control over casting temperatures and speed of pouring. It may be carried around in shanks or hand ladles, and a great number of moulds poured with one ladle. There is no excuse for running a mould short, as the operator can always see the amount of steel he has in the ladle.

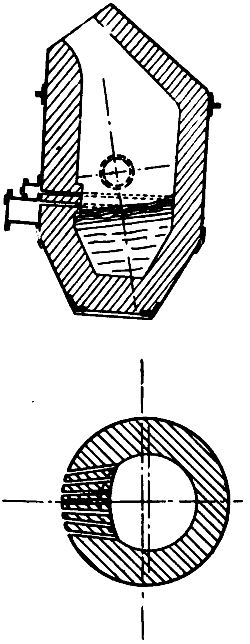

FIG. 216.—Tropenas Converter for Surface Blowing.

Important Claims made for the Process.—1. The form of the bottom of the converter gives a greater depth in proportion to the surface area and cubic contents than in any other pneumatic process, preventing the disturbance of the bath when blowing.

2. The symmetrical position of the tuyeres from the centre tuyere prevents any gyrating or churning of the bath. This is directly opposed to all other processes.

3. The special position of the bottom tuyeres during blowing, so that they are never below the surface of the bath, reduces the power necessary for blowing, as only enough air is introduced to make the combustion and not to support or agitate the bath.

4. The oxidation of the metalloids takes place at the surface only, the reaction being transmitted from molecule to molecule without any mechanical disturbance.

5. The addition of a second row of tuyeres completely burns the CO and H produced by the partial combustion of carbon and the decomposition of moisture introduced with the blast, and this increases the temperature of the bath by radiation.

6. Very pure steel is obtained, as the slag and iron are not mixed together.

7. There is a minimum of waste on account of the bath being kept comparatively quiet.

8. Less final addition is needed on account of the purity of the steel and its freedom from oxides.

Chemistry of the Process.—No fuel is needed in the converter, the metal being introduced in a liquid state and the subsequent increase of heat being brought about by the combustion of the metalloids which it is desired to remove. These elements are silicon, manganese, and carbon, of which silicon is the most important, contributing by far the greatest part of the useful heat. It is therefore necessary that the composition of the bath before blowing should be that which has been found to give the best results. No particular mention is made of sulphur and phosphorus, except to say that they are as unaffected here as in any other acid-lined furnace, and the content of these elements in the finished steel will depend on how much the melting stock contains. The cupola mixture generally consists of low phosphorus pig-iron and steel scrap, consisting of runners, risers, and waste from previous heats, and as much as 50 per cent. of scrap may be carried successfully. They must be mixed in proportions such that the analysis, after melting, will be:—

Silicon, ...	1·90 to 2·25	per cent.
Manganese, ...	·60 to 1·00	,,
Carbon, about, . . .	3	,,

The result of low silicon is to make the blows colder, and of high silicon to make the blows unduly long and increase the wear on the lining. Manganese should be kept within the limits specified, low manganese tending to make the slag thick, and high manganese making the blow sloppy and corroding the lining.

During the first period of the blow the silicon chiefly is oxidised and the carbon changed from graphitic to combined. The manganese is the most active element in the middle of the blow, being most rapidly eliminated at the boil. The last period is the carbon flame, and the indications are so plain that it is feasible to stop the blow before all the carbon is burned out, thus reducing the amount of carburiser needed. In addition to these elements a certain amount of iron is unavoidably oxidised, and the total loss of all elements included is about 12 per cent.

Converter Linings.—The converter is generally lined with an acid, that is, a silica lining. Successful experiments have been made with a basic or dolomite lining, but it has never been developed commercially. The lining may be made in a variety of ways. Special shaped blocks made to fit the converter may be used, or the regular standard brick shapes. This is a matter of choice, but the material must be of the highest grade silica stock, burnt at the highest possible kiln temperature. They usually contain from 95 to 97 per cent. of SiO_2, and are practically free from lime and magnesia.

Another method frequently used is to ram ground ganister around a collapsible form. This is probably the cheapest method. Before making the first blow the converter is made white hot by means of coke or fuel oil.

CHAPTER XXXIII.

NOTES ON METALS OTHER THAN IRON, INTRODUCTORY TO ALLOYS.

THE metals themselves in a state of purity, even of commercial purity, are seldom used for the making of castings. That the influence of impurities or admixture on metals is great is a fact brought prominently forward at every turn of experiment and by every memory of experience. Still, the changes, though in many cases profound, are seldom revolutionary; and as they are, of whatever magnitude, still changes in the properties of the main constituent, it is well to consider the properties of at least the commercially pure samples as preparatory to the study of alloys. In the case of iron it has already been indicated what a very large amount of skill and patience has been expended on that metal, most difficult to prepare in the pure state, to obtain the values for its mechanical and physical properties as a foundation for comparison with those of its varieties, wrought-iron, steel, cast-iron, and malleable cast-iron. From this point of view the properties of such metals as copper, zinc, tin, lead, nickel, aluminium, and silver are of interest as the bases of various alloys used in the cast state. A word also may be said about antimony, bismuth, and mercury, used to some extent in modifying alloys, if only for the purpose of recognising them among other metals. An extensive experience in determining various properties of the varieties of iron and steel convinces one that exact figures cannot be given even for wrought materials; and, where determinations must be made on the cast material, still greater variations will occur in results obtained on different samples, not only owing to slight differences in impurities and in structure which may happen in the wrought condition, but also in the number and disposition of small blowholes, and shrinkage places (even in apparently sound material) in the cast state. The numbers given may, however, be taken as approximately correct, and more than accurate enough for general use in the foundry. Bands of skilled experimenters have recently been redetermining many of the numbers required for the table at the end of this chapter, and, wherever available, the latest work has been examined and incorporated. The enormous amount of work that has been expended on the determination of the figures in this small table can hardly be estimated. The atomic weights determined and redetermined, ever necessary for all analyses, are also required for the study of the compounds formed in alloys. The value of specific gravity or weight compared with volume need hardly be pointed out to the founder who so frequently uses it in calculations of weights required for given castings. Specific heat, though less prominently useful, is interesting, say, in the comparatively long time it takes to melt aluminium, considering its melting point. Melting points come forward at every turn, and memory recalls a case where we asked a good melter accustomed to hard steel to melt one heat of lead-antimony alloy, with the passing remark, "now, keep it cool"; coming in later we found the place filled with antimonial fumes, and the alloy at a bright cherry red, while, as a matter of fact, a hot crucible on the floor melted the required charge thoroughly. The coefficient of linear expansion gives a measure of contraction after solidification, the electric and thermal conductivities being obviously useful in many special cases.

The conductivities for heat have the least corroboration, and those for electricity are varied so much by small quantities of impurities and changes of structure that the figures given must only be taken to refer to pure metals, and for accurate work must be determined on the samples used.

Copper has a very characteristic feature in its peculiar red colour, which, on the fibrous fracture of a sample of best tough pitch, nicked and bent double without breaking off, is a beautiful salmon pink. In similar samples containing increasing amounts of cuprous oxide, brittleness develops, and the fracture approaches a brick-red colour. The colour of pure copper, as ordinarily seen, may be said to be the real coloured rays, as sifted out by the metal, mixed with a large proportion of white light reflected without change; and the real colour is seen when the light has been reflected many times from the copper, as in a deep and narrow copper cup or a deep hole bored in an ingot, both of which show quite a bright scarlet; just as the ordinary yellow colour of gold becomes a bright orange under similar conditions, as in a deep goblet, gold-plated on the inside. The specific gravity of copper determined by various workers on different samples varies from 8·6 to 8·95, but for best wrought copper 8·9 may be taken as the most probable number; and in the cast state, probably, the best samples would not be more than 8·8, and in some cases as low as 8·2. The melting point of copper has been the subject of much research, and, quite recently, by the most skilled investigators with the finest of apparatus. For many years the question of whether gold or copper had the higher melting point was doubtful, and gold was given at 1045° C. and copper at 1050° C. Gradually pyrometric methods were improved, and it was also found that copper which had been melted in the air, and had thus taken up its full dose of cuprous oxide, solidified at 1065° C.; but when pure, and melted in a plumbago crucible with a layer of carbonaceous matter on the top to prevent oxidation, it registered a melting point of 1084° C. Copper is very malleable, and can be rolled or beaten into the thinnest sheet. Being also of high tenacity it can be drawn into very fine wire. It becomes hardened by this cold work, but can be softened by annealing at about 800° C. It is only feebly weldable, and becomes brittle at a temperature near its melting point. It is not appreciably volatile at ordinary alloy-making temperatures, but is said to be volatile at such high temperatures as those of the electric arc or of the oxyhydrogen blowpipe. Copper crystallises in the cubic system, and it must be borne in mind that even the toughest sample is crystalline, although it may not break with a crystalline fracture. Good copper having great ductility breaks with a fibrous fracture, the crystals holding together and drawing out so that the fibres seen at or near the fracture have really been formed out of groups of crystals drawn out in one direction, the material of the individual crystal being highly ductile, and the different crystals holding together at their junctions. Copper is susceptible to the deteriorating influence of small quantities of certain impurities, such as bismuth, arsenic, antimony, and sulphur;

while other substances, such as gold, silver, zinc, and tin affect its properties, but in such a way that they form valuable series of alloys for industrial uses. The tenacity of cast copper is given as about 8 tons, of wrought bolts 17 tons, and of wire 26 tons per square inch. Samples of commercial wrought copper turned to ·564 diameter, or ¼ square inch in area, and 1 inch parallel, and tested for this work, gave a maximum stress of 21·4 tons per square inch, an elongation of 21 per cent., and a reduction of area of 59 per cent. Results obtained by Kirkaldy from test-pieces cut from a cast ingot are as follows:—

	Elastic Limit. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 10 inches.	Reduction of Area per cent.
Top. . .	1·6	5·1	5·0	13·4
Bottom. .	2·0	10·7	30·6	29·1

The average of three copper castings from commercial copper remelted, worked out at 8·1 tons per square inch maximum stress, with an elongation of 9·2 per cent. on 2 inches. Copper is used in a nearly pure state for electrical castings, and also as a constituent of brasses, bronzes, German silver, brazing solders, and bearing metals (antifriction alloys).

Zinc is a white metal, with a pale bluish-grey tint, with a high lustre on a fresh fracture, which is not affected in dry air, but in ordinary damp air becomes coated over with a layer of hydrated basic carbonate of zinc, which helps to protect the zinc underneath from further action.

Its specific gravity is about 7·15 as cast, taking the mean of the results of various experimenters; a sample cast and determined by P. Longmuir gave 7·3. The melting and boiling points of zinc have also been the subject of several recent investigations, the former being a point strongly recommended for pyrometric calibrations, recent results done with great care giving 418°, 419°, 419°, 421°, leaving 419° C. as the most probable result; the greatest variations being only 2° C. from this number. The determinations of the boiling point, not so reliable, vary from 918° C. to 930° C.; the mean, 925° C., may be taken as not more than a few degrees from the true boiling point. At or above this temperature then, zinc, whether covered with a layer of charcoal or not, will give off vapour of zinc which burns with a brilliant greenish flame where it comes into contact with the air, forming the flocculent oxide of zinc, yellow when hot, but white when cold, as always seen in the brass and in the German silver melting shop. Thus, in melting for alloys of a given zinc content, allowance must be made for this loss in calculating the mixture to be used, the loss in the quickest crucible-melting amounting to at least 2 lbs. of zinc in the 100 lbs. charge. At ordinary temperatures zinc is brittle, and the ordinary commercial cakes can be broken for use with a hammer. Zinc can be rolled into sheet or drawn into wire between 100° C. and 150° C., but at higher temperatures, over 200° C., it again becomes brittle. Brassfounders will often have noted that if a cake of zinc has been laid on the furnace covers, and warmed through, that it will bend considerably before breaking, while, if thoroughly hot, it is as brittle as at ordinary temperatures. The tenacity of zinc may be taken at about 1·5 tons per square inch, a result representing the mean of three tests made on the cast material. Zinc is used for galvanising, and to a small extent, in a nearly pure state, for under water fittings, such as propeller sheathing, etc., the object being to lessen corrosion, as zinc, being one of the most highly electro-negative of the common metals, protects any metal with which it is in contact; that its protective influence does not depend merely on the perfection of the coating is well in evidence on comparing the appearance of sheet iron or steel vessels coated respectively with zinc (galvanised bucket), tin (a tin can), and nickel (bicycle handle bars), after being exposed to damp for some days, which makes one wish to try the highly polished zinc coating of the low temperature Sherardising process, in which the zinc is applied by allowing commercial zinc dust to alloy with the surface of the iron at a very low temperature (about 300° C.), which gives a fine structure instead of the rather violent appearance of the ordinary galvanised article produced by dipping into the molten zinc. Zinc is used for the manufacture of imitation bronzes, and as a constituent, with copper, in brasses, bronzes, German silver, etc.

Tin, when of great purity, has a beautiful white colour, with the faintest yellowish tinge, being only surpassed in the purity of its white by the metal silver. It is soft, but cannot be scratched by the thumb nail, and has a peculiar odour when held in the hand till warm. The specific gravity of tin is 7·29 as cast, and, like lead, is practically the same in the rolled or hammered state. Its melting point has been the subject of much recent work, as this is taken as one of the standard temperatures for pyrometer calibration, and the results are most concordant at 232° C., which is most probably within 1° of the truth. Tin is highly malleable, and can be rolled into very thin sheets (tin foil), but, owing to its low tenacity, cannot be drawn into wire. It is flexible, as cast, but not elastic; and, if nearly pure and subjected to bending, it emits a curious grating noise known as the "cry" of tin, which is supposed to be due to its crystals rubbing on one another. The cry is also plainly heard when tin is being pulled in the testing machine. Tin is said to be dimorphous, that is, to crystallise, sometimes in one system, the cubic; and, under different conditions, in a second system, the tetragonal. Tin plate is merely sheet iron or mild steel covered with a thin layer of tin, which may almost be said to be in the cast state. Its crystalline condition may be brought out very beautifully by etching the surface with hydrochloric acid, and the fern-like appearance produced may be preserved by varnishing. The bright surface of tin is only slightly affected by exposure to the air, and on account of its unalterability it is used in many domestic utensils, as in the so-called tin vessels and for tinning the inside of cast-iron pots and pans. The tenacity of cast tin is about 2 tons, two special tests averaging 2·0 tons per square inch maximum stress, with an elongation of 30 per cent. on 2 inches.

Tin, besides the uses already mentioned, is a constituent of bronzes, type metals, fusible alloys, and antifriction metals.

Lead has a pale bluish-grey colour, and, when pure, is so soft that it can be scratched by the thumb nail, a fact which gives a rough idea of its purity, for, when alloyed with, say, a small proportion of antimony, it becomes harder than the thumb nail. The specific gravity of lead in its cast state is about 11·35, and it seems to be increased very little by rolling or hammering. The melting point of lead has received much attention in recent years, and from 1895 to 1901 the numbers found by different methods have lain between 326° and 329°, and, all points considered, 327° C. may be taken as the most probable value within 2° C. of the truth. Lead is highly malleable, and can be rolled into very thin sheets, but, owing to its low tenacity, cannot be drawn into wire.

Clean surfaces of lead weld perfectly when hammered together or when pressed together, as by passing the lead through rolls.

Lead crystallises in the cubic system, and has the curious property that the distorted crystals of rolled or hammered lead rearrange themselves at ordinary atmospheric temperatures, adjacent crystals even altering their orientation or direction of crystallisation so as to become one larger crystal. Thus, old sheet lead on roofs has always large crystals, while freshly rolled lead has distorted crystals similar to those in rolled iron. Three test pieces, cast at decreasing temperatures, gave on testing 1·13 tons, 1·43 tons, 1·30 tons maximum stress, with elongations of 18, 35, and 42 per cent. on 2 inches respectively; while duplicates from the same cast, laid away and tested three months later, all gave practically the same test, viz., 1·7 tons per square inch and 40 per cent. of elongation. The tenacity of lead, as cast, may be taken at 1·5 tons per square inch, with an elongation of 36 per cent. on 2 inches, the average of twelve tests specially made. Lead is easily flexible, but is not elastic. Lead in a nearly pure state is used for certain castings. The authors have lively recollections of trouble with a furnace air valve, the "brasses" of which were ultimately discovered to be of this metal! It is also used as a minor constituent of brasses and bronzes and as a major constituent of certain anti-friction alloys and type metals.

Nickel is a white metal, with a slight steel-grey tinge, but takes a very brilliant polish, owing to its colour and hardness. It is highly malleable, and, with its great tenacity, can be drawn into the finest wire. Its specific gravity, as cast, is given by Mr R. A. Hadfield (*Proc. C.E.*, vol. cxxxviii. part iv.) as about 8·84 and forged 8·83. He also records the following test of a sample as cast, unannealed, and of about 99 per cent. purity, as elastic limit 11 tons; maximum stress, 16¼ tons; elongation per cent. on 2 inches, 4½; reduction in area, 9¾ per cent. Its melting point is given at about 1450° C., but more work is required on this point, although the latest determination by Harker is 1427° C. As a metal, nickel is sold in commerce in two principal forms, (1) malleable rods, etc., of nickel, with the characteristic colour and high metallic lustre; (2) in small dull cubes about ½-inch side or in cylinders about 1¾ inches diameter by 1 inch deep, which have been formed by pressing oxide, mixed with charcoal or other suitable reducing agent, into these shapes in moulds, and then heating them in furnaces to such a temperature that the oxide is reduced to metal. The former is nearly pure nickel, but, being much more expensive, is not used for alloy-making; the best qualities of the latter yield over 98 per cent. Ni, although the pieces are brittle and may be crushed with a sledge. If either malleable nickel or superior alloys are to be made, steps must be taken for the removal of the small residue of oxygen in the nickel, as by the use of manganese in non-iron alloys or of ferro-manganese in iron alloys, or of magnesium in the manufacture of malleable nickel. This last must be used with caution, as, at least on addition to a molten steel casting mixture, it explodes on reaching the surface, unless care is taken to plunge the magnesium beneath the surface of the bath of metal, say, with tongs. Nickel castings are occasionally made for the supply of anodes, but the chief use of nickel in the foundry is as a constituent of German silver and of certain special nickel steels.

Aluminium is a white metal, with a very slight bluish-grey tinge, not so white as tin or silver, but whiter than zinc. Its specific gravity is about 2·65, as cast, and this is slightly increased by hammering or rolling. Aluminium is another of the metals, the melting point of which has been redetermined by many experimenters recently, and its melting point may be taken at about 657° C. It can be melted with little oxidation. It removes oxygen from most metallic oxides, but, at the temperature of molten steel, oxidises very rapidly, and even reduces that prince of reducing agents, carbon monoxide, to carbon, the aluminium oxidising to alumina, $Al_2 + 3CO = Al_2O_3 + 3C$. The oxide formed is "dry," and, if in large quantities, would injure the metal and must be fluxed off. The tenacity of aluminium, as cast, may be taken at 5 to 7 tons per square inch, with but slight elongation; the average of three special tests for this work giving maximum stress 5·1 tons, with 5·3 per cent. of elongation on 2 inches. Aluminium is largely used in a state of commercial purity, and also as a constituent of aluminium bronze and brasses. It is hardened by alloying with small quantities of copper, zinc, or magnesium. Considerable quantities are also consumed for adding, in small percentages, to molten steel, to prevent the formation of blowholes.

Antimony is a white metal, with a pale greyish tinge. It is so brittle that it can easily be powdered in a mortar. For the specific gravity of antimony recorded results vary from 6·6 to 6·8, and 6·7 may be taken as a fair average. Recent accurate work puts the melting point at 630° C., probably within a few degrees of the truth, the best results being 629°·5 and 630°·6 C.

When a mass of antimony of a certain degree of purity solidifies, the upper surface shows a very marked and coarse crystalline pattern, known as the antimony star. The metal is not affected by exposure to air at ordinary temperatures, but above its melting point oxidises rapidly. It crystallises in the hexagonal system, its rhombohedra having an angle of 87°·35, according to Bauerman. It is only of use as a constituent of alloys, chiefly type metal and bearing or antifriction metals. Antimony is often added to a common casting brass, in order to enable it to carry a larger "dose" of lead, and it is also a constituent of hard lead castings.

Silver, the whitest of metals, takes a very high polish. In malleability, and capability of being drawn into wire, it is only inferior to gold. Its specific gravity is 10·5, and its melting point, which has been recently thoroughly investigated, may be taken at 962° C., within a very few degrees, recent results being 962·7, 962, 961, 961·5, 961·5· Where circumstances permit, its freezing point is strongly recommended as a standard point for pyrometric calibration. It must be noted, however, that in contact with air it absorbs oxygen, and its melting point falls to 955° C.; hence, if used as a standard, it should be melted in a plumbago crucible, and its surface kept covered with a layer of charcoal or other reducing or protecting covering.

Silver crystallises in the cubic system. At a high temperature it is volatile, yielding a green vapour, and it may be distilled by the oxyhydrogen blowpipe. When molten silver has absorbed oxygen it gives it off again suddenly on solidifying, which causes the familiar spitting of silver after a crust has been formed on the surface. The silver solidifies quite quietly when alloyed with copper, as in standard silver, or when oxygen is kept away, as by melting it under charcoal or under a layer of salt or carbonate of soda. It is unchanged by any agents in the air, excepting sulphuretted hydrogen, H_2S, which tarnishes and ultimately blackens it by the formation of the black sulphide of silver, Ag_2S. Pure silver is soft; but standard silver, which consists of 925 of pure silver alloyed with 75 parts of copper, is much harder and more durable. Silver is a constituent of hard silver solders, and, with copper, it is alloyed with gold to form the various carats.

Bismuth has a characteristic greyish-white colour, with a tinge of red, and is so brittle that it can easily be powdered in a mortar. Bismuth expands on solidifying, and melts at a temperature of 269° C., three recent determinations being 268°, 269°, and 270° C. It is volatile at very high temperatures, and, according to Bauerman, it crystallises in the hexagonal system as rhombohedra, which, having an angle of 87°·40, are easily mistaken for cubes. It is chiefly employed as a constituent of fusible metals, and sometimes to the extent of from ¼ to ½ per cent. in certain bearing metals.

Mercury.—In a stock of metals, mercury is prominent as being the only one liquid at ordinary temperatures. It has a silver-white colour, and, when pure, a very high lustre. The pure metal does not "touch" glass; so, when a small quantity is placed on a glass surface, globules run freely over the surface with the slightest disturbance, hence its old name of quick-silver. If the mercury contains base metals as an impurity, then the globules, instead of being nearly spherical as they move over the glass, seem to hold to the glass and leave a tail. It freezes at − 39° C., and is then malleable. It crystallises in the cubic system in the form of octahedra; and the specific gravity of the liquid, which has been determined with great care, is 13·596, that of the solid being 14·4. Mercury is volatile at all ordinary temperatures of the air, and boils at 350° C. Mercury unites or alloys with many of the common metals; an alloy of two or more metals, of which mercury is a prominent constituent, is known as an amalgam. Added in small quantities to certain fusible alloys it forms an alloy of much lower melting point.

TABLE OF PHYSICAL CONSTANTS OF METALS.

	Symbol.	At. Weight. 0 = 16.	Specific Gravity. Water = 1.	Specific Heat. Water = 1.	Melting Point °C.	Coefficient of Linear Expansion for °C.	Thermal Conductivity. Silver = 100.	Electric Conductivity, Mercury at 0° = 1.
Aluminium, . .	Al	27·1	2·65	0·212	657	0·0000231	31·33	31·73
Antimony, .	Sb	120·2	6·7	0·051	630	·0000105	4·03	2·05
Arsenic, . .	As	75·0	5·67	0·081	...	0·0000055	...	2·68
Bismuth, . .	Bi	208·5	9·80	0·031	269	0·0000162	1·8	0·80
Cadmium, . .	Cd	112·4	8·60	0·057	321	0·0000306	20·06	13·95
Chromium, . .	Cr	52·1	6·80	0·120	> Pt	...	...	...
Copper, . .	Cu	63·6	8·7	0·094	1084	0·0000167	73·6	55·86
Gold, . . .	Au	197·2	19·3	0·032	1064	0·0000144	53·2	43·84
Iridium, . .	Ir	193·0	22·4	0·033	2250	0·0000070	...	...
Iron, . . .	Fe	55·9	7·86	0·110	1550	0·0000121	11·9	8·34
Lead, . . .	Pb	206·9	11·35	0·031	327	0·0000292	8·5	4·82
Magnesium, . .	Mg	24·4	1·74	0·250	633	0·0000269	34·3	22·57
Manganese, . .	Mn	55·0	6·9	0·120	1245	...	...	...
Mercury, . .	Hg	200·0	13·59	0·032	− 39	...	1·3	1·00
Molybdenum, .	Mo	96·0	8·60	0·072	...	...	...	...
Nickel, . . .	Ni	58·7	8·84	0·110	1450	0·0000127	...	7·37
Platinum, . .	Pt	194·8	21·5	0·033	1750	0·0000089	8·4	8·26
Rhodium, . .	Rh	103·0	12·1	0·058	2000	0·0000085	...	...
Silver, . . .	Ag	107·9	10·53	0·056	962	0·0000192	100·0	57·23
Tin, . . .	Sn	119·0	7·29	0·056	232	0·0000223	15·2	8·21
Tungsten, . .	W	184·0	19·10	0·033	> Mn	...	...	...
Uranium, . .	U	238·5	18·7	0·028	...	...	...	...
Vanadium, . .	V	51·2	5·5	?	...	...	...	...
Zinc, . . .	Zn	65·4	7·15	0·094	419	0·0000291	28·1	16·92

CHAPTER XXXIV.

ALLOYS.

Metals, other than iron, have been dealt with in the preceding chapter, and the properties there given form a necessary foundation for a study of alloys. At the outset some definition of a metallic alloy ought to be given, and the nearest to our purpose is that included in the "Nomenclature of Metallography," which reads as follows:—

"An alloy is a substance possessing the general physical properties of a metal, but consisting of two or more metals or of metals with non-metallic bodies in intimate mixture, solution, or combination with one another, forming, when melted, a homogeneous fluid."

Foundry alloys are produced by fusion of the constituent metals either in crucible or reverberatory furnaces.

Having decided the composition, the first essential is that of accurate weighing of the constituents entering the alloy; the second essential is that undue oxidation must be prevented; whilst the third lies in the fact that any changes taking place during melting must be allowed for, if exact compositions are required. Generally speaking, industrial alloys in which copper is an essential constituent may be divided into three groups—(1) brasses, (2) gun-metals, (3) bronzes.

Ordinary Brasses.—The term brass is applied, in foundry practice, to those alloys in which copper and zinc are the essential constituents. In composition, brasses range from 90 to 35 per cent. copper and from 10 to 65 per cent. zinc. Between these proportions a range of colour from coppery red to light yellow is obtained and also wide ranges of mechanical properties and of cost of production. Thus, the higher the content of copper the greater the cost of production, and there is therefore a natural tendency to keep the content of zinc at the highest possible limit consistent with the colour, or the mechanical properties required. The following tests by the authors illustrate the range in mechanical properties:—

	Condition.	Content of Copper.	Content of Zinc.	Maximum Stress, Tons per sq. in.	Elongation per cent. on 2 inches.	Reduction of Area per cent.	Specific Gravity.
Copper, . . .	As cast	...	...	9·0	11·0	...	8·80
Zinc, . . .	,,	...	...	1·5	...	...	7·30
Red brass, . .	,,	89·6	10·2	12·6	26·0	30·0	8·55
Yellow brass, . .	,,	73·0	26·0	13·0	43·0	35·0	8·10
Muntz metal, . .	,,	59·0	40·0	19·0	15·0	16·0	8·03

The foregoing tests each represent the mean of several determinations from bars cast in sand under normal foundry conditions. The value of alloying is shown by comparing the results obtained from metallic copper and metallic zinc with those from the three brasses. Thus, the brittle metal zinc which, alone, has a tenacity of 1½ tons per square inch, yields, when added to copper to the extent of 40 per cent., an alloy of high tensile strength and at the same time possessing a fair degree of ductility. It will be noted that from 26 to 40 per cent. zinc, an increase in maximum stress is associated with a distinct fall in extensibility. Exceeding 40 per cent. zinc, maximum stress and extensibility fall together. Common casting brasses may contain 50 per cent. zinc, but the resulting alloy is decidedly light or pale yellow in colour, and its mechanical properties are low. As the content of zinc exceeds 50 per cent., decisive brittleness is evidenced, and with further increase of zinc the yellow tint is replaced by grey or white. Still, keeping to the legitimate brasses of red or yellow colour, the following compositions show the variations found in practice:—

	Ormolu or Red Metal.	Brazing Metal.	English Standard Brass.	Muntz Metal.
	Per cent.	Per cent.	Per cent.	Per cent.
Copper, . . .	90	90 to 80	70	60
Zinc, ...	10	10 to 20	30	40

These are essentially sand-casting alloys, although sheet and wire brasses verge on that described as English standard brass. Ormolu is largely employed for artistic castings, which, after buffing or burnishing, yield a rich copper red colour. A typical yellow colour is obtained from the standard brass, whilst a lighter yellow is obtained from the Muntz alloy. From an ornamental point of view, these colours are of some importance, and permit of good contrasts being obtained in composite figures. Brazing metal is chiefly cast into the form of flanges and connections which have to be brazed on to copper pipes. The term brazing metal should not be confused with that of brazing solder. The latter, otherwise known as hard solder, is a copper-zinc alloy of comparatively low melting point, or, in other words, a high content of zinc. These solders, whilst forming an important class of copper-zinc alloys, are only rarely made in brass foundries. Composition ranges from 60 to 34 per cent. copper and from 40 to 66 per cent. zinc; they are granulated by pouring through a sieve into water, a fall of 10 feet before reaching the water giving very uniform shot.

Special brasses are copper-zinc alloys, the properties of which are modified by the presence of a third or fourth element. Of these elements the most noteworthy are lead, tin, iron, aluminium, and manganese. Lead added to a brass makes it "sweeter" to machine, that is, the turnings chip off, instead of curling round and clogging up the tool. With an ordinary yellow metal a limit is found at about 6 per cent. of lead; and even with this amount, if the castings are heavy, the lead will tend to liquate, that is, during cooling the lead will collect in the heavier portions of the casting, or, if of equal section, it will gather at the bottom of the casting. A trace of antimony added to a yellow brass will enable it to "carry" lead with less fear of liquation.

Lead, as noted, is of much assistance in enabling the alloys to be machined at a higher speed; it also lessens the cost of production, but lowers the mechanical properties, and, when exceeding 1 per cent., has a marked deleterious effect on maximum stress and elongation. Lead should never be present in varieties of brass known as dipping metal, that is, ornamental castings which are treated in "aqua fortis." If present under such conditions disfiguring black stains result after dipping.

Of the remaining elements, tin, iron, aluminium, and manganese, when individually or collectively present in small amounts, have the effect of considerably raising the mechanical properties. Taking their individual effect first, it will be necessary to examine them in conjunction with the influence of zinc on copper, as shown in the tests already given. These tests show that a content of 26 per cent. zinc gives a maximum stress of 13 tons per square inch, and an elongation of 43 per cent. on 2 inches; whilst 40 per cent. zinc gives a maximum stress of 19 tons and an elongation of 15 per cent. The latter alloy is, therefore, a good base on which to test the effect of other elements in that it yields the highest maximum stress of the copper-zinc series. If to the alloy 1½ per cent. iron be added, zinc being reduced accordingly, maximum stress will increase from 19 to 23 tons and elongation from 15 to between 20 and 24 per cent. It may be noted that the iron must be alloyed with the copper and zinc and not be present as free iron. The effect of aluminium on high zinc alloys is at the best erratic; but ignoring variations so far as possible, average results obtained by adding 0·5 per cent. aluminium to an alloy of 60 per cent. copper and 39·5 per cent. zinc, are as follows:—

Maximum stress, 20 tons per square inch; elongation, 22 per cent. on 2 inches. Average tests of an alloy containing 1·5 per cent. manganese, 60 per cent. copper, and 38·5 per cent. zinc, are, maximum stress 22 to 24 tons per square inch, and elongation from 25 to 30 per cent. on 2 inches. Tin in contents up to 1 per cent. increases tensile strength, but beyond this limit mechanical properties begin to fall. An average test for an alloy containing 0·8 per cent. tin, 60 per cent. copper, and 39·2 per cent. zinc is maximum stress 20 tons, and elongation 25 per cent. on 2 inches.

In other words, the foregoing may be given as follows:—Iron and tin stiffen a brass when present in small amounts; aluminium and manganese have a similar effect, but, further than this, possess the virtue of acting as powerful deoxidising agents. In this respect it must be noted that zinc is in itself a deoxidising agent, but its activity is considerably less than that of aluminium or manganese.

The following compositions show a series of copper-zinc alloys embodying some of the features noted:—

	Common Casting Brass.	Sterro Metal.	Naval Brass.	Aluminium Brass.	Manganese Bronze.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
Copper, . .	60·0	60·0	61·0	60·0	57·0	60·0
Zinc, . . .	34·0	38·0	38·0	39·0	40·0	37·3
Iron, . . .	...	2·0	...	...	1·5	1·5
Lead, . . .	6·0	...	...	...	...	...
Aluminium, .	...	...	...	1·0	0·3	0·5
Manganese, . .	...	...	...	...	0·2	...
Tin, . . .	...	...	1·0	...	1·0	0·7

Of these compositions the common casting brass is typical of the ordinary yellow metal casting; sterro metal shows a type of alloy with iron as an essential constituent, whilst the naval brass represents a genuine brass with a small amount of tin present. Both sterro and naval brass are extremely tenacious, and, as they resist corrosion remarkably well, are largely used in marine work for under-water fittings. However, chief interest is found in the **manganese bronze**, which would be more correctly termed manganese brass, though by trade usage we are compelled to adopt the word bronze. As will be seen, this alloy is in one sense a combination of sterro, naval, and aluminium brass *plus* manganese. In many ways manganese bronzes are remarkable alloys, for a maximum stress of 28 tons per square inch, with an elongation of 30 per cent. on 2 inches, is an average commercial test.

For sand castings, and absolutely untreated, it will be readily granted that the foregoing figures are good, and their value is further emphasised by the fact that they are typical of many tons of commercial castings. Notwithstanding this, we have met with many founders who have failed to obtain tests at all approaching these values, a failure due entirely to the non-recognition of chemical changes taking place during melting and also to the alloy being cast under unsuitable conditions. In glancing over the two compositions of manganese bronze, it will be noted that one of them contains no manganese, and this represents an alloy which, in our hands, yielded excellent mechanical properties. In point of fact, we have examined many manganese bronzes absolutely destitute of manganese and yet excellent alloys. So long as the manganese does its work efficiently it is immaterial whether any remains in the final alloy. The particular work of manganese is of a two-fold character; first, as a cleansing or scavenging agent; and, second, as an aid in promoting the alloying of the iron with the remaining constituents. Aluminium should not fall below 0·3 per cent.; iron should be in the near vicinity of 1·5 per cent; tin between 0·7 and 1·0 per cent.; with zinc not less than 38 per cent. in the final alloy for casting in sand moulds. Forging alloys are slightly different, but with these we have, at present, no concern.

Iron and manganese may be added by means of ferro-manganese, which is the usual plan; or they may be introduced separately, as metallic iron and metallic manganese, or cupro-manganese may be used. In calculating a charge it is necessary to know the analyses of the available materials, and then proceed by the method already given for calculating mixtures.

Before leaving brasses a brief reference must be made to what are known as "white brasses." These alloys, containing over 60 per cent. zinc, are far too brittle for ordinary commercial work; but, where brittleness is immaterial, they find an industrial application in the casting of ornaments, statuettes, fancy buttons, and so forth. Such castings may be in sand or chill moulds, and, owing to the repetitive character of the work, the latter type of moulds is usually employed.

Compositions range as follows:—

	1	2	3
	Per cent.	Per cent.	Per cent.
Copper, ...	40	20	10
Zinc, ...	60	80	90

The castings are artificially bronzed, and a series of tints, varying from olive green to chocolate, may be readily obtained.

Gun-Metals.—Under this general heading are included copper-tin and copper-tin-zinc alloys, all known as gun-metals, a term the origin of which is familiar, but copper alloys have long been superseded by steel for ordnance, and the only guns now made of them are small decorative cannon for yachts. As a matter of passing interest, it may be noted that one of the authors at one time worked in a brass foundry in which a series of moulding-boxes, known even then as gun-boxes, had survived.

In writing of alloys, it is the usual custom to give considerable space to the copper-tin series, which would be of value if this series had any application. As a matter of fact, copper-tin alloys are hardly used in practice, the nearest approach being found in phosphor bronze, which, however, represents copper-tin *plus* traces of phosphorus. In an extensive practice the only genuine copper-tin alloy we have used is found in bell metal, an alloy in which "tone" is the chief requirement. The Admiralty requirements for ships' bells are 5 of copper to 1 of tin, or copper 83·3 per cent., tin 16·7 per cent.

This alloy casts well, presents a good appearance when turned up, and gives a good clear tone. A trace of phosphorus in the form of phosphor tin may be added just before casting; or the alloy may be made up from copper 82 per cent., tin 17 per cent., yellow brass 1 per cent.

Under such conditions the zinc of the yellow brass will, to some extent, act as a deoxidiser. Gong metal approximates 80 per cent. copper and 20 per cent. tin, a composition which represents the highest content of tin in the bell-metal series. Speculum metal is white in colour, brittle in properties, and admits of a very high polish. Its application is, however, exceedingly limited, and for the greater part these alloys have been replaced by glass. A general composition is 67 per cent. copper and 33 per cent. tin; Ross's alloy contained 68·21 per cent. copper and 31·79 per cent. tin. Whilst the copper-tin series are, in a foundry sense, of limited application, this by no means applies to the copper-tin-zinc series, which find an application in, practically, every branch of engineering. All modern gun-metals contain zinc in amounts varying from 1½ per cent. upwards, the addition of this zinc not only giving sharpness or life to the fluid alloy, but also, by virtue of its deoxidising properties, leading to the production of sounder castings.

Three types of high quality gun-metals are as follows:—

	1	2	3
	Per cent.	Per cent.	Per cent.
Copper, ...	88	86	87
Tin, ...	10	10	8
Zinc, ...	2	4	5

In the form of castings these alloys are used for high-pressure steam fittings, air- and water-pumps, engine and machine details, boiler mountings, and the like. Typical tests obtained by the authors are as follows:—

No.	Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.
1	18·0	11·0
2	17·0	10·5
3	15·0	9·0

The Admiralty specification for No. 1 is a maximum stress of 14 tons per square inch and an extension of at least 7 per cent. on 2 inches. The foregoing tests, which represent an average of many, show very little difference, and it is a fact that with careful casting No. 3 can be made to give very similar tension results to those obtained from No. 1, a remark also applicable to steam or hydraulic tests. No. 3 is the least costly of the series, and is decidedly easier to treat in machine or finishing shop than the comparatively hard alloy No. 1. The highest and lowest tests obtained by the authors from some hundreds of experiments on composition No. 1 are as follows:—

	Maximum Stress. Tons per square inch.	Elongation on 2 inches.
Highest, ...	20·0	16·0
Lowest, ...	6·5	3·7

This wide range of variation emphasises the care necessary when the best results are required, for though only obtained from one type of alloy, similar variations have been obtained from most of the industrial alloys.

The gun-metals given represent high quality, and, therefore, costly types. Typical compositions of ordinary commercial gun-metals are included in the following table. Nos. 1 and 2 represent the usual run of alloys for valve bodies, engine and boiler fittings, but not fittings used in conjunction with high-pressure boilers or high-speed engines. Nos. 3 and 4 represent cheaper types of gun-metal in which outside scrap enters largely into the composition.

No.	Copper.	Tin.	Zinc.	Lead.	Merchant Scrap.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	80	4	10	6	...
2	80	6	8	6	...
3	70	4	4	4	18
4	55	5	...	...	40

As with brasses, the addition of lead to a gun-metal facilitates free turning. Merchant scrap is a variable factor, and previous to use it should be sorted so far as possible into uniform grades.

Bearing Brasses.—Solid bearings are being largely replaced by shells lined with antifriction metal. When a copper-tin alloy is used as a bearing brass, its composition will vary between the following limits:—

Copper from 88 to 82 per cent.
Tin ,, 10 to 14 ,,
Zinc ,, 2 to 4 ,,

An intermediate alloy, copper 84 per cent., tin 12 per cent., and zinc 4 per cent., represents an alloy which has successfully met severe service conditions. A cheap and hard bearing may be made from copper 52 per cent., tin 8 per cent., and merchant scrap 40 per cent. However, on the whole, bearing brasses of phosphor bronze yield better results than are obtained from copper-tin alloys.

The increase in hardness, following an increase in the content of tin, is also associated with a decisive increase in brittleness. Only in the case of bearing brasses is it advisable to exceed a content of 10 per cent. tin, a feature illustrated in the following table:—

Analysis.			Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.
Copper.	Tin.	Zinc.		
85	13	2	11·9	1·5

These results, representing the average of six specially conducted tests, are of importance in view of the fact that gun-metals are often stated to contain 16 per cent. tin. Such a composition would be far too brittle for the purpose to which gun-metal is usually applied; it is, in fact, a bell metal.

Bronzes.—Manganese bronze, so called, has already been dealt with. The next most familiar member of this group is **phosphor bronze**, an alloy which may be produced in various grades, possessing many valuable properties. Two typical grades are as follows:—

	Ordinary.	Hard.
	Per cent.	Per cent.
Copper, ...	90·0	88·5
Tin, ...	9·6	10·5
Phosphorus, . . .	0·4	1·0

The hard grade is used, in foundry practice, for casting pinions, spur and bevel wheels, slide valves and bearing brasses. The ordinary grade is extensively used for various machine and engine details, and also for heavy castings, such as the ram and stern fittings of a cruiser. A large series of tests of the ordinary grade have yielded results varying between the following limits:—Maximum stress, lowest, 12·5 tons; highest, 26·2 tons per square inch; elongation per cent. on 6 inches—lowest, 5·0; highest, 51·0.

The usual specification for castings of this grade is a maximum stress of 17 tons per square inch and an elongation of 15 per cent. on 6 inches. A comparison of the lowest and highest tests obtained by the authors is of much interest in showing the range of properties in an alloy of constant chemical composition, and, incidentally, as illustrating the importance of careful melting and casting. It may be added that the series for which the foregoing extreme tests were taken represent sand castings tested in the condition "as cast."

As the amount of phosphorus increases beyond 0·5 per cent., ductility decreases, whilst hardness and brittleness increase. For a hard type of bronze 1 per cent. phosphorus is a suitable limit, but where extreme hardness is required 1½ per cent. may be added. Exceeding 2 per cent. phosphorus, the alloys, owing to their brittleness, become useless for castings. It will be noted that the foregoing alloys approximate 90 per cent. copper and 10 per cent. tin, corresponding to the old gun-metal formula. Sound copper-tin alloys may be produced by the aid of phosphorus, sufficient being added to remove the oxygen absorbed by the copper and tin, and leaving only a trace of phosphorus in the final alloy.

Another type of phosphor bronze represents one in which lead is present in considerable quantity. Such alloys are used for bearing brasses in this country and in America. In the latter case the alloys are chiefly used in the form of car brasses. A typical percentage composition is:—Copper, 79·7; tin, 10·0; lead, 9·5; phosphorus, 0·8.

The addition of phosphorus is made by means of phosphor-copper or phosphor-tin, containing respectively 15 per cent. and 5 per cent. phosphorus. Stick phosphorus is extremely difficult, and somewhat dangerous to handle, owing to its inflammability in air.

Aluminium Bronzes.—The most general composition is copper 90 per cent. and aluminium 10 per cent., an alloy discovered and investigated by Dr. Percy. For some reason these alloys have not met with a very wide industrial application, probably owing to the fact that their properties have not been systematically investigated. From the composition given, we have obtained results varying as follows:—Maximum stress, 18 to 26 tons per square inch; elongation, 2 to 18 per cent. on 2 inches.

These represent untreated sand castings, but we hope in the future to supplement them by others obtained from a more exhaustive investigation. Finally, although there are many special casting bronzes on the market, it will be found that the majority of them approximate to 60 copper and 40 zinc, specially deoxidised and stiffened up in a similar manner to that of the manganese bronze. This type of bronze is certainly the best we have handled, and, provided careful treatment is given, the resulting castings may be made to yield excellent mechanical properties.

German Silver.—Of remaining alloys only two groups call for note in a work devoted to foundry practice, and the first group is found in the copper-nickel-zinc alloys, commercially known as German silver. Essentially they are copper-zinc alloys whitened by the addition of nickel, and the range in composition is as follows:—

No.	Copper.	Zinc.	Nickel.
	Per cent.	Per cent.	Per cent.
1	63	32	5
2	66	26	8
3	62	28	10
4	50	32	18
5	62	23	15
6	65	20	15
7	67	14	19
8	60	20	20

Of these compositions No. 8 is recommended for colour and lustre. Generally speaking, the higher the content of nickel the better the appearance, as also the greater the cost of the alloy. Lead and iron are sometimes present, though not advisable, in German silver castings. Types of such alloys are as follows:—

No.	Copper.	Zinc.	Nickel.	Lead.	Iron.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	48	32	15	5	...
2	57	30	10	3	...
3	60	28	10	...	2
4	56	32	11	...	1

In making up German silver, cost and colour are the ruling factors, and the content of nickel is regulated by these factors. Apart from these, a feature not shown in the foregoing compositions lies in the fact that the nickel must be deoxidised, and this is effected by manganese either in the ferro or cupro form. Zinc will deoxidise copper, but it will not remove the oxygen present in nickel; hence the necessity for manganese.

White or Antifriction Metals.—The second group of alloys consists of the white or antifriction metals which have often to be made up in the brass-foundry. These alloys are extensively used for lining the bearing surfaces of brass, steel, or iron bushes. Before lining, the inner surfaces of the bushes are cleaned by sand blast or acid pickle, and then tinned in order to ensure a better contact of the lining metal. The thickness of the lining varies from ¼ inch to ½ inch, and lining is effected by running the metal into the space left by the insertion of a sheet iron core into the bush. The diameter of this core or mandril is less than that of the finished bearing, in order to allow material for machining up to size. The white metal is maintained in a molten condition in a cast-iron pot fired from the bottom, and is ladled out as required. Three types of high quality white metal are found in the following table:—

No.	Copper.	Tin.	Antimony.
	Per cent.	Per cent.	Per cent.
1	5·5	86·0	8·5
2	7·0	85·0	8·0
3	8·5	83·0	8·5

These compositions vary only slightly, but they may be taken as representing the highest quality Babbit metals. The following compositions represent less costly types of white metals, the content of tin being the governing factor as regards cost:—

No.	Copper.	Tin.	Antimony.	Lead.	Zinc.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
4	9	73	18	...	...
5	3	53	10	33	1
6	...	40	6	54	...
7	5	...	10	...	85
8	4	19	3	5	69
9	...	...	16	84	...

These compositions are simply given to show the range, and are not necessarily recommended. Where Nos. 1, 2, or 3 are too costly, then the best substitute is found in lead-antimony alloy of the type shown in No. 9, which is sometimes made with the addition of 4 to 5 per cent. of tin, and even a few tenths per cent. of bismuth, in place of an equal amount of the lead.

It is well known that lead and copper alone will not alloy, yet if the two metals can be made to alloy an antifriction metal results, which for certain purposes is ideal. In our own efforts in this direction, we have taken advantage of the carrying power of antimony, and achieved successful results. An antimonial lead, containing 7 per cent. antimony, is first made; 28 per cent. of this is added to 72 per cent. copper, and the resulting castings show no segregation. It is advisable to remelt the alloy before pouring into a sand mould.

An alloy used in the form of cast rings for piston-rod packing is as follows:—

Tin.	Lead.	Antimony.	Arsenic.
Per cent. 21	Per cent. 69	Per cent. 9·5	Per cent. 0·5

The arsenic is added in the form of white oxide mixed with charcoal.

Some types of antifriction metals contain graphite, and we have heard theorists gravely discuss the extraordinary phenomenon of the presence of free carbon in tin-lead alloy, but the fact is that the graphite is added to the alloy after its production. Thus, an alloy of 43 per cent. tin, 56 per cent. lead, and 1 per cent. antimony is made and cast into blocks. These blocks are machined into thin shavings, and the shavings, when mechanically mixed with vaseline and graphite, are used for packing purposes.

Many of the metals considered in the foregoing as constituents of alloys are at times required in the form of castings. Thus, lead and antimony in the form of castings are used for certain purposes in chemical works. Making moulds, and melting the metal for such castings, offers no difficulty, but subsequent handling does. Thus, lead is easily distorted, and antimony is exceedingly fragile. Acid pumps of metallic antimony, even though the bodies are 1 inch thick and the flanges 3 inches, are difficult to dress without breakage, and the greatest care is therefore required after casting. Copper castings are often required, and the majority of them represent copper *plus* 3 or 4 per cent. of zinc. Sound castings of metallic copper can be made by controlling the absorption of copper oxide. Nickel castings are also required at times, and here the problem is entirely one of eliminating oxygen. This aspect of oxidation is hardly germane to this chapter, but is fully discussed later.

Castings of tin do not call for special comment; but, when the metal zinc is used, then the moulds must readily admit of free contraction. The latter remark is also applicable to aluminium castings. With metallic aluminium, manganese bronze, and phosphor bronze, fairly large gates are necessary in order to obtain castings free from pin holes or draws. If the castings are at all massive these runners should be supplemented by feeding heads placed on the heavy portions. With metallic aluminium, aluminium alloy or bronze, and manganese bronze, much cleaner castings are obtained by the use of plug heads, which consist of a dry sand or loam reservoir with a cast-iron plug fitted into the runner. The head is filled with metal, the plug withdrawn, and a constant level maintained by the ladle until the mould is filled. By this precaution no dirt or oxide enters the mould, and extremely clean castings result.

It may be noted that alloying in the case of aluminium is chiefly followed with a view to raising its tensile strength, but, if carried too far, the special virtue of low specific gravity is lost. These stiffening agents are found in copper in contents up to 5 per cent., or in zinc in amounts up to 10 per cent.

Method of Making Alloys.—As already noted, foundry alloys are produced by fusion of the constituent metals. Many foundries purchase alloys in ingot form, and in such cases the process of melting for castings is one of simple fusion either in crucible or air furnace, when any loss taking place during melting must be made good before drawing or tapping. This loss is chiefly confined to zinc, and in everyday practice we have found an allowance of 25 per cent. fairly safe; that is, 25 per cent. of the zinc contents of the alloy, and not 25 per cent. of the weight of the alloy. Brass castings are sometimes produced by simply melting outside, or merchant scrap. In this case the scrap as it comes in is carefully sorted into grades, and examined for iron or steel bolts, studs, etc., which must be removed before melting. Merchant scrap is necessarily of a varied character, and, even with the best of care, is likely to lead to erratic results. By far the best plan is to melt it in large weights in an air furnace and cast into ingots. An analysis will then give the exact composition, and, when remelting for casting, any desired alteration can be made. This plan is also a good one for dealing with borings and turnings.

When using new metals, a plan we personally prefer, the usual practice is to charge the metal of highest melting point first, and, on its partial fusion, to add the remaining constituents in their order of fusibility, any volatile one, such as zinc, being left to the last. The heat is then raised to a good casting heat, the alloy well stirred and cast. When large quantities of an alloy are required, and an air furnace is not available, the cupola furnace may be used. Under such conditions the copper only is passed through the cupola, which must be blown with a soft blast, that is, from 4 to 6 ounces (according to diameter). The molten copper is collected in a ladle, and the weighed amounts of zinc and tin added in the solid form. The contents of the ladle should be well stirred, but in a 5- or 10-ton ladle this is easier said than done. A plan we have found of value lies in sticking a small potato on a forked iron rod, and holding it for a minute at the bottom of the ladle. The resulting agitation efficiently mixes the contents of the ladle.

When melting in either crucible or air furnace, liberal coverings of charcoal should be used as a measure of protection from oxidation. It may be noted that in brass or gun-metal melting lids are rarely used on the crucibles, hence the greater need for a charcoal covering. The best quality of alloys are always produced without fluxes, and extensive experiments in this direction are not at all favourable to the use of any type of flux during melting. A small amount of phosphor copper, phosphor tin, or cupro-manganese may with advantage be added to all copper alloys of low zinc content immediately before casting. Such additions should not exceed 0·1 per cent. phosphorus, or 0·2 per cent. manganese.

A distinction has already been drawn between iron present in a free state and iron alloyed with the constituents of an alloy. Free iron simply represents iron mechanically trapped in the alloy, that is, it has accidentally entered the crucible, and never been liquefied. As these specks of iron are objectionable and sufficient to condemn a casting, every care should be taken to prevent their presence. This necessitates careful use of stirring bars and skimmers, and a point of interest is found in the fact that iron bars or skimmers are better than steel ones. A coat of blackwash is always good in preventing the taking up of iron. After black-washing, the bar should, of course, be dried. All borings or turnings before melting should be passed through a magnetic separator in order to remove iron. If a crucible of brass containing free iron is allowed to stand, it will be noticed that the iron floats to the surface and sparks; advantage may be taken of this by squeezing a swab over the surface, and then skimming, a treatment which will remove some of the iron.

CHAPTER XXXV.

MECHANICAL TESTING.

MECHANICAL tests are applied to castings for a variety of reasons, but always as an attempt to obtain a measure of their qualities. The ideal test must surely be behaviour in the work for which they are intended; but again, in the foundry, as, indeed, in most other places, the ideal is but seldom attainable, although that is no reason why the educative effect of viewing it should be missed. This is strikingly enforced in those rare cases where even mild forged steel, such as boiler plate, has passed ordinary mechanical tests to prove its ductility, and yet has broken in an exceedingly brittle fashion in use. Some hold that the mechanical tests showed the steel to be good, and yet, having failed to show any faults in the design of the boiler, they can hardly hope to succeed in convincing the owner of the burst boiler that their ideas are correct. With forged steels these cases are comparatively rare, but in castings the difficulty often arises of a sample standing the tensile, and failing under the drop test, or passing a satisfactory drop test, but not reaching requirements under the tensile. These matters are mentioned to impress the point that blindly following the apparent teachings of the results of ordinary mechanical tests may readily lead to dangerous practices; and that, if possible, these tests should always be supplemented by the results of trials in use before very radical changes are made in situations where failure would produce disastrous results. Castings are sometimes produced which give tensile tests almost equal to forgings, and the claim has been made that this proves their equal suitability for almost any and every purpose; but as he who recommends either man or casting for work in which either is likely to fail is their enemy, it is well to remember that, although such tests may point to new uses, it is advisable to have the results of actual behaviour in work before embarking largely on a new scheme; for, frequently, the different internal architecture of the casting has prevented it confirming in use what the static tensile test had appeared to indicate. Nevertheless, in the great majority of cases, mechanical tests, supplemented for special service, by chemical and even micrographic analyses, are successfully relied upon in the making and in the selecting of castings for given purposes.

Castings are sometimes divided into test and non-test castings, the latter term being somewhat of a misnomer; for, under this head are generally included those which are subjected only to some rough test, such as dropping from a certain height on to an iron plate.

Steam and Water Tests.—Apart from the drop test, the only test which tries the behaviour of the casting as a whole is the steam or the water test.

In its simplest aspect this test consists in closing all outlets and filling the casting with steam or water under pressure. Pressures vary according to specification. Thus, cast-iron has often to meet 300 lbs. water pressure, and steam and boiler fittings in gun-metal may have to pass a test of 1700 lbs. water pressure. Any leakage or sweating at the specified pressure condemns the casting. Where a steam or water test is specified, the whole of the castings undergo the test. In the case of mechanical tests, only selected parts of certain castings are tested, or even special test pieces cast from the same material as the castings.

The transverse test, probably the simplest type, is the one most generally applied to cast-iron. In this country the standard test piece is a casting 3 feet 6 inches long × 2 inches deep × 1 inch broad, which is evenly laid on two knife edges 3 feet apart, a third knife edge being brought down midway between the other two and a gradually increasing pressure brought to bear until the specimen breaks. The result is generally recorded in cwts., and a refinement of the test is to measure the deflection for given pressures, or, more usually, the total deflection before fracture. It would be easy to give numerous actual results of such tests, but it is much more useful to remember the three numbers 18, 28, and 38 cwts., of which 18 represents a distinctly poor, or, even bad, result; 28 cwts. a fair average; and 38 cwts. a very good test. These tests are easily made on the more elaborate testing machines, such as the Buckton single lever, but fig. 217 shows an efficient apparatus by W. & T. Avery, specially designed for transverse testing only.

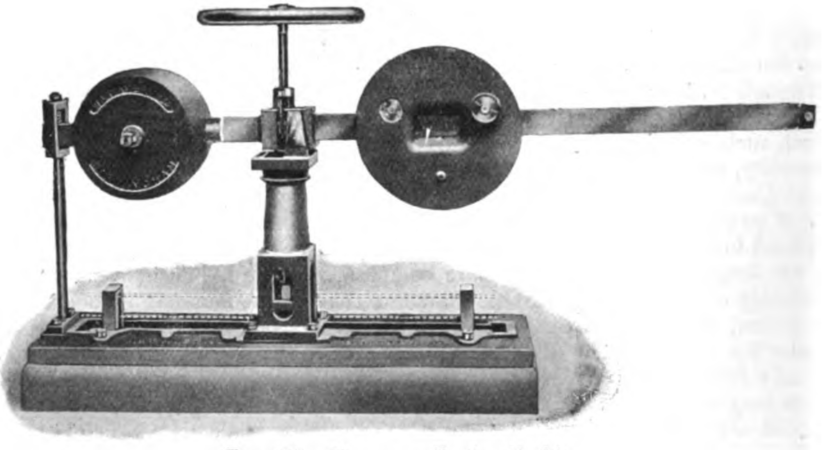

FIG. 217.—Transverse Testing Machine.

It is important to note that the dimensions of the section in this test should be correct or carefully measured, a fact sometimes ignored, as these pieces are tested as cast. Take the formula $W = \frac{cbd^2}{l}$, representing the resistance to fracture of a beam of this form, and, therefore, the relationships between W, the weight required to break the test bar; *c*, a constant for any one material; *b*, the breadth of the section; *d*, its depth; and *l* the length between the knife-edge supports. Assuming *l* and *b* to be true to standard, and 36 cwts. recorded, but *d* found afterwards to be 2·1 inches instead of 2 inches, then

(1) 36 cwts. $= \frac{c \times 1 \times (2''\cdot 1)^2}{l}$; and, if x be the correct number desired, $x = \frac{c \times 1 \times (2)^2}{l}$; from equation (1) $\frac{c}{l} = \frac{36 \text{ cwts.}}{4\cdot 42}$, then $x = \frac{36 \times 4}{4\cdot 42} = 32\cdot 6$ cwts.

This not only serves as a warning, but shows how to arrive by calculation at the correct result for the true standard size from a result obtained from another size. For cast-iron the calculation should only be used when the sizes are something near the standard; as, even assuming a constant composition, the structure of this material varies so much with different sizes of castings. In some cases in this country, and more so in America, the transverse test is made on 1-inch square section on supports 12 inches apart.

The compression, or crushing test, is another that is sometimes applied to cast-iron, and, although the transverse test is most generally relied on to judge of the quality of cast-iron, its resistance to crushing is very commonly the property that is used. The name sufficiently describes the test, and the form of the piece and results obtained are all that need be given. In fig. 218, 7 is an unused test piece, 6, 5, 4 are grey irons, 3, 2, 1 are white irons (all after testing), in which the shattering of the white iron should be noted. The test piece for crushing is generally a cylinder of which the length is about twice the diameter. The results are read in tons and calculated to tons per square inch; and, as in technical work calculation must be reduced to a minimum in order to save time in doing a series of tests, the diameter is arranged so that the area of the circle shall be 1 square inch or some simple fraction, generally ¼, ½, or 1 square inch, represented by 0·564 inch, 0·798 inch, and 1·128 inch respectively, and hence 1·128 inch, 1·596 inch, or 2·256 inches in length. The cylinder chosen is set between two parallel plates of hardened steel, and the crushing pressure applied in the special manner designed for the particular machine in use. With regard to results: for cast-iron the three numbers 30, 40, 50 may be remembered; 30 tons per square inch being a bad result, 40 a good average, and 50 tons a very good result. In the case of steel castings, the test pieces, as a rule, do not break, but merely

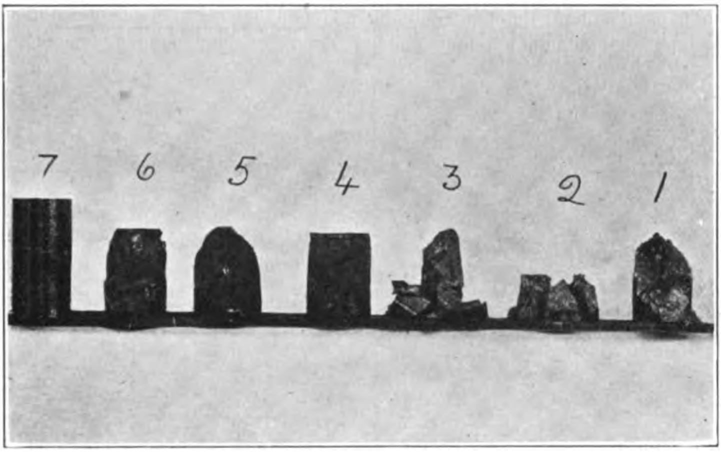

FIG. 218.—Crushing Test Pieces.

assume a cheese shape, and the result is expressed as a compression of, say, 41 per cent. at 100 tons per square inch; several are given in the proper chapter. The test, unless for cast-iron, is seldom used in commercial work, and is principally reserved for scientific investigations, in which it is desired to throw every available light on the subject. Fig. 220, C, shows the appearance of a 0·35 per cent. carbon steel crushing piece after testing.

The Drop Test.—Many castings, such as wheel centres, are required to stand a drop test. This is somewhat similar to the transverse test, only, instead of a pressure gradually applied, a specified weight, say 1 ton, is lifted so many feet above the casting between guides and then dropped on it, so as to gauge how it would behave under severe shock. The method of raising and releasing the weight is practically that shown in fig. 169 for breaking up castings, only the weight is raised and falls between guides, and it has a part underneath, V-shaped in one view and rectangular in the other, with the object of striking the casting on a definite line or place.

The Bending Test.—In this test the section of the piece is specified as round or square, and dimensions are given; while one part is held firmly, the other is bent either by hammering or by pressure over a specified radius, for the smaller the radius the more severe the test. The bending is continued until either the specimen breaks or the required angle is reached, when, in commercial work, it is usually not bent further, although, in experimental work, the bending is continued until fracture is produced or until the sample bends double. Fig. 219 shows two pieces after testing, the upper having broken at 89° and the lower bent double without sign of distress.

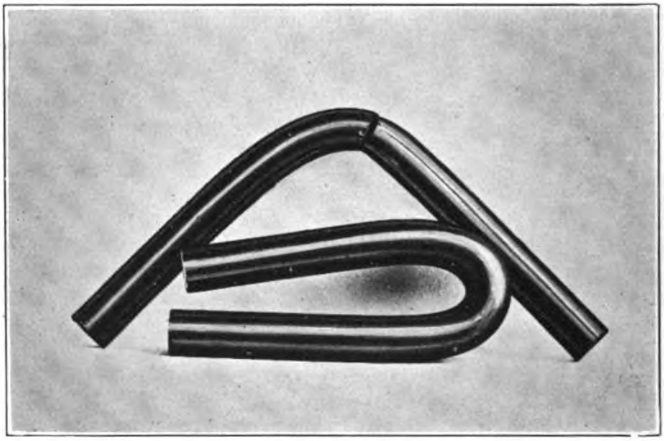

FIG. 219.—Bending Test Pieces.

The Tensile Test.—The tenacity of a metal is the resistance it offers to rupture by a tensile stress, a force which tends to pull its particles asunder, and it is generally expressed here in tons per square inch; in America, in lbs. per square inch; and, on the continent, as kilos. per square millimetre. In fig. 220, 4 represents a common form of tensile test piece for 2 inches parallel, before testing; 1, a gun-metal; 2, a yellow brass; 3, a steel casting; 5, a forged steel; 6, a lead; and 7, a cast-iron test piece after breaking in the testing machine. With substances such as grey cast-iron, white cast-iron, and certain hard steels, the test piece resists the force up to a certain point, and then suddenly gives way. With mild steel castings and many alloys the behaviour is different, for, up to a certain point, there is the same resistance and only a very slight elongation and consequent reduction in area of the piece, which are proportional to the force applied; and, when the force is removed, the piece practically regains its original dimensions, as is the case with the other materials mentioned above. With these, however, a point is reached where the conditions no longer hold, for the elongation suddenly becomes much greater than proportional to the stress, the beam of the machine drops, and the lengthening of the piece is now sufficient to be clearly seen by measuring with finely-pointed dividers held during testing in fine centre punch marks. Before this stage, if the stress be removed, the piece will return to its original dimensions. The force which enables the piece to do this is called elasticity. When the stress is equal to the maximum elastic force, it is known as the elastic limit. The slightest increase in the stress now produces permanent set. The sudden drop of the beam of the testing machine, or the very decided lengthening of the piece as shown by the dividers, is taken, perhaps somewhat loosely, as the elastic limit, but is styled by some the yield point. It will readily be seen that it must be a delicate matter to obtain the true elastic limit according to the definition, that perfect elasticity is measured by the exact return to original dimensions after removal of the stress. It is also held that exact proportionality between the stress and the elongation does not cease at exactly the same point as perfect return, and that neither is exactly at the yield point as measured by the drop of the beam,

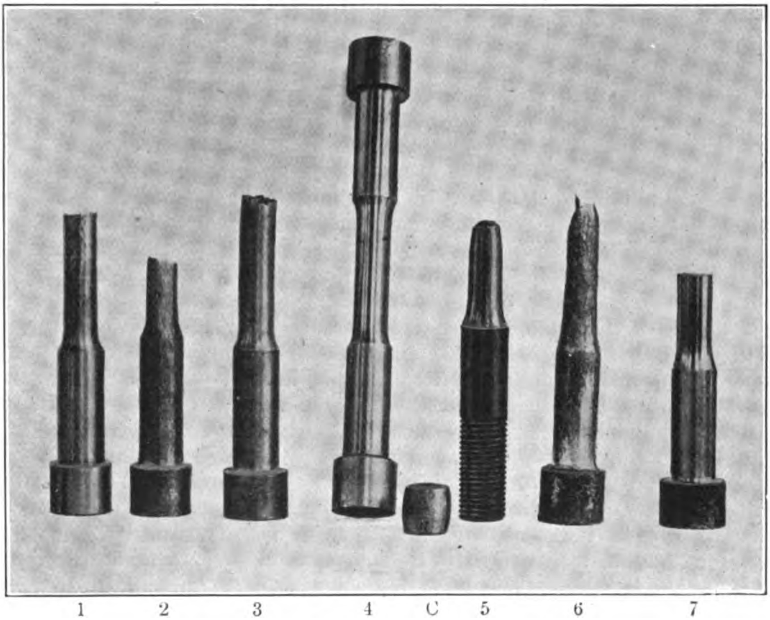

FIG. 220.—One Crushing (C) and Seven Tensile Test Pieces.

and the more delicate the measuring instrument the sooner is disagreement shown. It is not therefore to be wondered at, that, in ordinary practical commercial testing, the settling of these fine points is left to specialists, who are very much at variance among themselves, and that the drop of the beam or the sudden lengthening already described is generally taken as the elastic limit, if, on running the weight back, there is found to be a distinct permanent set.

On further increasing the stress, the piece continues to elongate, at first fairly regularly throughout the parallel part; and, finally, at one point a special "waist" is formed. Soon after, the piece fails to lift the beam, and the maximum stress has been reached. Generally, the piece is then allowed to break by continuation of a force which is not measured; as, the beam having dropped, and the strength of the piece being unequal to lifting it, the real stress acting now must be less than that recorded on the beam, and the real stress required generally continues to decrease until fracture takes place. Hence, when the maximum stress that the piece will stand is meant, it is obvious that breaking stress, and, much more so, breaking strain are not terms that should be used. In some special work, when the maximum stress is reached, arrangements are made for measuring the then gradually decreasing stress, which can be done by a pressure gauge, or by running back the weight so that the beam is kept floating, and obtaining the result from an automatic recorder. It may seem strange that the breaking stress should be less than the maximum stress; but, when the continuous decrease in diameter is allowed for by calculating the stress per square inch of the smallest section at each stage, it is found that this number increases to the end of the test. The readings on the beam give the elastic limit (E.L.) and the maximum stress (M.S.) in units of weight on section; and these are calculated and reported as units of weight per unit area of the original section, as, for example, in tons per square inch of the original section. The ductility of the material is represented by the amount the test piece elongates or draws out after the elastic limit is reached. This is the definition of the user of such material, the engineer, and is the best. The old metallurgical definition of ductility as the property which enables a metal to be drawn into wire is founded on a confusion of ideas. A metal is not merely drawn out into wire, but its tenacity is taken advantage of to draw it through a hole, smaller than its own diameter, in a steel wortle or wire drawer's plate, and the fact that it yields at this point is due to its malleability; hence, the properties that enable a metal to be drawn into wire are its tenacity and its malleability combined. The amount, then, that the test piece elongates after the elastic limit is passed, determined as the total permanent elongation when broken, is a measure of the ductility of the material, and is expressed as so much per cent. on so many inches. One is often asked why trouble to say on 2 inches or 4 inches (as the case may be), for is that factor not eliminated by stating the result in percentages? This is necessary, however, as there are two distinct permanent elongations, one fairly regular over the whole parallel part and one relatively great, but restricted generally within about an inch of the length and constituting the waist, where the piece decreases in diameter comparatively rapidly. Thus, the general elongation would be the same per inch on a 2-inch as on a 4-inch piece, but there would be only one elongation for each due to the waist; hence the elongation per cent. is greater on 2 inches than on 4 inches, and, in general terms, it is less the greater the length of the test piece. It is interesting to note that, given the elongations of two test pieces differing only in length, the two separate kinds of elongation can be calculated from these; and, hence, also the elongation per cent. for any other length of test piece of the same diameter and made of the same material; this result is often desired for comparing specifications or experimental results. The authors have tested this by several experiments, but the following should be interesting, and make the matter clear:—

Let l_1 represent the regular elongation per inch, and l_w the special elongation due to the waste. Take the elongation on 3 inches and on twice that length, namely, 6 inches, which it is seen are 0·94 inch and 1·46 inch respectively. The former contains three times the general elongation per inch and once that specially due to the waist; hence, twice this, or:—

$$2 \times 0{\cdot}94 \text{ inch} = 6l_1 + 2l_w, \text{ and } 1{\cdot}46 \text{ inch} = 6l_1 + l_w,$$

$$\text{hence} \quad 1{\cdot}88 - 1{\cdot}46 = l_w = 0{\cdot}42, \text{ and } l_1 = \frac{1{\cdot}46 - 0{\cdot}42}{6} = 0{\cdot}173 \text{ inch.}$$

It is obvious from the sketch that the actual measured elongation on the first inch from the left is 0·17 inch and on the next 0·18 inch. Of the others only the last is marked and clear of the waist, and it measures 0·17 inch, an average of 0·173 inch. From these it is easy to calculate the elongation on 4 inches, for, assuming a homogeneous material, it must be 4 × 0·173 inch + ·42 = 1·112, or 27·8 per cent.; whereas, it will be seen from the figure that the measured elongation is 5·11 − 4·0 = 1·11, or 27·7 per cent.; this is an exceptionally close agreement, obtained by using an exceedingly homogeneous piece of forged material, Farnley iron, and having the different lengths of test pieces all on the same piece. Disagreements obtained from similar calculations, using non-homogeneous materials and different test pieces, are only such as are obtained in the actual testing of the same. It will further be seen by measurement, where possible, or otherwise by calculations similar to the above, that the elongation is 38·3 per cent. on 2 inches, 31·3 per cent. on 3 inches, 27·7 per cent. on 4 inches, 26·0 per cent. on 5 inches, 24·3 per cent. on 6 inches, and would be 22·5 per cent. on 8 inches.

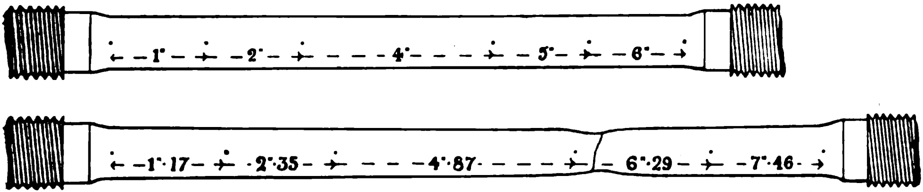

FIG. 221.—Tensile Test Piece before and after Fracture.

According to the Law of Similitude of M. Barba, not only do different lengths give different elongations, but also the same lengths only give the same elongations on pieces of the same diameter, and, in general terms, for the same material only, similar figures give the same elongations. Thus, a test piece 0·564 inch diameter by 2 inches long (as we have already shown) would not give the same elongation as a test piece 0·564 inch diameter by 4 inches long, nor would one 0·798 inch diameter by 2 inches long give the same elongation per cent. as one 0·564 inch by 2 inches long; but one 0·798 inch diameter by $\frac{0{\cdot}798 \times 2 \text{ inches}}{0{\cdot}564 \text{ inches}}$, or 2·83 inches long, gives the same elongation as the first. These points are well worthy of careful thought, for, although complications can be avoided in most cases in one's own testing by keeping to standard dimensions, it is impossible to compel others to do the same; yet it is often necessary to compare one's own results with those of other workers. Hence, some engineers ask for the figure $\frac{l}{\sqrt{a}}$ to be always given, so that a fair comparison between elongations may be made; for those test pieces in which $\frac{l}{\sqrt{a}}$ are equal are obviously similar figures, l representing the length between centre punch marks and a representing the area of the section, $\sqrt{a}$ is proportional to the diameter. Several people to whom these matters have been mentioned have doubted their accuracy, whether from prejudice or experiment is not known to us; but it is well to state that we have made several experiments as occasion arose in ordinary testing work on all these points, and all have corroborated M. Barba's statements. As an example, a test piece of one steel 0·564 inch diameter by 2 inches long gave an elongation of 23·0 per cent.; whilst one 0·712 inch diameter by $\frac{0{\cdot}712 \times 2 \text{ inches}}{0{\cdot}564}$, or 2·53 inches long, gave an elongation of 23·3 per cent. In case it might be thought that the difference in length was too small to make any difference in the elongation per cent., a test piece of another steel was tested later to meet the objection, when 0·564 inch diameter by 2 inches long gave 32 per cent. elongation and on the same diameter, but 2·53 inches long showed 27·7 per cent. elongation.

Alternating Stress Test.—The fact already mentioned that tensile testing sometimes fails to give all the information desired has led engineers to specify other or added tests for certain work, as in the case of the drop and the bending tests. Behaviour under rapid alternations of stress below the elastic limit has been much to the fore among experimenters recently; but Prof. Arnold has designed an alternating stress test which, unlike most of the others, can be made in a very short time, and the peculiar feature of which is that the sample is stressed above the elastic limit, a piece ⅜-inch square or round being held firmly in a hardened steel die and struck 3 inches above the surface of the die, so that it is moved to and fro ⅜-inch on each side of the centre about 670 times per minute. The method has given some interesting and important preliminary results in studying the treatment of castings, but it is too soon to make any special pronouncement, and there is not space to discuss the detailed results.

CHAPTER XXXVI.

MICROGRAPHIC ANALYSIS.

To many the microscope may seem an unnecessary refinement, and not at all in keeping with the work of a foundry. Experience proves, however, that its use has a commercial value, as has been distinctly shown in Chapter XXXII., the micrographs there given illustrating one method of attacking problems not open to solution by other means. Not only must the founder know the constituents present in his metals, but he should also know how those constituents are distributed in the mass of the metal. This involves a study of structure, and, at the outset, structure must not be confused with the appearance presented by a fractured surface. A fracture reveals only the appearance after breaking by a force, such as a blow or a pull, and even the nature of the force used to effect rupture and its manner of application have a considerable effect on the appearance of the fracture. In breaking pig-iron the greater portion of the fracture follows the plates of graphite, and, as a result, the broken surface may suggest a preponderance of graphite inconsistent with the actual composition of the mass. A crystalline fracture, one having a brilliant or sparkling appearance, generally indicates a crystalline material, the crystals of which are only loosely held together, or are separated by some brittle cement, or even the individual crystals, which are so perfectly developed that they show real crystal cleavage, definite planes of weakness within the crystal. A fibrous fracture may also be given by highly crystalline bodies, such as lead, copper, or pure iron, for in that case the crystals are soft and ductile, and cling together, so that the fracture is fibrous because these crystals have been pulled out in the direction of the stress.

Structure, then, may be described as the internal architecture; and whilst, under certain conditions, the architectural arrangement may be visible to the naked eye, in the majority of cases aided and magnified vision is essential. This study of the structures of metals is known as metallography. Amongst early workers in the science the name of Henry Clifton Sorby will always stand pre-eminent as the father of the introduction of the microscope to the study of the structure of rocks, as he also, some years later, was the first to apply the microscope to the examination of the minute structure of metals. Professor Wm. Nicol of Edinburgh had prepared thin transparent sections of fossil wood which revealed the structure of the original wood. Dr Sorby saw these, and applied the methods to rocks, thereby revealing their internal structure. He also carried the work on to the examination of the opaque bodies, metals, and thus laid the foundation of metallography. For a long time Sorby's work lay dormant, and we have heard him tell how geologists ridiculed the idea of examining mountains under the microscope, and metallurgical applications were ignored for years. Although, as Sorby showed, there are remarkable similarities between the structure of igneous rocks and metals cast or forged, a rock section when ground down to a thin slice can be examined by transmitted light; whilst a metal section is opaque, and can only be examined by reflected light. This deprives the metallurgist of some of the most valuable tests open to the petrographer.

Martens in Germany did a vast amount of microscopical work on the structure of metals, but the renaissance and extension of Sorby's pioneering work in the true spirit is largely due to Arnold, Osmond, and Stead. Since then the field seems to have become almost fashionable; but, unfortunately, although much valuable material is to be found scattered through various publications, much ill-digested matter has been contributed by careless or incompetent workers, which must sorely try the student.

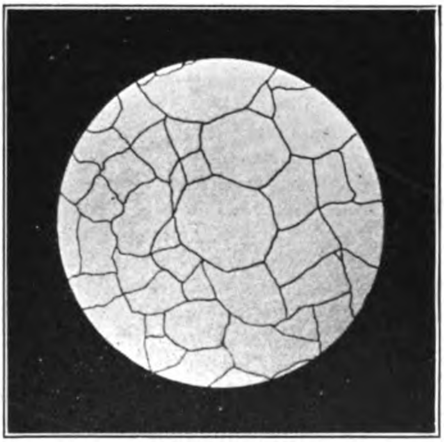

FIG. 222.—Structure of Pure Metal.

Only a general survey of metallography is given here from a purely foundry point of view, drawing all examples from our joint experience and avoiding the technics of the microscope as an instrument and the preparation of sections. No attempt is made to discuss conflicting theories, or to enlarge on theoretical niceties, and the views given are those deemed suitable for practical men. Practically speaking, all metals are crystalline. Assuming the metal to be chemically pure, then in mass it will be built up of a series of crystals, each bounded by its contact with its neighbours and not necessarily by crystal faces. A plane section cut from a pure metal, when polished and etched, shows under suitable magnification a series of lines which mark the crystal boundaries, as in fig. 222. Whilst representing the general appearance of most pure metals when viewed under the microscope, this illustration does not define the size of the crystals. Actual size varies with the metal, and, for any one metal, with the rate of cooling from a high temperature, the slower the cooling the larger are the crystals and the more geometrical are their boundaries; conversely, rapid cooling results in a finer type of crystallisation.

Deeper or more prolonged etching will generally show not only crystal boundaries, but also a little of the internal structure of the individual crystals. Certain lines appear, which, consisting of parallel series in each crystal, have different directions in different crystals. This is expressed by saying that the orientation is constant within one crystal, but varies from one crystal to another. Comparatively few metals are met with in a state of perfect purity, but the foregoing is essential as a basis for the study of the nature and distribution of impurities or other constituents.

When a foreign substance is added, or is present, it may be isomorphous with the metal, that is, it may crystallise in the same form and solidify as one substance with the metal; or, on the other hand, it may of itself, or when combined or alloyed with a portion of the metal, form a substance that will not crystallise with the metal, and in this case the crystals separate in a state of purity and reject the impurity, which is found on solidification as a separate constituent. With the former type of impurity the structure is, practically, as shown in fig. 222, whilst with the lätter type the impurity may show in section as a network embracing pure crystals, as in fig. 223, or as small rounded particles, as in fig. 210.

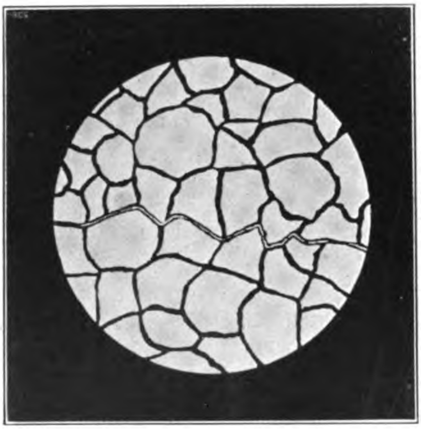

FIG. 223.—Structure of Pure Metal, with Trace of Impurity.

One of the most troublesome problems of metallurgy is that of determining the particular form of this thrown-off material when it is a brittle substance, and the importance of this form has already been discussed in connection with steel castings (Chapter XXXII.).

Obviously, the properties of a metal possessing a structure like that shown in fig. 223 are represented by the character of the network. Assuming the network to be brittle, then, no matter how ductile the individual crystals may be, the mass will be brittle, for the ductile crystals are completely isolated from each other. The rejected material may also have a lower melting point and a different contraction coefficient to that of the pure metal. Thus, the contraction of the pure crystals may be well advanced before the rejected compound solidifies and commences to contract. The nett result is that the cohesive force acting between the crystals and the network is weakened, or, in aggravated cases, a minute space may be developed. This is of some moment in the case of water or steam-tests, and, for the sake of clearness, a narrow space is shown traversing one of the lines of network in fig. 223. Translating such a structure into the solid, the metal would be traversed by minute intercrystalline spaces, and thus tiny routes are offered for the percolation of water under pressure. A result of this kind may be actually obtained by adding small amounts of sulphur to pure iron, the result being that the leakage takes place along the interspaces between the crystals of pure iron and the meshwork of iron sulphide.

Mere optical effects, in the case of sections which have necessarily to be examined by reflected light, must be allowed for, and fig. 224 shows a typical example representing an actual photograph of perfectly pure copper. The crystal junctions will be readily seen, and it will also be noted that some of the crystals are much darker than others. The white junctions might be mistaken in a photograph for brittle or other cements, but when examined by suiting the focus to each point in turn, it is plain that they only represent reflection off a sloping portion of one crystal leading up to the other. That the dark crystal is only due to an effect of lighting may be proved by revolving the section, when the dark one becomes light and some of the lighter crystals change to dark.

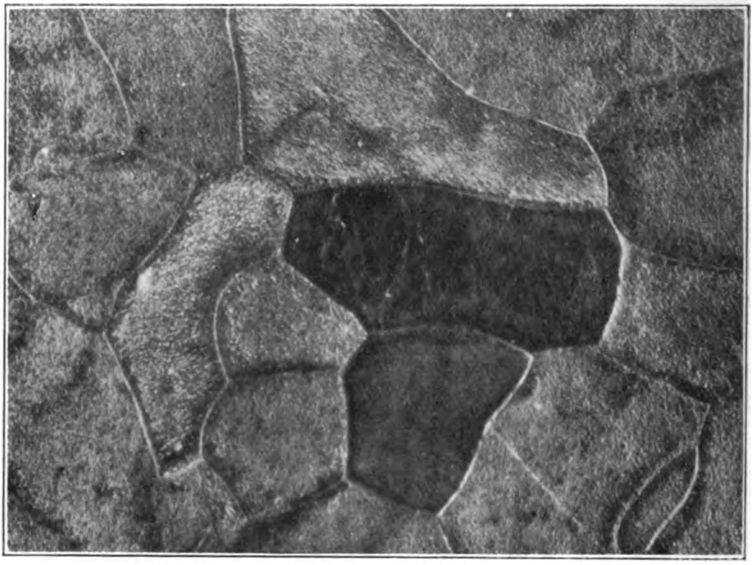

FIG. 224.—Structure of Pure Copper. × 58.

Fig. 225 represents the same copper as is shown in fig. 224, but alloyed with 0·2 per cent. of antimony. This impurity is an exceedingly objectionable one, and the meshwork shown in fig. 225 gives a very clear reason for the adverse influence of antimony on the mechanical and electrical properties of copper. Figs. 224 and 225 are from the authors' photographs from sections expressly prepared by Arnold & Jefferson to illustrate the influence of small amounts of impurity. Obviously, when the addition combines with a certain amount of the excess metal to form an alloy, then its effect is intensified.

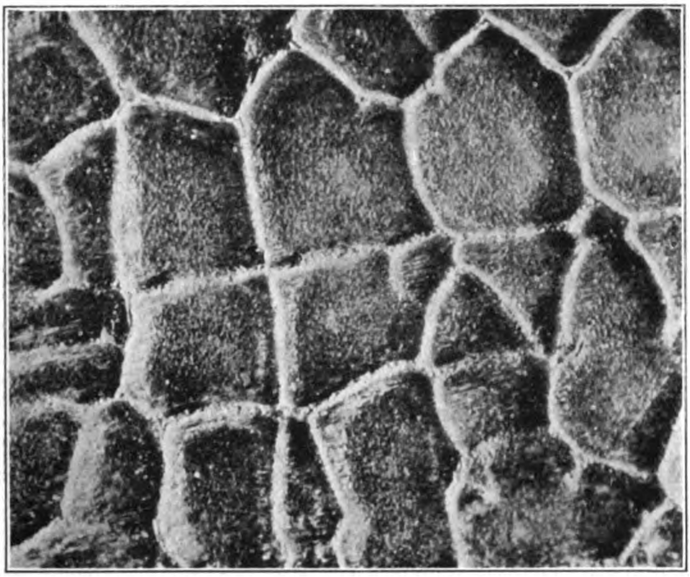

Fig. 225.—Structure of pure Copper, with 0·2 per cent. of Sb. × 58.

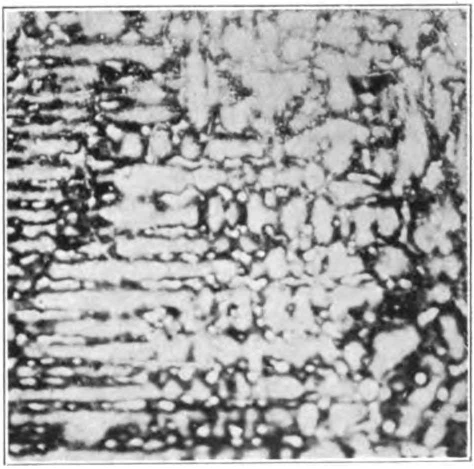

Fig. 226.—Stucture of Pure Copper, with Oxygen. × 58.

Whilst it is unlikely that less than $\frac{1}{4}$ lb. of antimony, evenly disseminated in a free state through 99·8 lbs. of pure copper, would have any marked effect on its properties, it is easy to realise that, when the antimony separates out as an alloy and forms thin walls, effectually isolating each ductile crystal, the strength of the mass will be that of the investing membrane.

Fig. 226 is an interesting structure to compare with that of the pure copper shown in fig. 224. It represents copper, melted without any special precaution as to oxidation; the result is a composite structure of apparently two distinct constituents. We have obtained many and various types of structures from sand cast copper melted under different conditions of oxidation, but fig. 226 is sufficiently far removed from fig. 224 to give an interesting comparison and to convey a moral to the student.

Good examples of these two types may also be drawn from gold and from iron. Fig. 222 might represent a microsection of either gold or iron at different magnifications. Add a few tenths per cent. of silver to the gold, the structure is unaffected, the silver crystallising out as one with the gold. Silicon added to the iron gives the same result, probably dissolving as a silicide of iron; similar substances, in which the added material crystallises out with the other as a homogeneous mass, are called solid solutions. It must not be assumed that in these cases there are no changes in properties, for the additions have a subtle influence, the silver stiffening the crystals of gold slightly and the silicon most probably helping to perfect the crystallisation of the iron and giving some tendency to the formation of cleavage planes. Add 0·2 per cent. of sulphur to the iron, the sulphur combines with the iron to form sulphide of iron, which, on cooling, is rejected by the crystals of the metal. Add 0·2 per cent. of lead to the gold, the lead forms an easily fusible alloy with a small quantity of the gold, and this alloy is also rejected by the crystals in such a way that the structure in either case is very much like fig. 223, and the metal is more or less brittle. A term very much used in speaking of the constitution of metals is Eutectic. The eutectic is the alloy of lowest melting point in a series of alloys. Thus, lead melts at 327° C., tin at 232° C.; but an alloy of 2 of lead to 1 of tin begins to solidify at about 230° C., when the lead crystallises out until a composition of 31 per cent. lead to 69 per cent. tin (nearly $PbSn_4$) is reached, which solidifies as a whole at 180° C. This alloy of lowest melting point or mother liquor of the lead-tin series is known as the lead-tin eutectic. It is of a definite composition, has a definite solidifying point; and a usual feature of eutectics is that, on solidification, they split up into two constituents, and on etching a polished section they show generally a more or less definitely striped appearance, as in the case of Stead's phosphide of iron eutectic containing 10·2 per cent. phosphorus (see figs. 241 and 242).

We have seen that sulphur combines with some of the iron, and the disposition of the sulphide may make the iron brittle, but sometimes the added material may combine with a portion of the metal, and the compound may have the effect of giving us alloys of great importance. Take the case of the copper-zinc alloys. The exact theoretical changes that take place are much discussed; but we give only one view, with the warning that there are others (which do not, however, affect the practical results). Copper alloyed with 10 per cent. zinc presents the structure shown in fig. 227, which is a network of a definite yellow compound or alloy of copper and zinc nearly corresponding to the formula Cu_2Zn (66 per cent. copper, 34 per cent. zinc), distributed through a groundwork of copper. The yellow portion of this alloy may be called true brass. As the content of zinc is increased, the area of the true brass is increased, until, when about 34 per cent. zinc is reached, the whole of the structure is just one yellow field of true brass. When the content of zinc is still further increased, the compound Zn_2Cu appears and increases in amount

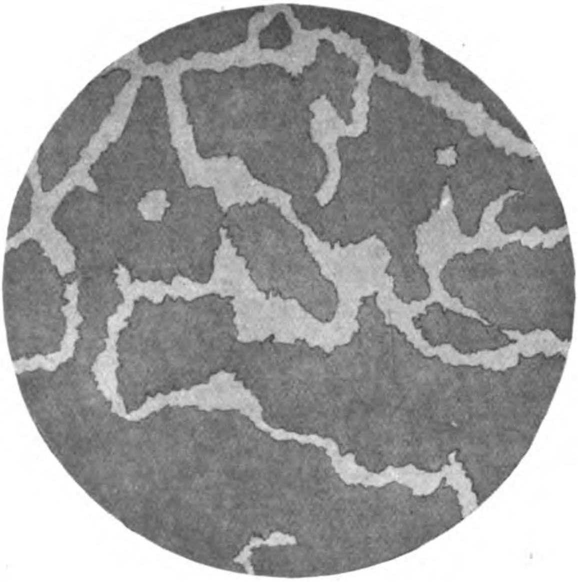

FIG. 227.—Structure of Red Brass. × 230.

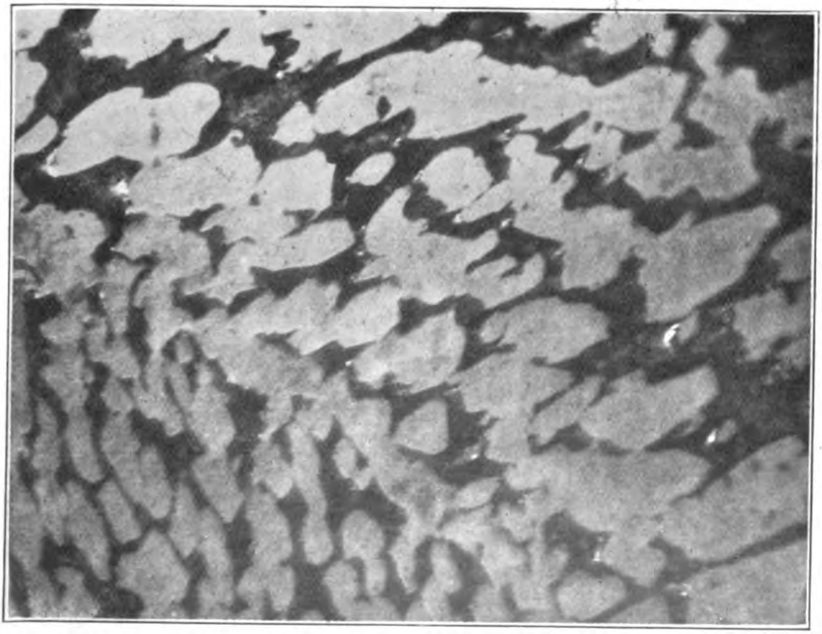

FIG. 228. —Structure of Muntz Metal. × 360.

as the content of zinc is increased, and thus, pure Muntz metal alloys consist of two constituents Cu_2Zn and Zn_2Cu. There is some difference of opinion as to the former being a real chemical combination, many workers holding it to be an alloy of CuZn with copper, but we think that Laurie has proved his point with regard to the Zn_2Cu being a true chemical compound, even in the solid metal. An average cast Muntz metal structure is shown in fig. 228, in which the light portions represent true brass and the dark areas the compound Zn_2Cu. Fig. 229 shows a more attenuated arrangement of the dark constituent in the yellow ground of true brass, and this represents a type of structure common in high-tension bronzes.

The copper-zinc series of alloys give a good illustration of the gain in properties due to a composite structure. Thus, ductile true brass is stiffened by the distribution through it of the harder compound Zn_2Cu; but when the compound is present in excess, as when 40 per cent. zinc is exceeded, then by virtue of its own brittleness, and owing to the decreasing amount of the ductile Cu_2Zn, decisive hardness and brittleness in the alloy is manifested.

Fig. 229.—Structure of Muntz Metal. × 230.

Another example of the beneficial effect of dissimilar crystals side by side is found in the case of gun-metal, for, as in fig. 230, we have ductile copper modified by the distribution of hard $SnCu_4$. This compound is extremely hard and brittle, it possesses a silver white colour, and to it is due the hardness of gun-metal. Here, again, an increase in tin results in an increase in the amount of hard $SnCu_4$, and, as noted in the chapter on alloys, experience has shown that a limit of 10 per cent. tin is sufficiently high for ordinary gun-metals. Exceeding this amount there is not sufficient ductile copper to temper the brittleness and hardness of the compound. Fig. 231 shows another type of gun-metal structure induced by casting at a very low heat. The differences mechanical properties are worth noting, and the very perfect type of

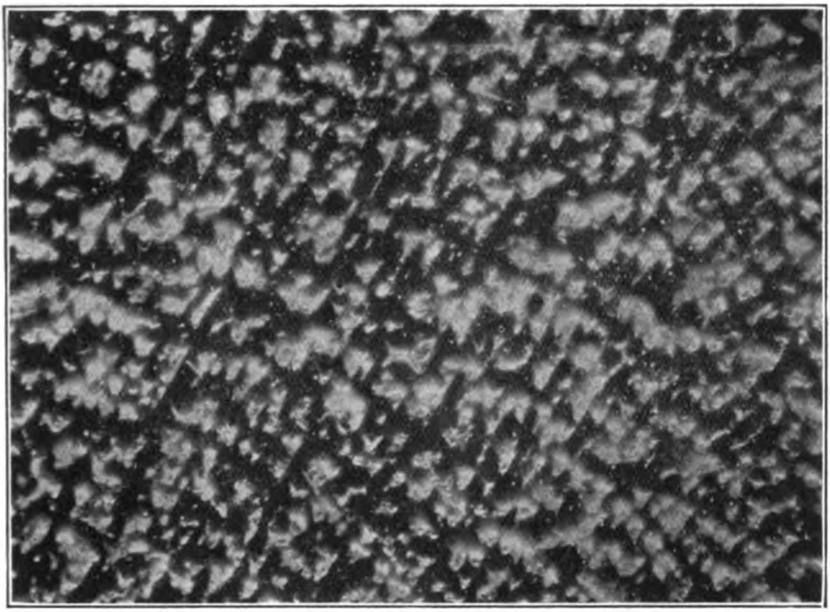

Fig. 230.—Structure of Pure Gun Metal. × 58.
Maximum Stress, 20·0 tons per square inch. Elongation, 16 per cent. on 2 inches.

Fig. 231.—Structure of Pure Gun Metal. × 58.
Maximum Stress, 9·5 tons per square inch. Elongation, 2·8 per cent. on 2 inches.

crystallisation of fig. 231 forms a strong contrast to the interlocked and broken up appearance of fig. 230. These two structures represent the two extremes met with in the examination of many gun-metals of identical composition. They show that, when two dissimilar constituents are present, each constituent should be merged well into the other, in order that the properties of the whole may be a blending of their separate properties. With crystallisation exhibiting a pronounced straight line structure, lines of weakness are evidently introduced.

Iron-carbon alloys have received a much greater share of attention than has been given to the copper alloys. Here metallography owes a very considerable debt to Arnold, who published "The Influence of Carbon on Iron" (*Proc. I.C.E.*, 1895), in which he clearly showed the influence of carbon, not only on the mechanical properties of iron, but also its influence on the microstructure. The structure of pure iron may be taken to be as shown in fig. 222. Crystals of pure iron, as seen under the microscope, are called ferrite. When carbon is added to iron it most probably diffuses evenly through the molten mass, but on cooling from a high temperature it segregates into areas containing about 0·9 per cent. C.; while above about 700° C. it forms a homogeneous constituent corresponding to the formula $Fe_{24}C$. If quenched above this temperature these areas remain homogeneous and form hardenite, a flint hard constituent. If cooled, at a normal rate, to the temperature of the air, then a little below 700° C., these homogeneous areas break up into iron and Fe_3C ($Fe_{24}C = Fe_{21} + Fe_3C$), and, still occupying practically the same areas, they now consist of alternate plates of carbide of iron (Fe_3C) and of iron varying in coarseness according to the rate of cooling and known as pearlite. Evidently, if a sample contains less than 0·9 per cent. carbon, its microstructure will consist of pearlite and ferrite (see fig. 207), and as the carbon is increased

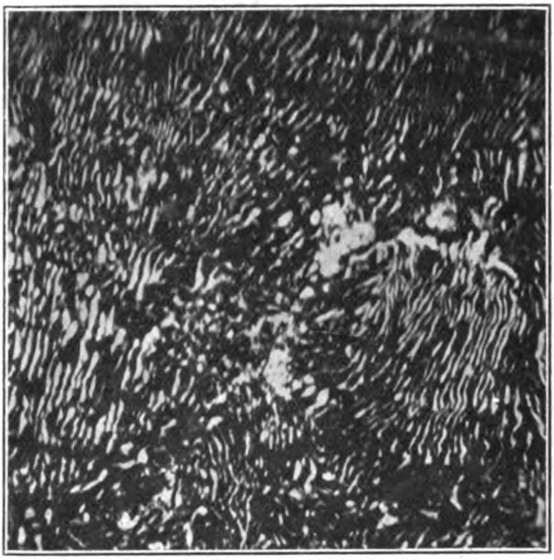

FIG. 232.—Laminated Pearlite. × 1000.

so does the pearlite increase and the ferrite decrease until 0·9 per cent. is reached, when the whole area is pearlite. Fig. 232 represents such a casting after long annealing; and, as it shows the striped character of a eutectic, pearlite has been called by some the carbon-iron eutectic; but, as it is formed long after the most fusible constituent of iron and steel has solidified, the unsuitability of the term need hardly be pointed out. Some of the advocates of the term, having tardily seen the true position, propose now the term

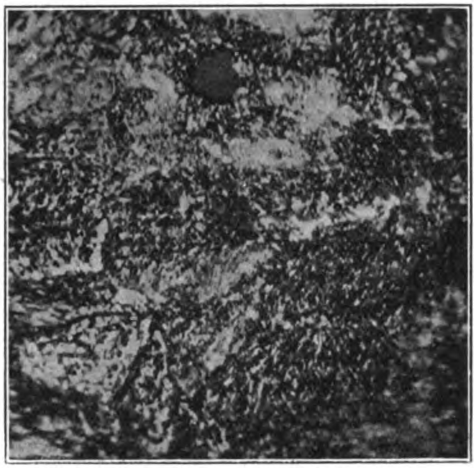

FIG. 233. Granular Pearlite. × 1000.

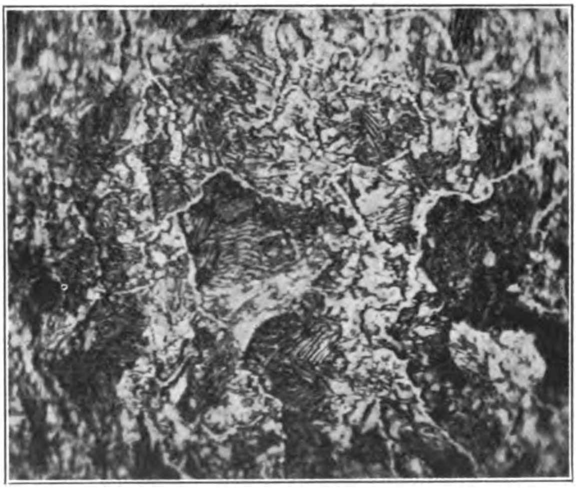

FIG. 234.—Supersaturated Steel. × 1000.

eutectoid (like eutectic) ; but to commonsense practical men, Prof. Arnold's seems to be the best, namely, saturated steel, or true steel as a descriptive term. Until the whole field is pearlite, the steel is an unsaturated one, containing areas of pearlite or true steel and ferrite. When more than 0·9 per cent. carbon is present, the excess is simply thrown off as Fe_3C structurally free, when it is known as cementite, so that this would be called a supersaturated steel, consisting of pearlite and cementite (fig. 234). Among all the controversies, the only views with much support are Arnold's view of pearlite becoming an attenuated compound $Fe_{24}C$ and the solution theory of Fe_3C dissolving in Fe_{21}, and, although important theoretical matters are involved, practically, there is little to worry about. In either case, if we think of Fe_3C combined with or dissolved in iron below 0·9 per cent. carbon, unsaturated is a correct term, and above 0·9, as the hardenite rejects the excess carbide, supersaturated steel is not only a correct but a good descriptive term. Some saturated steel-castings were comparatively brittle, and their structure was represented by striped or laminated pearlite (fig. 232). They were heated to about 950° C., and cooled in air, with the result that their pearlite is of the type represented in fig. 233, and their quality was greatly improved. The harmless little bleb of manganese sulphide may be noted in the photograph.

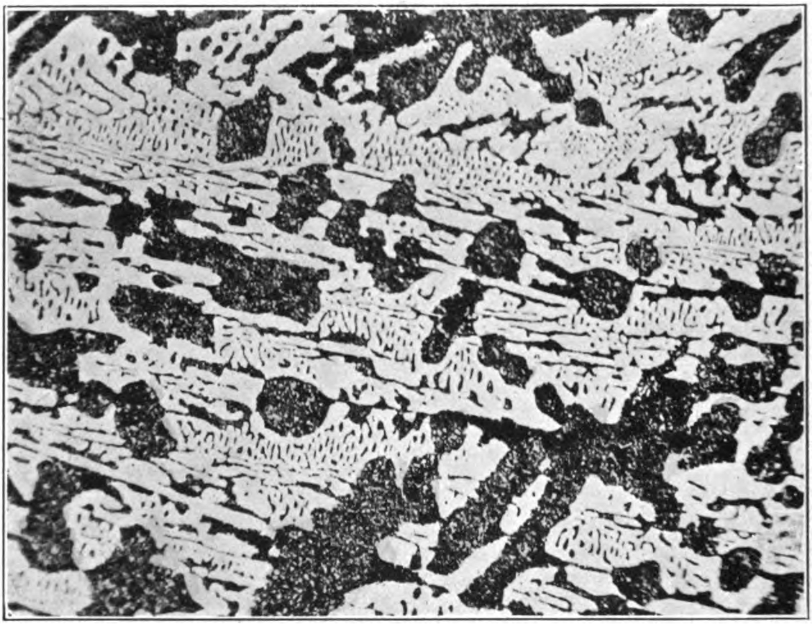

FIG. 235.—White Cast-iron. × 150.

As the amount of carbon is increased, so the cementite increases until the composition of a pure white iron is reached. The microstructure of such an iron is shown in fig. 235, in which it is seen to consist of pearlite and cementite ; the effect of these on the nature of the mass has already been discussed under cast-iron. When other elements are added, the problem becomes increasingly complex, and, instead of a few pages, a treatise would be required to give an adequate idea of the subject. A few points may be mentioned to show tendencies. If manganese be present, it tends to prevent the pearlite becoming

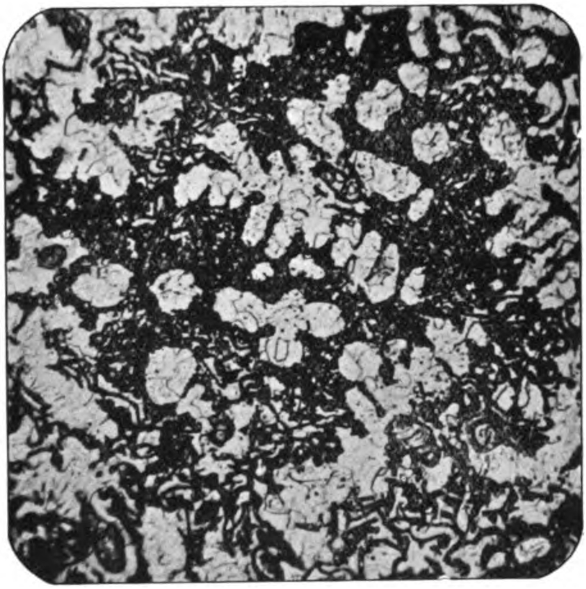

FIG. 236—Grey Cast-iron. × 150.

FIG. 237.—Grey Cast-iron. (Section prepared by Dr. Sorby in 1864.) × 460.

laminated, but a slow enough cooling neutralises this tendency. Also, with manganese, the saturation point is sooner reached than with pure iron and carbon; thus, with 0·4 per cent. of manganese the saturation point would be somewhere about 0·85 per cent. carbon. When silicon is added to the high carbon series it probably dissolves as silicide in the iron, and seems to decompose or prevent the formation of carbide, so that, on cooling, a portion of the carbon is present in the free state, and crystallises out, as graphite; and the whole structure is made up of graphite, ferrite, and more or less pearlite, with, sometimes, cementite (depending on the amount of carbon retained in the free state). The bearing of this on the properties of grey iron have also been discussed under cast-iron. Fig. 236 shows a pure grey iron made by adding 2½ per cent. silicon to the washed metal shown in fig. 235. Small groups of ferrite crystals are very plainly seen, together with graphite and some pearlite. Fig. 237 is of interest as being a micrograph from one of Sorby's sections of No. 3 Renishaw grey iron, polished and etched in 1864, and showing pearlite, graphite, and phosphide eutectic. Figs. 238, 239, and 240 show how the size of the plates of graphite varies, and the important bearing of this on the strength of the metal should not need to be further impressed. 238 is from a casting of ½ inch diameter × 150 diamaters, 239 from a casting 2 inches in thickness × 58 diameters, whilst 240 is a section of No. 1 pig × 58 diameters.

FIG. 238.—Fine Graphite. × 150.

When phosphorus is also present in grey pig-iron it exists as Fe_3P, and separates as a brittle phosphide eutectic, as shown in figs. 241 and 242, and those who would study this question in detail should digest Mr Stead's classical paper on the subject, "Iron and Phosphorus," *Jour. I.S.I.*, 1900. II., pp. 60–155.

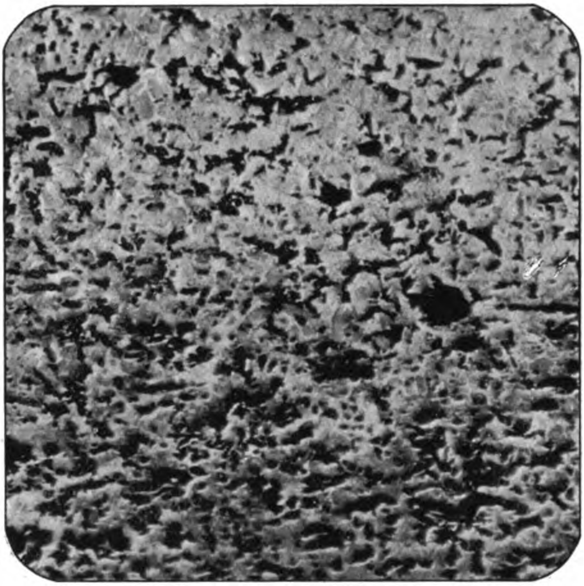

FIG. 239.—Medium Graphite. × 58.

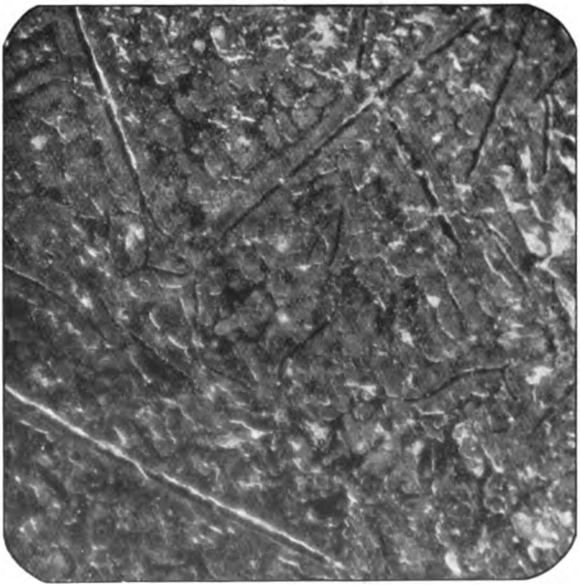

FIG. 240.—Coarse Graphite. × 58.

Fig. 243 represents the structure of an American blackheart casting. Here a white iron has first been formed, and a varying quantity of the carbide subsequently decomposed by heat treatment. Under these circumstances the carbon separates in a free, but, apparently, in an amorphous form, so that, in the present state of our knowledge, it may be called simply amorphous carbon. There are also pearlite, ferrite, and some manganese sulphide blebs present.

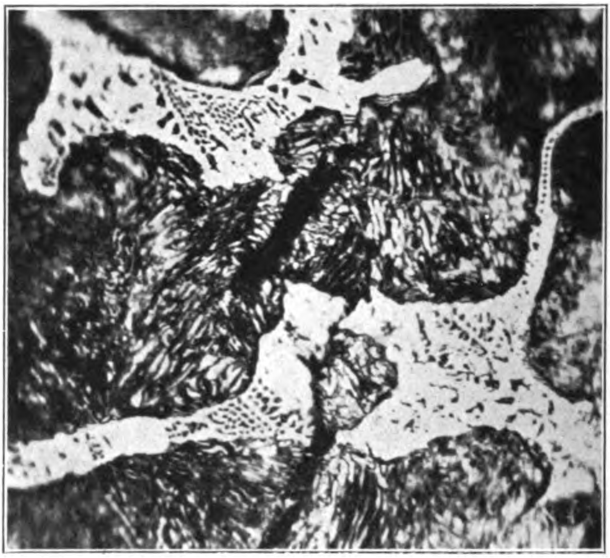

FIG. 241.—Phosphide Eutectic. × 1000.

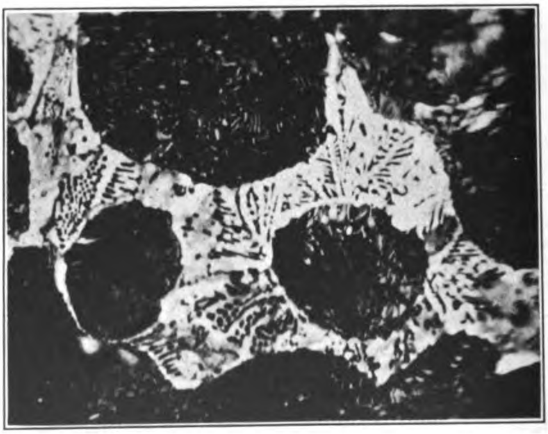

FIG. 242.—Phosphide Eutectic. × 1000.

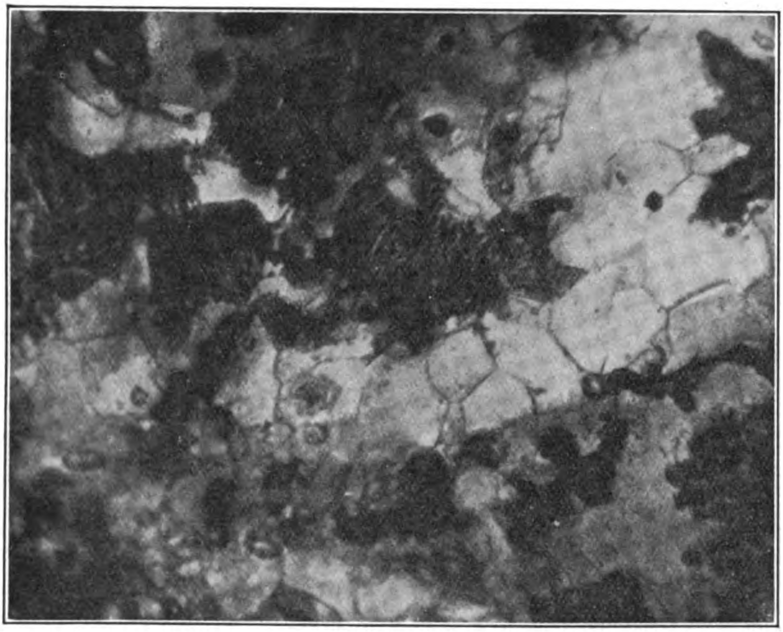

FIG. 243.—American Blackheart. × 360.

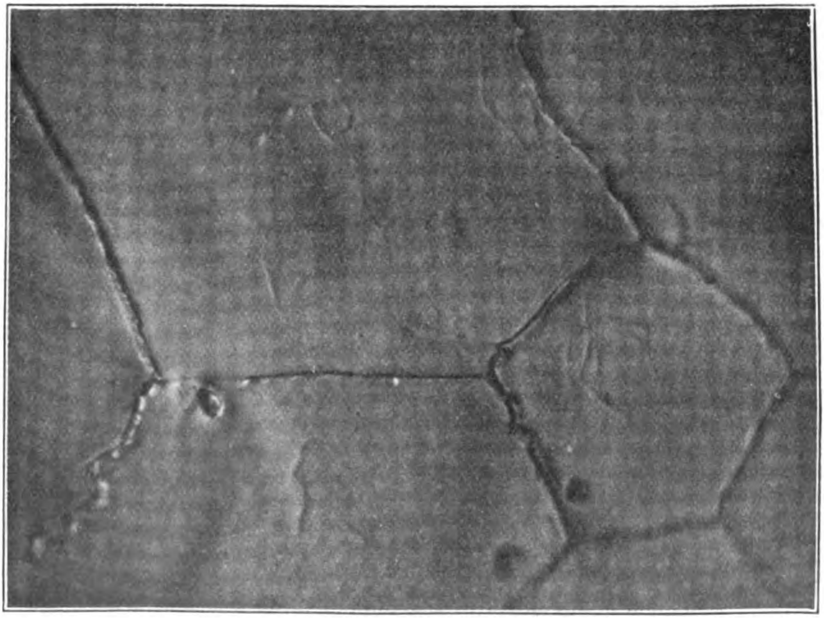

FIG. 244.—Alloy of 50 Copper, 50 Nickel. × 1000.

As a final word, let it be remembered that this is but an introduction to metallography, and that not only variations of the types given are met with on every hand, but that two dissimilar types may be found in the same piece of metal. Fig. 244 shows the structure of a 50 copper, 50 nickel alloy, and fig. 245 shows a portion of a very mild steel with large crystals on the outside and small on the inside; and as the figure represents about one-fiftieth of an inch across, the endeavour to picture the conditions under which such a structure was formed will be an interesting puzzle for the student, and tend to foster that modesty of thought which comes when one has attained sufficient knowledge to reach the stage of seeing how great is the field yet unexplored.

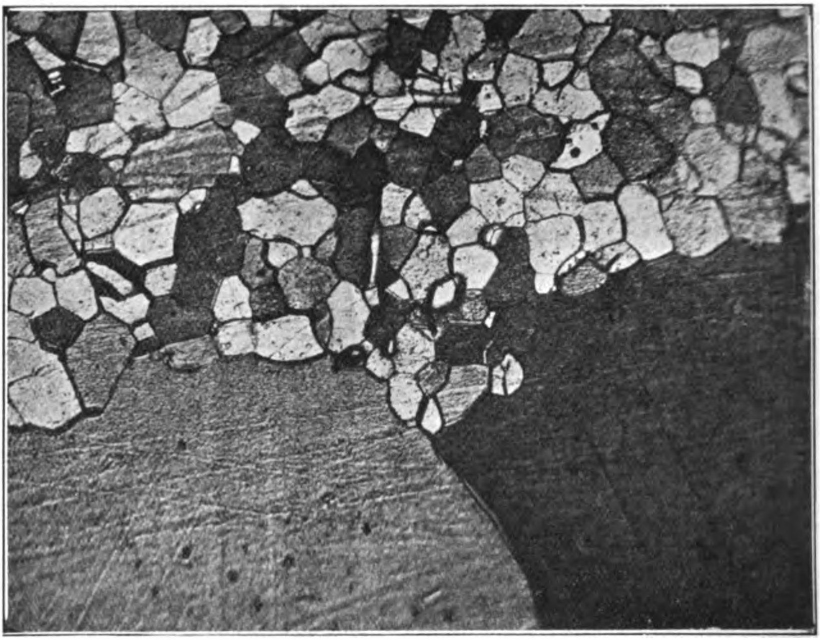

FIG. 245.—Example of Fine and Coarse Crystallisation. × 150.

CHAPTER XXXVII.

COMMON FAULTS DUE TO THE METAL.

It is obvious that a waster casting may be due to faulty moulding, or to faulty metal, or even to a combination of the two causes. These sources admit of much discussion, but for the present we are concerned with inherent faults in the metal. Should the fracture of the metal show blowholes, these may be due to either of the causes. In the case of steel, if from the mould, they are coloured or oxidised, whilst those for which the metal must be blamed are clear and bright, unless with very badly blown metal, when some, next the skin, seem to break through, and admitting air, are consequently discoloured. Blowholes are generally an effect of composition, although it has recently been shown that it is not enough to consider only composition as ordinarily determined, but that the manner of working the heat in making the metal has a considerable influence (see p. 303). One good point about deep-seated blowholes is that they minimise contraction stresses, but their use for this purpose is not generally available, as they are apt also to appear at surfaces which are required to be solid. Drawn holes represent faulty feeding, and the line of attack to remove the fault should be clear. In this work, due prominence has been given to the importance of chemical composition; and in a case of failure requiring investigation, the first step is to ascertain, by analysis, the constituents present in the metal. Should impurity be in excess, or the general composition prove to be one known to be unsuitable for the purpose, then a necessary alteration is at once revealed. The composition being favourable, then the condition of the metal is of importance, and here a microscopical examination will often indicate whether the treatment has been correct. In this way, faulty annealing in the case of steel or of malleable iron castings may be detected. Apart from any of these features, troubles may arise in the form of wasters, the causes of which are extremely hard to locate.

Of matters not already dealt with, the problem of the influence of oxygen, principally in its character of dissolved oxygen or oxide, is of the first importance, and has to be faced daily in every steel and brass foundry. An oxidised metal does not necessarily imply a blown metal, for, though steel castings made of metal from which the oxide has not been properly removed, are generally much blown, copper castings may be perfectly free from blowholes and yet be so saturated with oxide as to be harsh and dry. Behaviour under forging is a characteristic test for iron containing oxide, and such an iron will crumble or work dry under the hammer. Excess of oxygen in metals induces red shortness, a point possibly in itself of little moment to the founder, only that at atmospheric temperatures excess of oxygen is distinctly shown in dry fractures and low elongations under tests.

Pure iron is not a commercial foundry product, although castings as low as 0·08 per cent. carbon are produced by the surface-blown Bessemer process. Before casting such a metal, additions of manganese and aluminium must be made in order to remove oxygen and bring the metal into a condition to make sound castings. Herein lies a point of moment, for the more intensely oxidising the conditions of manufacture, the greater the amount of deoxidising agents required not only to be added, but to be left in the steel as excess, in order adequately to remove the oxygen in the time available. Thus, bottom-blown Bessemer castings, to ensure a sound and oxide-free product, must generally contain 0·8 to 1·0 per cent. manganese in the finished casting. Castings from the surface-blown Bessemer process, in which apparently the oxidation of the iron is not so pronounced, are successfully produced when required so pure, by adding sufficient manganese to leave a content of 0·3 per cent. *plus* the addition of 0·05 per cent. aluminium just before casting, to prevent the formation of blowholes. With carbon under 0·1 per cent. this constitutes a nearly pure iron casting, and as such is specially applicable to electrical purposes. Given a high temperature coke crucible furnace, pure iron can be melted, and, by the aid of aluminium alone, sound and tough castings obtained. Here, however, the oxidising influence is at a minimum, the surroundings being often actually reducing. Prof. Arnold was the first to produce successfully sound castings of practically pure iron in sand, and typical results are as follows :—

	C.C.	Si.	Mn.	S.	P.	Al.	Elastic Limit. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 inches.	Reduction of Area per cent.
Arnold, . .	0·07	0·023	0·05	0·02	0·01	0·018	9·1	19·2	46·0	65·1
Authors, . .	0·08	0·04	0·06	0·03	0·01	0·02	7·2	18·5	35·0	52·2

These tests have a two-fold interest, as illustrating the mechanical properties of sand-cast pure iron, and as exemplifying the activity of traces of aluminium in preventing the formation of blowholes and enabling sound castings of such purity to be made. One of the best examples of oxygenated iron is found in overblown Bessemer metal, a condition brought about by the fact that although, when considerable amounts of carbon, silicon, and manganese are present in the bath, the oxidation is preferential, and the iron is not vigorously attacked, these elements are nearly eliminated when the oxygen of the blast combines with the iron to form oxide of iron which is retained by the metal. P. Longmuir, in conjunction with Dr. Carpenter, as a preliminary to determining the solidification ranges of a series of nickel steels, melted some pure iron in an injector gas crucible furnace under conditions which proved to be strongly oxidising. The particular object in view was to ascertain if any difference existed between the readings given by a protected and a bare thermo-couple. This object was not realised, for the oxide of iron on the surface of the molten metal immediately attacked the platinum wires of the couple, and, on again heating up for another test, the crucible broke down. Exactly 3 lbs. of iron had been charged into the crucible, and, after the furnace had cooled, every particle of metallic iron was recovered, this being assured by the fact that the solid bottom of the furnace was thoroughly chipped out. The exact weight of metallic iron recovered was 36 ozs., representing a loss of 12 ozs., or 25 per cent. of the charge. The value of the experiment lies in giving in a tangible form the influence of oxygen on molten iron, even when the melting is done in a crucible, but surrounded by a strongly oxidising atmosphere, and as showing that, although at first the oxide formed may be absorbed by the iron, on reaching saturation the excess oxide attacks the walls of the containing vessel. The metallic iron remaining was dry, indicating its saturation with oxide.

A simple and easily conducted experiment consists in heating iron turnings in a dry but oxidising atmosphere, when, even at a dull red heat, the whole of the turnings are converted into oxide. This, in the solid; hence, in melting furnaces with their higher ranges of temperature and the consequently increased chemical activity, the matter demands every attention from the founder.

With grey cast-irons, owing to the very appreciable amounts of silicon and manganese present, the oxide problem during melting is of less moment. That a slightly oxidising atmosphere exists is shown by the silicon and manganese losses and the slight change in carbon. In our personal experience we have not in any instance been convinced of the absorption of iron oxide by passing grey cast-iron through a normally worked cupola, nor have we had trouble with grey iron castings that we had cause to think was due to oxide. However, Dr. Moldenke, the weight of whose authority none would dispute, advances a strong plea for the view that, under certain conditions, oxides are present in cast-iron and advises the use of titanium as a deoxidiser. As a side light, certain irons have the reputation of being of a stronger nature than others of a similar composition, and our observations point to this special nature or body as being coincident with conditions which would favour the absence of oxide. It is also singular that pig-iron from a rapidly driven furnace does not seem to possess the same body as do similar grades of iron from a normally worked furnace. If oxygen is present in cast-iron, in all probability it is there before that cast-iron has been through the cupola. Dr. Moldenke's views may therefore simply reflect one result of the rapid driving of American blast furnaces. The question of oxygen in cast-irons is, however, a very open one, and calls for much further investigation.

The relations between copper and oxygen are perhaps more fully appreciated than those between iron and oxygen. Sheet copper heated to a good red heat in the oxidising temperature of a muffle furnace is completely converted into oxide, a process used in laboratories for preparing pure oxide for use in carbon estimations by combustion. One characteristic feature is the influence of cuprous oxide on the melting point of copper. Heyn and Bauer have shown that, although pure oxygen-free copper solidified at a temperature of 1084° C., as the content of oxygen increases, the temperature of solidification steadily falls, until, when 3·5 per cent. of cuprous oxide is reached, the mass solidifies at 1065° C.; in a sense this lower limit of 1065° C. marks a saturation point, for, with further increments of oxygen, the cuprous oxide appears structurally free in the solid metal, and the temperature of solidification rises as the amount of oxide present is further increased.

Various methods are followed in order to prevent the retention of oxide by copper during melting. The usual text-book advice is to cover with a layer of charcoal; but this method, under foundry conditions and using commercial copper, will not regularly produce good copper castings. It should be remembered that, in the case of ordinary copper, a small amount of oxide must be retained in the metal to obtain the best effect, as this, in some way, neutralises the evil influence of the impurities present. Thus, in the refining of copper, which is carried out in a reverberatory furnace, when the metal has too much oxide left in it, the ingots are sunk on the top, are dry and brittle, and break with a curiously dark red granular fracture. After the greater proportion of the oxide has been removed by a layer of anthracite or of charcoal thrown on the surface of the bath, the process is hastened and perfected by stirring with a pole of green wood, an operation known as poling. The gases given off by the wood bubble up through the metal, and not only mix it well but help to reduce oxide. When this has gone far enough, a spoon sample will forge well, and a nicked bend test on the forged sample bends double, showing a beautiful salmon coloured fibrous bend; and ingots cast from the bath now set almost level. If poling is carried too far, then the metal in the ingot is blown, and the surface of the ingot is raised in the middle or convex, and the metal has again become brittle. The first metal is said to be under-poled, the second is called tough pitch, and the third is over-poled metal. These points are readily tested by experiments in a small crucible, and we have often repeated them with commercial copper on as small a charge as 8 ounces of copper. Percy says that pure electrolytic copper cannot be overpoled, and this lends support to the view that the function of the oxide in ordinary copper is to neutralise the effect of the impurities therein. It will thus be clear why it is no easy task to make copper castings by removing the oxide by means of some carbonaceous material. In making commercial copper castings we have found a modification of the poling method successful. The copper was melted, as usual, with a charcoal covering, and, immediately before casting, was stirred with a small piece of wood stuck on the end of an iron rod. The operation requires considerable judgment, for, if carried too far, the results will be bad, owing to the formation of overpoled copper.

The more easily handled methods of deoxidation lie in the use of agents, such as zinc, phosphorus, manganese, etc. Not a few commercial copper castings contain appreciable quantities of zinc. So-called copper hammers, for example, are made by adding 5 per cent. of zinc to the molten copper. A more sparing use of zinc can be made to yield exceptionally good castings of high copper content (99·5 per cent.) and high electrical conductivity. The method is, after melting under charcoal, to "flare" the copper, that is, for a 50-lbs. crucible charge, to push a piece of zinc the size of a peach to the bottom of the crucible. The oxygen of the cuprous oxide will pass over to the zinc, and, as the temperature of the molten copper is above the boiling point of zinc, the vapour of the zinc coming up through the copper will carry any oxide formed to the surface. Practically, no zinc remains in the copper, and by this plan we have made electrical castings in which high electrical conductivity was an essential. The favourite deoxidiser is phosphorus, preferably in the form of phosphor-copper containing 15 per cent. phosphorus. An addition of ½ lb. to 50 lbs. of copper will give a theoretical phosphorus content of 0·15 per cent. Contrary to what is the case for steel, the actual amount of phosphorus remaining in the metal is less than that added, and will depend on the amount of oxygen present in the copper.

Assuming a loss of about 50 per cent., which is not excessive, there would be about 0·07 per cent. phosphorus in the castings, an amount which, under ordinary conditions, is beneficial rather than injurious.

Manganese and silicon act in a similar manner to phosphorus, and may be procured in either the ferro- or the cupro- form, the latter being used for copper, the former for alloys in which the introduction of iron is not a disadvantage.

In the case of nickel, oxide is most tenaciously retained by the metal. When making nickel castings the metal must be deoxidised before pouring, and the most suitable agent is manganese added as 80 per cent. ferro-manganese; but, if the iron introduced is objectionable, then magnesium or metallic manganese, such as the Goldschmidt metal, should be substituted. Not only must nickel, when used alone, be deoxidised, but also when employed as a constituent of alloys, such as German silver and nickel steels.

Of the metals already dealt with, iron, copper, and nickel, the chief feature lies in the fact that they are readily oxidised, and the oxides formed remain in the metal, affecting its properties. Metallic tin will unite with oxygen at high temperatures, and will also reduce copper oxide, thus:— $2Cu_2O + Sn = 4Cu + SnO_2$, the resulting oxide of tin being retained by the alloy.

On remelting an alloy containing zinc, a certain amount of the zinc is lost, mainly by volatilisation or boiling off, the vapour burning into oxide (ZnO) when it reaches the air, forming the beautiful "yellow when hot, white when cold," material familiar in blowpipe tests. The following example, in which a mixed alloy of manganese bronze was simply remelted in a crucible furnace, is instructive:—

	Original Alloy. Ingot Metal.	After Remelting. Sand Casting.
	Per cent.	Per cent.
Copper, ...	59·00	68·88
Tin, ...	0·58	0·86
Zinc, ...	37·92	28·13
Iron, ...	1·40	1·45
Manganese, . . .	0·42	0·23
Aluminium, . . .	0·48	0·20

The most striking features are the loss of zinc, which approaches 26 per cent. of the zinc present in the original alloy, and the loss of manganese, which is nearly 50 per cent. The increase in copper is simply the result of concentration. A change similar to the foregoing always takes place on melting a zinc alloy, and this change should meet with greater recognition than is usually accorded it.

Taking, first, a financial view, a glance at the analysis of the remelted metal will show that its constituents have a greater money value than the ingot metal, owing to the higher content of the costly metal copper. But, although of greater value in a monetary sense, its properties are decidedly inferior to those of the original metal. The original metal would yield a maximum stress of 25 to 28 tons per square inch, whilst the remelted metal would not exceed 15 tons per square inch. This illustrates the point, noted when describing alloys, that all high-tension bronzes for sand castings should approximate 60 per cent. copper and 40 per cent. zinc. Therefore, before any zinc alloy is cast, the amount of zinc lost during melting must be allowed for, if exact compositions are required.

Brassfoundry losses are usually estimated on the total weight of the alloys handled, and figures in the neighbourhood of from 6 to 8 per cent. result. This is misleading, and a much better plan is to ascertain which constituents of the alloys are lost, in order that the loss may be covered. Necessarily these losses must be determined for individual furnaces, but the following figures obtained from a typical crucible furnace are of interest. In conducting the experiments the authors followed the usual plan of melting the copper under charcoal and adding the zinc when the copper was sufficiently fluid to take it. The crucible was then heated up to the requisite temperature, drawn, and cast. The highest temperature reached is recorded in the following table:—

Alloy.	Highest Temperature.	Zinc present in the Casting.	Loss of Zinc.
		Per cent.	Per cent.
Red brass, ...	1308° C.	10·2	28·6
Yellow brass, ...	1182° C.	26·0	26·1
Gun metal, ...	1173° C.	1·8	27·7
Muntz metal, ...	1038° C.	40·5	19·0

The loss of zinc is calculated from the difference between the amount charged and that found in the castings, and is expressed in terms per cent. of the original amount of zinc present. The total weight of alloy melted was in each case 50 lbs. The results clearly show that a standard loss of zinc cannot be given, and also that the percentage loss of zinc is unaffected by the amount present. A glance down the temperature column will show that the determining factor is, under normal conditions, the highest temperature reached during fusion, but, if the charge is kept an abnormally long time at a high temperature, the loss will be greater. Whilst casting a series of moulds from a crucible of yellow brass, zinc oxide fumes are constantly emitted, from which it would appear that the content of metallic zinc would be steadily lessened. This, however, is not the case, and a wide series of tests have shown that the loss of zinc at this stage is practically negligible.

Taking a composition of the following order, copper 60 per cent., nickel 3 per cent., tin 1 per cent., and zinc 36 per cent., an application of the principles noted would involve treatment as follows:—First melt the copper and nickel under charcoal, and deoxidise by the addition of 0·5 per cent. metallic manganese, draw the crucible, add the tin, stir, and cast into ingot moulds. These ingots are remelted under charcoal, zinc added *plus* the necessary allowance for loss, and, when at the right heat, the crucible is drawn and its contents poured into sand moulds. It will be obvious that all scrap of whatever nature should, on remelting, have the necessary additions made to cover zinc loss. Although it may seem that a little too much space has been given to the questions of oxide and oxidation, still their importance is such that every founder must perforce give them attention, and only in this way can the full properties of alloys, especially high-tension bronzes, be reached.

Given the right composition, correct treatment in melting, with due reference to oxidation and a properly formed mould, then one would naturally expect the fullest properties the composition is capable of yielding. This expectation is not always realised, as witness the following results:—

	1	2	3	4	5
Maximum stress, tons per square inch, .	19	21	21	22	26
Elongation per cent. on 6 inches, . .	19	25	33	27	50

These tests are all from ordinary grade phosphor bronze, and the composition throughout is identical. The fact that from one alloy, melted and cast under normal foundry conditions, a range in elongation of from 19 to 50 per cent. is obtainable is sufficiently startling; but, in addition to this, we can definitely state that, with one exception, the conditions of melting and casting were identical throughout the series. Variations, such as the foregoing, have led P. Longmuir to make a special study of the matter which, commenced in 1897, is by no means complete yet. However, in broadly viewing the case one must recognise that each of the stages adopted in the production of a casting contributes its quota to the success, or otherwise, of the final product, and also that one stage cannot be specially watched to the exclusion of others. Taking the more general of these stages it will be found that the chief determining conditions are:—

1. Composition of the metal or alloy.
2. Method of melting, including the problems of change of composition, absorption of oxide, and influence of gases.
3. Initial casting temperature.
4. Preparation of the mould.
5. The presence of blowholes and mechanically-held foreign matter, such as sand, slag, etc.
6. Shrinkage faults, due to inefficient feeding.
7. Contraction cracks and stresses.
8. After-treatment, in the case of white iron and steel.

With the exception of No. 3, these determining conditions have been fully considered, and, in this exception, initial casting temperature will be found the only variable in the phosphor bronze tests just quoted. It is only fair to add that these tests are selected from a large number, and that No. 5 is an abnormally high value.

In modern foundry practice the governing conditions indicated are readily controlled by the exercise of suitable care. The greatest variable in a well-organised foundry operated under efficient chemical supervision is the factor of casting temperature. To it many mysterious failures may be attributed, and it may be that in the case of cast-iron the transverse test is a few hundredweights short; or with steel that the elongations and bending angles are too low. With brasses mysterious failures are chiefly shown under water or steam tests, and an apparently perfect casting will leak or sweat under pressure. Such failures are exceedingly vexing in the case of boiler mountings, and frequently, in a series of castings poured from one crucible under apparently identical conditions, one or two will leak, whilst the majority are sound. This appealed powerfully when making high-pressure steam and hydraulic fittings, and attention to casting temperature led to a very considerable reduction in the wasters on testing. Some years ago, when conducting experiments on this question, we also observed that the temperature of the metal, in the case of chill castings, had an effect on the depth of chill, but subsequent experience clearly showed this aspect to be of very much less importance than that of the effect on mechanical and water-resisting properties. Some exact figures have been given by Longmuir in the *Journal of the Iron and Steel Institute*, No. 1, 1903, and No. 1, 1904. The results there given were obtained by studying a series of alloys and the effect of varying casting temperatures on their mechanical properties. The temperatures were measured by means of a thermo-couple passing directly into the moulds. Fig. 246 shows the plan followed; and the use of cold junction, switchboard, etc., will be understood after a study of Chapter XXXI.

The results obtained from a few typical alloys are embodied in the following table:—

Alloy.	Cu.	Zn.	Sn.	No.	Casting Temperature ° C.	Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.	Reduction of Area per cent.
Gun metal, . .	87·5	1·80	10·20	1	1173	8·38	5·5	4·2
				2	1069	14·84	14·5	16·7
				3	965	11·02	5·0	6·4
Yellow brass, . .	73·0	26·0	...	4	1182	11·48	37·7	31·4
				5	1020	12·71	43·0	35·7
				6	850	7·45	15·0	15·2
Red brass, . .	89·6	10·2	...	7	1308	6·85	13·2	12·6
				8	1073	12·65	26·0	30·3
				9	1058	5·67	5·5	6·6
Muntz metal, . .	58·6	40·5	...	10	1038	12·45	6·0	10·6
				11	973	18·89	15·0	16·1
				12	943	16·29	9·5	14·8

In each case every condition, other than casting temperature, was identical, special efforts being made to obtain uniform moulds and uniform rates of pouring. Pattern runners and gates were used in order to minimise any variation due to hand-cut gates.

In considering these results it may be well to recall specification for gun-metal castings, viz., maximum stress 14 tons per square inch, elongation 7½ per cent. on 2 inches. These requirements are met by No. 2; but No. 1, cast only two minutes before, and No. 3, cast two minutes later than No. 2, would most certainly meet with rejection. The elongations in each case from

1 to 12 are worth special notice, and it must be remembered that the only variable is that of initial temperature.

Obviously, in the case of a misrun casting, if it is not due to the mould or to the method of pouring, the casting temperature is at fault; but the results given, and those to follow, all represent variations within the range of perfect fluidity.

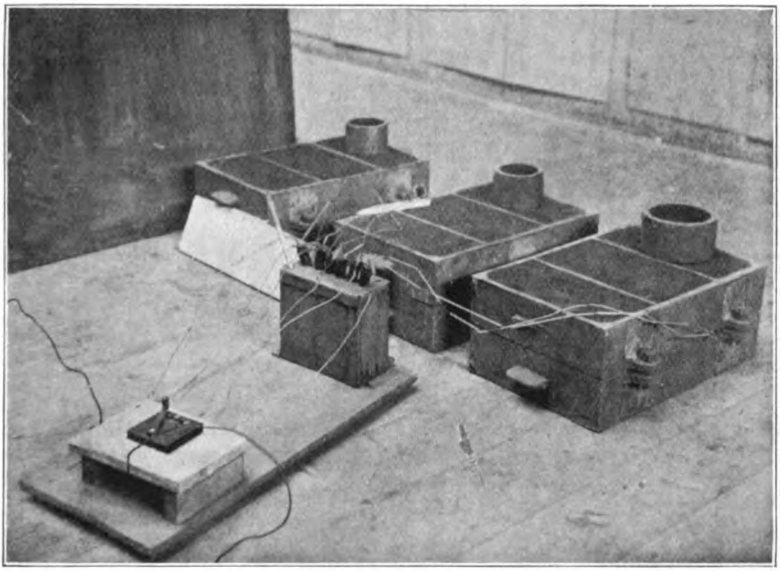

Fig. 246.—Method of Measuring Casting Temperature.

For comparison with Nos. 1, 2, and 3, we extract the following results from a large series of commercial experiments:—

	Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.	Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.	
Poured at intervals from one crucible.	*a* 13·2	5·0	7·2	1·0	Cast at intervals within the range of fluidity from one crucible.
	b 17·0	11·0	10·1	4·0	
	c 15·0	8·5	9·5	2·0	

These represent Admiralty grade gun-metal, melted and cast under the best conditions of foundry practice, the first set showing high, fair, and low heats, as judged by the eye of an independent observer, and the second set representing temperatures as judged visually to give erratic results.

Some results obtained from commercially pure metals are embodied in the following table:—

Metal.	No.	Casting Temperature ° C.	Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.	Remarks.
Zinc, . .	118 119 120	580 528 491	1·30 1·81 1·37	... ...	Poured at intervals from one crucible.
Aluminium, .	121 122 123	725 691 662	4·48 5·62 5·12	2·5 8·5 5·0	Poured at intervals from one crucible.
Copper, . .	124 125 126	1500 1446 1141	6·60 7·80 8·80	8·5 11·0 8·0	All from one crucible.
Copper, . .	124A 125A 126A	... ...	4·52 6·86 8·51	8·0 10·0 8·0	Companion bars of Nos. 124 to 126 heated to 646° C., and cooled in air.
Copper, . .	124B 125B 126B	... ...	5·80 8·36 9·04	9·0 15·5 10·0	Companion bars of 124 to 126 heated to 543° C., and quenched in water.

The particular feature of this table is, that, in the case of copper, companion bars submitted to equal after-treatment are not brought to one level. In the case of lead the variations due to casting temperature do not survive, for it was accidentally discovered that by the lapse of time an apparent recrystallisation obliterates the variations. The following results are typical of the work done on commercial lead :—

No.	Casting Temperature ° C.	Maximum Stress. Tons per square inch.	Elongation per cent. on 2 inches.	Remarks.
127 128 129	566 426 356	1·70 1·71 1·64	40·0 40·0 35·0	Tested some time after casting.
130 131 132	580 430 360	1·13 1·43 1·30	18·0 35·0 42·0	Tested the day following casting.
133 134 135	580 430 360	1·44 1·46 1·46	30·0 37·5 46·5	Companion bars of 130–132 tested three months after casting.
136 137 138	575 450 370	1·41 1·47 1·51	20·0 35·0 50·0	Tested six days after casting.

The work carried forward to cast-iron has shown very similar variations to those obtained in the case of alloys. The following results are typical of grey iron castings :—

No.	C.C.	Gr.	Si.	Mn.	S.	P.	Casting Temperature ° C.	Maximum Stress. Tons per square inch.
37	0·52	3·40	1·78	0·28	0·04	0·27	1400	9·7
38	,,	,,	,,	,,	,,	,,	1350	14·1
39	,,	,,	,,	,,	,,	,,	1245	10·6

These particular results are from grey cast-iron melted in a crucible. We have obtained similar variations from cupola metal, and, in particular, recall a series of transverse test bars, poured from one ladle, the highest result being 35 cwts., and the lowest 23 cwts., on a standard test piece 3 feet 6 inches x 2 inches x 1 inch, placed on supports 3 feet apart.

Results obtained from white cast-iron may be typified by the following examples:—

Casting Temperature.	As Cast. Maximum Stress. Tons per sq. in.	Annealed in Ore.		Heated to above 1000° C., and slowly cooled. Maximum Stress. Tons per sq. in
		Maximum Stress. Tons per sq. in.	Elongation on 2 inches.	
1320° C.	10·7	20·6	1·0	18·6
1230° C.	15·9	29·2	3·5	24·0
1120° C.	12·1	26·5	2·0	21·6

The analysis of the iron "as cast" was as follows:—

C.C. 3·40, Si 0·39, Mn 0·05, S 0·02, P 0·02.

The improvement in properties due to treatment will be noted, nevertheless the treated castings have not reached one level. Thus, in spite of the chemical changes induced by annealing in ore, and the complete structural rearrangement, the influence of casting temperature still holds good. It will also be noted that the castings treated by the short anneal also remain a relative distance apart in properties. American blackheart castings, poured at different temperatures, but otherwise treated alike, have shown similar variations to those of the foregoing heat-treated metal.

In the case of alloys, the comparatively low fusibility gives an exceedingly wide range of casting temperature, but as the melting points rise the practical range of fluidity is narrowed. Thus, steel with its higher melting point does not in most furnaces offer the same range of variation as is to be found with cast-iron and alloys. Taking crucible steel first, it is well within the range of possibility to cast a hard tool steel at too high a temperature, but, under ordinary conditions, mild steel by the same process can hardly be overheated. Fairly similar conditions hold good in the case of open hearth steel, for the milder the steel, the less the danger of obtaining excessively high casting temperatures. The surface-blown Bessemer converter gives, of the three methods, the greatest range of fluidity, and, therefore, the widest range of casting temperature. If, in the case of mild steels, the probability of exceeding a fair casting heat is remote, it would appear that casting temperature, as a governing condition, is of comparatively little moment. For example, the following tests do not differentiate between the properties of two sets of castings poured from one crucible at two distinct temperatures:—

Analysis.					Casting Temperature° C.	Condition.					
						As Cast.			Annealed.		
C.	Si.	Mn.	S.	P.		Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 inches.	R.A. per cent.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 inches.	R.A per cent.
0·29	0·14	0·92	0·06	0·02	1611	30·9	7·5	13·1	29·1	19·5	18·4
...	...	...	...	..	1560	30·1	7·0	12·1	28·4	18·5	18·4

These results are practically identical, and might be duplicates of the same steel. Bending angles of the two steels, as cast, were identical. After annealing, the first steel bent through an angle of 180°, and in doing so developed no flaw. The second one, annealed simultaneously with the first one, fractured on reaching an angle of 105°. Other tests on similar low-carbon crucible steels, where the fair casting heat can hardly be exceeded, show that differences in casting temperature do not result in any marked differences in properties, as shown by the tensile tests. Harder types of crucible steel show differences under tension-tests, but such types are beyond the range of ordinary foundry products. Generally speaking, open hearth steels follow the same order as crucible steels; but when the range of fluidity can be widened by obtaining higher initial temperatures, then the influence of varying casting temperature is decisively shown on the tensile properties of the resulting steels. The perfect fluidity of low-carbon steels from a surface-blown converter has been shown in another chapter, and this fluidity necessarily involves high initial temperatures. In order to investigate this wider range, Messrs. D. Rennie & Co., Glasgow, have conducted many experiments for the authors, employing for the purpose a 2-ton Robert converter. All conditions, other than casting temperature, were identical, the analyses of the cold castings agreed exactly, and annealing conditions were perfectly comparative for each series of castings. The following results represent four sets of castings poured from one ladle within a few minutes of each other. The castings are in the annealed condition:—

Analysis.					Casting Temperature.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 inches.	Reduction of Area per cent.
C.	Si.	Mn.	S.	P.				
0·29	0·07	0·16	0·07	0·06	High	24·2	9·5	18·0
					Fair	27·2	24·0	32·3
					Medium	27·0	12·5	17·5
					Low	25·5	8·0	12·0

The fact that castings poured within a few minutes of each other and from the same ladle yield elongations rising from 9½ per cent. to 24 per cent., and falling again to 8 per cent., is of some moment to steel founders working to a specification. As a further example the following results are given, the values being obtained from annealed castings:—

C.C.	Si.	Mn.	S.	P.	Casting Temperature.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 inches.	Reduction of Area per cent.
0·28	0·15	0·29	0·06	0·05	High	30·9	15·5	16·4
					Fair	28·0	33·5	45·6
					Medium	30·3	27·5	39·2

It is hardly necessary to quote further results; the two sets given are typical, and should be studied in conjunction with those yielded by the crucible steels. Such comparisons as we have made between crucible and surface-blown steels show that, with a low-carbon and light castings, surface-blown metal always gives the best elongation and bending angles. This is suggestive, and, so far as steel castings are concerned, would indicate that the best results are obtained by having a high initial temperature and cooling down in the ladle until the right casting heat is reached. This is certainly the case with cast-irons, brasses, and bronzes, and we have found in practice that the best results were always obtained by melting hot, drawing, or tapping, and allowing to cool to a suitable heat.

A recognition of the fact that there are high, fair, and low casting heats within the range of fluidity for the majority of foundry alloys and metals will remove many of the vexations associated with specification work. The fair heat of any metal or alloy necessarily varies with the contour and weight of the casting, but by associating a certain appearance of the molten metal with a given type of casting and its resultant mechanical properties, invaluable data as to the influence of varying casting temperature is obtained. The knowledge is necessarily intuitive, but it is a comparatively reliable guide, and its exercise will lead to more regular results. It should be noted that in visually judging the heat of alloys containing aluminium, the deceptive appearance of the sluggish skin, graphically described by one melter as "like mutton fat," must be allowed for. Such alloys often appear much colder than is actually the case.

Finally, one word on brittle steels. It will be remembered that, in the case of the mild crucible steel, tensile tests did not distinguish between the two heats, although some difference in behaviour under bending test was registered. This steel was not overheated, a statement also applicable to the following results obtained from crucible steel of slightly higher carbon:—

No.	C.	Si.	Mn.	S.	P.	Casting Temperature. °C.	Condition.	Maximum Stress. Tons per sq. in.	Elongation per cent on 2 inches.	Bending Angle.	Arnold Test.* Reversals to complete Fracture.
97	0·36	0·22	0·89	0·02	0·02	1550–1600	As cast	35·8	12·5	75 broken	68
98	...	...	...	...	...	1470–1500	,,	34·2	11·5	80 ,,	48
97A	...	...	...	...	...	...	Annealed	27·0	17·5	180 unbroken	122
98A	...	...	...	...	...	...	,,	28·2	18·5	160 broken	62

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* 270 reversals per min., $\frac{9}{16}$-inch each side of vertical. Test piece, $\frac{3}{8}$-inch square × 4 inches from top of die to striker.

In the alternating-stress results it will be noted that No. 98, even after annealing, does not quite reach the value obtained from 97 in the cast condition. Here, again, tension tests do not differentiate between the two conditions, either as cast or annealed. In this fact lies the significance of the results, for, if with mild steel not overheated, but cast at too low a temperature, the usually accepted tests do not select the brittle samples, there may be risk of a dangerous steel going into service. This aspect is extremely suggestive and well worth further inquiry.

It is by no means intended to advance faulty casting temperatures as a source of all mysterious wasters, for, in view of the many influences at work during the production of a casting, such a procedure would be absurd. When studying variables, every condition, other than the one under investigation, must be as nearly constant as possible. For example, when investigating the tensile properties of a series of alloys, every mould, each gate and height of runner must be uniform throughout the series, and the fluid pressure on each casting, due to the depth of molten metal, should be the same. Further, the moulds should be rammed to a uniform degree of hardness in order that contraction stresses shall be approximately equal in each case. W. H. Hatfield, in a recent communication to the *I.S.I. Journ.*, 1906, II. pp. 157–188, has shown that, experimenting with a series of extremely pure cast-irons, he does not obtain similar variations to those of P. Longmuir. The reasons for the differences in mechanical properties produced by varying casting temperature are not yet properly understood; and as both these investigators are continuing their experiments in this direction, but on different lines, a careful comparison of their future results may help towards the discovery of the fundamental cause. In conclusion, so far as any given grade of metal is concerned, if, in the first place, the composition is right; in the second place, oxidising influences are avoided or neutralised; in the third, it has been brought into a suitable condition with regard to gases: and, in the fourth, a suitable casting heat is chosen, then, under normal conditions, any resulting failure will not be due to the metal, but must be traced to the mould.

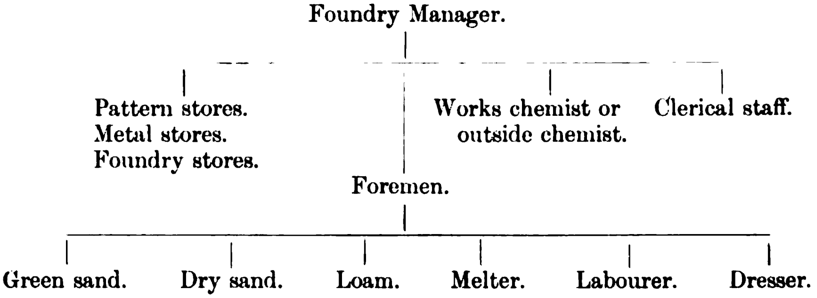
CHAPTER XXXVIII.

NOTES ON FOUNDRY MANAGEMENT

GENERALLY speaking, the production of good castings at an economical rate demands good equipment in the foundry; but, however necessary good tools may be, they are useless if mated with bad management and correspondingly poor organisation. In this respect an old-fashioned or even antiquated foundry, if managed by a good head, will compete with the most up to date plant, if that plant is under the charge of an inefficient manager. This is only another way of saying that each tool, whether new or old, should be so managed as to produce its maximum amount of work. Amongst the tools so-called, none are more important than the skilled men of the foundry, and it is manifest that any valuable tool is only profitable when engaged on the work for which it is specially fitted. Moulders do not make good labourers, and a moulder is only profitable when actually moulding. Therefore, any scheme of organisation will endeavour, in the first place, to relieve all skilled labour of work which can be done by unskilled labour; in the second place, it will endeavour to obtain from each unit or tool its fullest output; and, in the third place, will arrange a definite sequence of operations by which no unnecessary ground is covered in the progress of the work.

Successful foundry management is largely a human question, and the temperament of the individual exercises a considerable effect on the result. However, excluding personal idiosyncrasies, we may examine some of the broad aspects of the matter, and the first question arising is that of dual control or divided responsibility between chemist and manager. Under certain conditions this plan may prove successful, but in the majority of cases it will fail, and fail hopelessly. Under normal foundry conditions no one of the various stages followed in the production of castings can be neglected. Each stage must be given its due share of attention, and it naturally follows that the head of the concern must be familiar with these stages and their relative importance. As faults may arise from mould or metal, it also follows that the chemist, if he be responsible for the metal, ought to possess a good knowledge of furnace working and of moulding, in order to apply his chemical knowledge to the particular needs of the case. On the other hand, a foundryman should have a knowledge of the metals he handles, which implies that he is able to interpret and use results supplied by the chemist. Therefore, if it is essential that the chemist be familiar with foundry practice, and that the foundryman be familiar with the metallurgy of the particular metals handled, it is obvious that two such heads with equal, but divided, responsibility would not lead to harmonious organisation. There must be one, and only one, responsible head, and experience shows that the best results follow when that head is a practical foundryman equipped with the requisite metallurgical knowledge. Such a man will readily avail himself of the chemist's results, and, with the aid of his melting and moulding experiences, translate them into efficient castings.

Given a large foundry, following the three branches of moulding, we find a good scheme of organisation in the following:—



This subdivision removes detail from the hands of the manager, but at the same time leaves him responsible for the efficient supervision of the whole. The duties of the foremen in the moulding sections are fairly obvious, but, in the case of smaller foundries, dry sand and loam would be combined and placed under the charge of one man. The foreman dresser supervises the effective cleaning of the castings and grouping them into their respective orders for delivery. If a series of furnaces are employed, then a charge hand becomes necessary; and his duties lie in keeping furnacemen and furnaces in efficient working.

The term unskilled labour has been mentioned, but, as regards foundry work, this term is relative only; for every operation demands some skill. Hence, where a number of labourers are employed it will be found advisable to have them under the supervision of a charge hand. This is of special value where gangs are employed in knocking out boxes, digging and ramming pits, etc. Under such a system a raw recruit is soon brought into line with the rest, and the nett effect is shown in the systematic assistance rendered to moulders and coremakers.

The duties of the clerical staff vary, according to whether the foundry is a constituent part of a works or an isolated unit. Generally, they comprise the ascertaining of labour and material costs and recording them in due form. The duties of dispatch clerk are: weighing and forwarding completed orders, with due attention to the clerical work involved.

Under this scheme it is the chemist's duty to provide the manager with analyses of raw materials entering the foundry. Here it may be noted that, with the exception of steel, comparatively few foundries handle a sufficient volume of work to warrant the retention of a qualified chemist. An unqualified chemist is worse than useless; therefore, unless the volume of work is very large, the analyses required are obtained from private laboratories.

The foregoing scheme is essentially simple in character, and is based on the well-proved system of having one head solely responsible for his department, but providing him with the requisite assistance for the conduct of that department. This assistance will naturally vary with the volume of work handled, and in a small foundry will be *nil*. The following details are worthy of note:—

Foundry Stores.—Given plenty of yard space and good handling facilities, systematic storage is an easy problem. Pig-iron should be stacked in grades arranged with a view to feeding the cupola hoist. Sand stocks may be planned so as to be almost self-feeding to the sand mills. Moulding-boxes and loam plates are more difficult to arrange systematically, but, provided the yard space is ample, they can be stacked according to size or type and each group arranged to be accessible from at least two sides. The systematic storage of pig-iron, coke, sand, and boxes, is, as a rule, well recognised, and therefore no further comment is necessary. The systematic storage of sundries, such as sprigs, chaplets, facings, etc., is not recognised, and usually these materials are distributed at haphazard in odd corners of the foundry. With a large foundry an internal foundry stores will not only lessen the wastage of material, but will also contribute to the smoother working of the foundry as a whole. In such a case, the storekeeper is held responsible for all small tools, special slings, etc., not regularly in use. All moulders' tools, shovels, riddles, etc., are issued by the storekeeper, and a new man on starting can be at once supplied with a full kit and immediately started to work. The wages of this storekeeper may seem an unnecessary expense, but in a foundry employing a large number of moulders this expense is easily met by the more legitimate use of sundries, and is far more than offset by the smoother working of the foundry.

In the case of alloys, lock-up stores are an essential, owing to the higher intrinsic value of the metals, such as copper, tin, etc. Here the system of storekeeping must be such as to show at once any illegitimate leakage.

Pattern stores are usual to all classes of foundries, and no difficulty should be found in methodically arranging the patterns in easily accessible positions.

Foundry Costs.—Methods of costing have now been developed to such a pitch that one is almost afraid to venture into a field so ably filled by that prolific writer, the foundry accountant. However, the man in the shop is often anxious to test his work by the cost of its production, and usually the factor of greatest moment is the labour cost. This is, of course, distinct from prime cost, that is to say, the cost of individual orders, for such work very properly belongs to the accounting side of the management, and details are seldom worked out until too late to be of service to the foundry manager. Further, prime cost details are often worked out from the time-records kept by the man working on the orders so treated, records which are not always reliable guides. The following notes give a plan personally found to be of value, and are drawn from an article by P. Longmuir in *The Engineering Magazine* for September 1902. A form of labour cost analysis often adopted is as follows:—

Week Ending 16th February. Output of Good Castings, 38½ Tons.

Items.	Class of Labour.	Wages.	Cost per cwt.
1	Furnacemen, ...	£9 8 8	£0 0 2·94
2	Labourers, ...	25 0 10	0 0 7·80
3	Dressers, ...	14 8 8	0 0 4·49
4	Moulders, ...	73 10 0	0 1 11·00
5	Clerks, timekeeper, etc., .	10 4 0	0 0 3·17
6	Foundry management, . .	11 17 0	0 0 3·70
	Total, . . .	£144 10 0	£0 3 9·10

Labour cost per ton, £3, 15s. 2d.

From a foundry manager's point of view this form is defective, as it does not indicate the cost of various classes of moulding nor the apportionment of the charges due to labourers. The output given is that of a foundry doing no machine or plate moulding, but engaged on a general class of work in green sand, dry sand and loam, none of which, however, is of an exceptionally heavy character. Dividing the work into representative classes and apportioning the unskilled labour as employed by each class, we get the hundredweight cost, as in the following table. Owing to inherent difficulties, coremaking could not be distributed in this manner, and is, therefore, regarded as a factor of the whole output. General labouring No. 6 includes such labour as is not directly chargeable to one class of moulding; of this there is always a fair amount in every foundry, and it is essentially labour from which all classes of moulding benefit, but not necessarily proportionately.

Item.	Class of Work.	Wages.		Weight Produced.		Cost per Cwt.	
		Moulders.	Labourers.	Tons.	Cwts.	Moulding.	Labouring.
1	Loam, . .	£7 10 0	£3 12 0	5	8	£0 1 4·6	£0 0 8
2	Dry sand, . .	20 0 0	4 10 0	13	7	0 1 6·0	0 0 4
3	Green sand, .	32 6 0	5 8 0	16	3	0 2 0·0	0 0 4
4	Apprentices, .	3 10 0	0 18 0	3	12	0 0 11·7	0 0 3
	Totals, . .	£63 6 0	£14 8 0	38	10	£0 1 7·7	£0 0 4·5
5	Coremakers, .	£10 4 0	£0 18 0	38	10	£0 0 3·3	£0 0 0·3
6	General labouring, . .	...	9 14 10	38	10	...	0 0 3·0
	Totals, . .	£73 10 0	£25 0 10	38	10	£0 1 11·0	£0 0 7·8

The value of this analysis lies in the fact that it at once shows any department in which costs are abnormal. The chief disadvantage of the average factor shown in the first table is that, by it, the good features of one section may be neutralised by the bad features of another section. The good work of the profit-making section is thus lost sight of or swallowed by the non-profit producers, and, assuming that the profit made by the former be such as when distributed over the whole to show fair working, then the backwardness of the latter may escape detection for a considerable period.

Weekly cost factors may be plotted in the form of curves which graphically show the progress week by week of each item of labour cost. The success of detailed cost analysis and graphic representation lies in the fact that it instantly and almost automatically directs the attention of the responsible man to the weak places of his department.

Where the wages books are not made up in the foundry office, or where they are not accessible to the foreman or his clerk, then weekly output charts may be plotted, which to some extent show the conduct of the department. It should be recognised that the capital invested in any foundry demands a definite return, and in this case the return may be very conveniently regarded as the production of a certain weight of castings each week. The weight necessary to yield this return may be arrived at by careful survey of past working for as long a period as possible. A higher output is recognised as good working, and a lower one is fixed which represents the amount necessary to meet all charges and keep just on the margin of profitable production. These three figures once estimated may be regarded as comparative standards, and distinguished on the charts as "good working," "caution," and "danger" lines. Such charts are easily plotted with ordinates and abscissæ of time (weeks) and output in tons or cwts. The three standard lines are ruled across in red ink, and the proximity of the output line to any of the standards is an index of the progress of the foundry.

Viewing the matter in the light of output only, it is readily apparent that a foundry may be producing castings at a very low labour cost, and yet be working at a decided loss. Thus, if the output is constantly below the danger line, no matter how low the cost of production may be, the establishment is working at a disadvantage in that capital costs are not being met. Taking an extreme view, an establishment fitted to produce 50 tons of castings per week, and only turning out one ton, will be working at a loss, even if that single ton is produced for nothing. Material costs may be detailed out in the manner advocated for labour costs, but these are usually worked out by the accounting department. The foundry manager or foreman is chiefly concerned with his labour costs, and, at regular periods, he should ascertain the exact cost of each class of labour in order that the comparisons so obtained shall form a guide to future working.

Having mentioned costs it may be well to state that low production costs do not necessarily imply economical castings. The condition of a metal in a casting, the method adopted in its production, and its requirement of the maximum or minimum of machining are strong factors in determining economy. Taking the last factor, that of machining, if a slight increase in foundry costs results in a large decrease in finishing costs, such an outlay obviously contributes towards economy. The majority of castings form parts only of a complete structure, and the work put on each part, after leaving the foundry, is often of a costly character. Therefore, a low cost of production in the foundry should not be at the expense of a high finishing cost in the machine shop. This is another example in which trained judgment must be exercised, for, in certain cases, although foundry costs may be high, ultimate costs may be low and the foundry working on a really economical basis. This true economy can only be obtained by a combination of good moulding and metallurgical practice, both of which have in their various aspects been fully dealt with in preceding sections. However, in conjunction with the foregoing, we may specially note an aspect of the question of economy having a more direct bearing on brassfoundry practice. Here, owing to the high cost of the constituent metals entering the alloys, greater and more stringent supervision is required than in the case of iron or steel. Losses by volatilisation have been treated of, and have been shown to have a twofold importance, with regard to (*a*) the properties of the alloys, and (*b*) the cost of the alloys. As these losses are usually confined to zinc, and as this metal is comparatively cheap, it is obviously more economical to make good the zinc loss than to allow the comparatively costly metal copper to increase by concentration. Other metallic losses in the brassfoundry are found in the form of shot metal, spilled when casting, or in the ashes of a crucible furnace. The latter are a fairly valuable commodity, and may be sold at from 15 to 18 shillings per ton. If carefully picked over and washed by hand, the refuse will still sell at from 7 to 10 shillings per ton. Should the volume of ashes be large, it will pay to put down a grinding and washing plant, thereby recovering the whole, or practically the whole, of the metallic value. Sweepings from the dressing shop are treated as ashes.

Losses due to unsteady pouring, filling a gate too full, or careless skimming, can be largely avoided by effective supervision during casting. The general treatment given to borings and turnings from the machine shop is to pass them through a magnetic separator and deposit them all in one bin. When a sufficient quantity has accumulated, they are melted down, together with the metal recovered from the washing plant, and cast into ingots. The ingots are generally used for the lowest quality of brass castings, or, at the best, only in admixture to give second or third quality alloy. As the intrinsic value of borings may vary from 5 pence to 10 pence per lb., this method of indiscriminate mixing does not take full advantage of the more valuable parts. The following system of classification has been proved to be a good one, and was advocated by P. Longmuir in *The Engineering Review* for October 1901.

Let it be assumed that the output is such as to give a return to the foundry of 15 cwts. of borings per week, that the value of these is 10d., 8d., and 6d. per lb. respectively, and, for convenience, that equal quantities of each quality are produced. Under the usual conditions of indiscriminate mixing, these borings would, of necessity, take their value from that of the cheapest grade present, that is, 6d. per lb., or a total of £42.

If classified into their respective qualities:—

5 cwts. at 10d. per lb.,	. . . .	£23	6	8
5 ,, 8d. ,,	. . . .	18	13	4
5 ,, 6d. ,,	. . . .	14	0	0
		£56	0	0

or a difference of £14.

The melting down, in either case, will be the same, and against the £14 there is the cost of classification, which should not, in any case, exceed £2; thus leaving a clear gain of £12 on 15 cwts. of borings. One handy man stationed in the machine shop can collect the borings or turnings from each machine before a change of work or different quality metal is put on. Copper and white metal borings or turnings are in the same manner taken away from each machine before changing work. The same man passes the borings through a magnetic separator, and delivers them to the foundry storage bins. In the foundry the borings are melted down as occasion serves, say in two or three ton lots in the air furnace, zinc losses are made good, and the ingots are equal to the original alloy.

Many white metals used for lining up bearings contain a minimum of 85 per cent. tin. These turnings, when separated, can be used as a means of adding tin to a non-specification alloy, and alloys so made up will be found to give very fair results. The dross and skimmings from the white metal shop may be reduced by charcoal and sodium carbonate, and will yield as much as 70 per cent. metal, consisting chiefly of tin with small amounts of copper and antimony. If antifriction alloys containing lead are used, more or less lead will be present in the recovered metal. The dross is better when worked down in fairly large quantities in order to obtain uniform batches, which are analysed and subsequently alloyed according to the analysis.

These examples indicate the opportunities for intelligent and profitable application of metallurgical knowledge as connected with alloys. Borings, slags, oxides, ashes, and, at times, even the very sand heaps of a foundry, offer problems that will yield profitable solutions.

As a final word on foundry management, we would say, that whilst the organisation should be as near perfection as possible, it must also be remembered that foundries are intended to produce profitable castings, a feature which demands certain elasticity. Red tape and mere officialism must be rigorously avoided; and, whilst at all times strict discipline must be maintained, that discipline should be tempered with judgment. Sympathetic management is the most successful; sympathy including firmness and justice for the men, sympathetic treatment of plant and tools, and a full appreciation of the metals handled.

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