# NOTES ON THE MANUFACTURE OF STEEL CASTINGS.

There are three methods of production of liquid steel for manufacture of light and medium weight castings :--

- (1) By Crucible.
- (2) Converter.
- (3) Electric Furnace.

**Crucible Process.**—This is probably the oldest process for melting steel, and it still has certain advantages where the manufacture of steel castings is carried out on a small scale, otherwise the process is uneconomical. Very fine castings have been produced, but it suffers from the drawback that the carbon usually, and the sulphur and silicon invariably, grow above the calculated amount. As this growth takes place in varying quantities dependent on the conditions of melting, the moulder cannot depend on obtaining the desired ultimate composition of the steel with any degree of certainty. The electric furnace has almost entirely displaced this process.

**Converter Process.**—There are several type of converters, and in principle they resemble the old Bessemer process for making steel. Suitable pig is first melted in a cupola and then transferred to the converter, in which the action of a blast of air suitably applied causes oxidation of the carbon, silicon and manganese in the molten cupola iron. The heat thus generated is sufficient to give the resultant low carbon metal sufficient fluidity for castings of the thinnest sections; in fact, it appears to be well established that converter metal possesses greater fluidity at approximately equal temperature than electric steel. This, combined with its small size and general adaptability, makes the converter a very suitable apparatus for light castings.

## ELECTRIC FURNACE.

This is the process in use in Portsmouth Dockyard, and it is therefore the one described in these notes. In commercial life the choice of the process to be adopted is governed by economic considerations. The electric furnace uses scrap, and where cheap supplies of scrap and current are available, it has the preference; on the other hand, if pig is cheap, the converter is adopted. In Sheffield, for example, electric furnaces and converters are sometimes installed in the same shop, and each process is used as may be more economical or convenient, the choice depending on the relative price and supplies available of scrap and pig respectively. In a dockyard large supplies of scrap are usually available, and the electric furnace, therefore, particularly lends itself to dockyard work. It has also the great advantage of affording almost perfect control over the resultant constituents.

# GENERAL ARRANGEMENT

FIGURE 1.



REAR ELEVATION.

210. 25996 0/ 015 1000.4.24

# OF 11/2 TON FURNACE.



H.M.S.O. Cr. Lith.

It will be convenient to subdivide a consideration of the general question under the following headings:—

- (1) Description of the electric furnace.
- (2) Operation.
- (3) Influence of constitutents of the mechanical properties of steel.
- (4) Moulding methods.
- (5) Heat treatment of castings.

#### 1. Description of the Electric Furnace.

The electric furnace for melting steel was first introduced commercially about the year 1900, and there are at present several efficient types on the market. The furnace described in these notes is that fitted in Portsmouth Dockyard.

Electrical Features.—The furnace is worked on the two-phase three-wire system. There are two electrodes entering the furnace through the roof, and an arc is formed between these and the bath of steel (vide p. 71—Papers on Engineering Papers No. 5). The electrodes are connected by flexible leads to the secondary terminals of a transformer, in which the Yard three-phase current of 6,600 volts is transformed down to a two-phase current of about 80 volts. The third "neutral" return conductor is connected to the hearth, which is conductive.

Mechanical Features.—The furnace body is built in the form of a rectangular tank, which is supported on rockers and carries the necessary columns for guiding the electrode carriages. A long vertical screw is carried centrally in each column. Rotation of this screw, which is effected by motor-driven gearing, raises or lowers the electrode. The actuating motors are operated by a regulator, which automatically lowers or raises an electrode according as the current going through it is too low or too high. The furnace is tilted by screw gearing, which is operated by a third motor. Access doors and a spout are fitted as shown in Fig. 1.

Lining .- Fig. 2 shows the arrangement of the refractory materials forming the hearth, walls and roof of the furnace. Those portions of the walls and roof which are exposed to high temperature are made of the best quality silica bricks, with a backing of ordinary firebricks in places, as these are better nonconductors of heat, and, moreover, are less expensive. The hearth electrode is copper, resting on a lining of magnesite bricks. surrounded by carbon powder and insulated from the steel outer As the working of this type of furnace depends on a casing. low hearth resistance, it is always lined with a basic material, which is arranged to extend from the hearth electrode to a position just above the slag line, the present known acid refractories being poor conductors. As shown in Fig. 2, the hearth itself is made of ground dead-burnt dolomite, the whole being mixed with anhydrous tar and rammed up against a wooden template. At and below the slag line, behind the dolomite banks, there are courses of magnesite bricks.

In view of the variety in the refractories composing the lining, a short description of each type and its intended function appears desirable.

Refractory materials in which silica predominates are acid; those composed of lime and magnesia are basic. The basic materials used in the lining are represented by the magnesite bricks and dolomite, while the acid materials are represented by the silica bricks.

The mineral dolomite may be regarded as a crystalline limestone, in which part of the calcium carbonate is replaced by magnesium carbonate. Before it is suitable as a refractory material it requires to be burnt, or calcined, until most of the carbon dioxide is expelled.

The composition of dolomite after burning is as follows:---

Dolomite is usually reserved for the construction of the working hearth, but it can also be used for the lining in small furnaces. In furnaces of any but small size, however, it becomes necessary to use magnesite bricks for the walls about the slag line.

Magnesite is the only material that can be satisfactorily used for the manufacture of basic bricks at present. The average composition of Austrian magnesite is : —

Magnesite bricks have a high co-efficient of thermal conductivity, and in order to prevent excessive heat loss, they should be backed wherever possible by a material having a much higher power of heat insulation, *e.g.*, firebricks. Magnesite bricks behave admirably in so far as they resist fusion at very high temperature and corrosion by basic slags, and the only serious objection to their use is their friability when hot and their tendency to burst after exposure to very high temperatures. Owing to this, it is necessary to use silica bricks for the upper walls and the roof of the furnace.

Silica is the predominating constituent of all acid refractories, and its content ranges from  $98 \cdot 5$  per cent. in the Sheffield "blackganister" to  $80 \cdot 0$  per cent. in the common grade of "cupola" ganister. If care is taken not to hasten the initial drying and heating to the full furnace temperature, good quality silica bricks in the roof will stand at least 50 melts. The softening point of silica lies between  $1,650^{\circ}$  C. and  $1,800^{\circ}$  C, and care has to be taken that this is not exceeded in the working of the

# FIGURE 2



furnace. Silica bricks are more highly refractory than any aluminous bricks excepting "Bauxite," which are very expensive. The average composition of a good silica brick and also, for comparison, of a Glenboig firebrick, follows:—

		SiO <sub>2</sub>	A1203	Fe <sub>2</sub> O <sub>3</sub>	CaO	Alkalies	Mg()
Silica brick		$96 \cdot 2$	.92	·63	1.5	.19	.22
Glenboig	Fire	63.0	$32 \cdot$	$2 \cdot 85$	•79	•94	·36

In addition to the deterioration of the silica bricks lining the walls and roof, owing to the heat of the furnace, further wear takes place through the re-action of the basic fumes from the slag, especially round the electrodes. This wear could be avoided by using basic bricks, but suitable ones are not yet obtainable for this work.

#### 2. Operation of the Furnace.

The object in view is to produce from steel scrap a liquid steel with a definite percentage of carbon, silicon and manganese (usually "C"-0.30 per cent. to 0.35 per cent., "Si"-0.25 per cent. to 0.35 per cent. and "Mn" about 0.6 per cent.), and as little sulphur and phosphorus as possible. In the basic process the operation is carried out in three distinct stages, viz.:-

Stage I.—Melting down the charge under oxidising conditions under a basic oxidising slag for removal of carbon, manganese, silicon and phosphorus (a partial removal of sulphur also takes place during this stage).

Stage II.-Skimming and carburising.

Stage III.—Refining under powerfully reducing conditions, with final removal of sulphur and finishing with alloy additions, &c.

The electric furnace under description is not adapted for the acid process of manufacture of steel and reference to this process is not called for. It may, however, be recalled that in the acid process the slag will only remove carbon, silicon and manganese, without any reduction of sulphur and phosphorus and, although steel made by the acid process from high-class raw materials by the open-hearth process is admittedly superior in quality to basic steel of similar composition, this does not apply to steel made in the electric furnace.

#### Stage I.

The hearth is charged with about 20 cwts. of punchings and 10 cwts.' of returns and the current switched on. If the hearth is cold there is usually some difficulty in striking an arc. When this is accomplished the metal begins to melt under the electrodes, torming two pools of molten metal which gradually extend. Lime is then thrown on as necessary to form a covering slag.

If the punchings are free from rust iron ore is added to the metal as the oxidising agent, but as a rule iron ore is not required, there being sufficient oxide on the scrap for oxidation. As the melting proceeds, further lime is added till the whole surface is covered by the slag.

Basic Oxidising Slag.—The function of the basic oxidising slag is to reduce the quantity of all constituents other than sulphur in the scrap and so produce a bath of steel as low as may be required in carbon, manganese and silicon, and as low as possible in phosphorus. The fluxes used for the formation of the slag are iron ore and lime, with fluor-spar added as necessary to thin it down. It is always advisable to use the best raw materials as they are found to pay in the end. For instance, local lime was tried in Portsmouth Dockyard, but its use led to trouble, and the best Buxton lime was reverted to.

A satisfactory slag will usually contain 25 to 30 per cent. of FeO and  $Fe_2O_3$ , 35 per cent. to 40 per cent. of CaO, the remainder being MgO, SiO<sub>2</sub>, MnO, etc. When cooled, the fracture is close and stoney in appearance and has a grey-black colour. An overoxidising slag is very fluid, black in colour and has a distinctly crystalline fracture. It can be made less oxidising by additions of powdered coal.

It is important not to over oxidise the metal in the bath as this is liable to result in spongy castings and affect adversely the mechanical properties of the steel. The correct quantity of ore is best determined by trial for a given class of scrap. The proportion of lime and ore should be such as to maintain a good black basic slag from the time of its first formation, in which case, the elimination of "C," "P," "Mn" and "Si" will proceed simultaneously with the melting, and be carried sufficiently far when the bath is hot enough for skimming. The time required for this stage of the operation is about four hours.

Slag Reactions.—1. Removal of carbon. Carbon in a bath of steel is oxidised both by the action of iron oxides dissolved in it and by the influence of a slag rich in FeO,  $Fe_2O_3$ , or  $Fe_3O_4$ , provided the temperature is high enough.

The carbon is oxidised to CO which either produces a frothy condition of the slag or bursts through it as numerous isolated bubbles, and in the latter case the steel is said to be " on the boil."

2. Removal of Phosphorus. In the presence of oxide of iron, either dissolved in the metal, or present in the slag, the phosphorus is oxidised to  $P_2O_5$ . If lime is present in the slag in a sufficient degree of concentration it serves as a base for fixing  $P_2O_5$ , forming 4CaO.  $P_2O_5$ . High carbon content of the scrap used leads to a risk of the phosphorus being imperfectly removed. The carbon in the bath during the melting down period should, therefore, at no time be high enough to prevent elimination of phosphorus. If the carbon is low enough, the removal of phosphorus proceeds gradually from the time a bath is first formed, and by the time the entire charge is melted and hot enough for skimming its elimination should be practically complete.

3. Removal of Manganese and Silicon. These are removed by the oxidising action of iron oxide dissolved in the bath or present in the slag. The oxidisation proceeds from the initial stages of melting down and is influenced by the amount of carbon present in the bath, and the bath temperature. They are oxidised to MnO and  $SiO_2$  and rise to the slag. There is usually no difficulty in reducing the manganese and silicon present in the ordinary steel scrap.

4. Removal of Sulphur. With a basic oxidising slag, the following reaction takes place :---

 $FeS + 2FeO = 3Fe + SO_{e}$ 

but it can only proceed if FeS and FeO are present in a sufficient degree of mutual concentration. The removal of sulphur is consequently only partial.

Condition of the Bath before Skimming.—Carbon. The makers of the furnace and text books recommend that the amount of carbon in the bath should be reduced to about 0.06 per cent. to 0.08 per cent. before skimming, but recent dockyard experience tends to prove that the castings are more likely to be sound and have better mechanical properties if the carbon is not allowed to go below 0.15 per cent.

Before the slag is skimmed, the amount of carbon in the bath is checked. This is done by taking a small spoon sample and testing it by the "colour test." The test is carried out as follows :—

0.1 grammes of standard steel drillings are thoroughly dissolved in a test tube in three cubic cms. of nitric acid, of S.G.1.2. A similar quantity of the sample is then similarly treated. Distilled water is then added until the colours agree, and the ratio of the amount of liquid in the test tube containing the sample to that of the standard will equal the ratio of carbon in the sample to that of the standard.

Phosphorus. With ordinary scrap there is usually no difficulty in reducing the phosphorus below 0.02 per cent., and this will usually rise to about 0.025 per cent. in the finished steel.

Manganese. This is usually reduced to about 0.2 per cent. in the bath. In adding the ferro-manganese later this figure is assumed without test and the ultimate percentage is practically always correct.

Silicon. If the carbon and phosphorus are properly eliminated this is reduced to a trace.

Sulphur. This is normally reduced to about 0.09 per cent.

#### Stage II.

If the correct slag and temperature conditions are realised, the slag can be removed without any difficulty. The main switch is broken, the electrodes lifted and the furnace tilted. The bulk of the slag is then poured off and the remainder is skimmed. This operation removes the surplus carbon, silicon, manganese and phosphorus and a portion of the sulphur. After returning the furnace to its normal position, the bath is carburised by throwing on anthracite coal in small nut size. The amount added is calculated so as to give roughly the required ultimate percentage of carbon in the bath, but a margin of 40 per cent. to 50 per cent. over this estimated quantity has to be made due to the partial combustion of the coal. It is important that good anthracite should be used, low in ash, phosphorus, sulphur and volatile matter (volatile matter not exceeding 10 per cent.), as otherwise irregular results are obtained.

#### Stage III.

Immediately after carburising, about 15 lbs. of 45 per cent. ferro-silicon is thrown in to deoxidise the metal. (The amount of ferro-silicon is worked out so as to provide that the ultimate silicon content shall not exceed 0.2 per cent.) This is followed by the addition of lime and fluor-spar for forming the new slag. After this slag has been formed and brought into a good condition and extending over the whole bath, it is maintained in a basic reducing condition by periodic additions of powdered anthracite, powdered ferro-silicon and lime.

Basic reducing Slag .- Up to the time of carburising, the process is conducted under conditions that exercise an oxidising action on the bath of steel. The act of carburising undoubtedly removes a portion of the dissolved iron oxide, but it is incapable of carrying the reduction beyond a certain point. It requires a far more powerful reducing agent to deoxidise the steel to such an extent that it will produce a sound casting, and this function is fulfilled by the slag formed by lime, powdered coal and fluor-spar, supplemented by ferro-silicon. It is also the function of this slag to finally remove the sulphur. In this connection, it will be appreciated that it is of vital importance that the lime and fluor-spar should be free from sulphur and the fluor-spar should be analysed before use; it should not contain more than 0.5per cent. Recently, great trouble was experienced with castings on account of excess of sulphur, which after much difficulty was finally proved to be due to the employment of unsuitable fluorspar.

The slag first formed will be brown or brown-yellow in colour when cooled. After the addition of carbon, lime, etc., it will become white or greyish in colour and fall to a fine powder in cooling from redness. This is the furnaceman's primary indication that he has the correct slag. Any tendency to revert to a darker shade of yellow or brown demands an addition of carbon dust. If the slag is too thick, a small quantity of fluor-spar should be added; if too thin, more lime is required. The total quantity of fluxes used should be sufficient to form a good covering to the bath, so as to prevent the absorption of carbon by the steel from the carbon dust added.

*Reactions.*—The reactions concern the removal of oxygen and sulphur. The oxygen is removed by the ferro-silicon and by the

carbon. The reducing action of ferro-silicon is simply due to the greater affinity for oxygen of silicon than iron. Silicon is oxidised and unites with unreduced metallic oxides still present to form silicates, which rise to the slag.

The reaction by carbon is a slag reaction. The deoxidising power is due to the formation of calcium carbide, which in contact with a bath of dissolved oxides, is immediately decomposed with liberation of CO and CaO, as follows :—

 $CaC_2 + 3FeO = 3Fe + 2CO + CaO.$ 

The reaction leading to the removal of the sulphur is comparatively slow until the slag is free from oxides, as is indicated by its white appearance; at this point the reaction proceeds with great rapidity, as follows:—

(1)  $\operatorname{FeS} + \operatorname{CaO} + \operatorname{C} = \operatorname{Fe} + \operatorname{CaS} + \operatorname{CO}$ .

(2)  $3\text{FeS} + 2\text{CaO} + \text{CaC}_2 = 3\text{Fe} + 3\text{CaS} + 2\text{CO}$ .

"CaS" is fixed in the slag.

For the satisfactory removal of sulphur the slag must be maintained in its correct condition for a definite period of time. In this respect Stage III. differs from Stage I., where removal of impurities takes place simultaneously with the melting.

Alloy additions.—After the correct slag and temperature have been maintained for a definite period of time, found by experience, a small spoon test of the metal is taken to ascertain if the metal has been "killed," in other words, deoxidised. The sample is poured from the spoon into a small metal mould. If the metal in the mould remains quiescent it is said to be "killed."

About 10 minutes before the metal is likely to be "killed," a second colour test for carbon is taken. On the result of this test the additions of spiegeleisen (C-5 per cent., Mn-20 per cent.) are made to bring up the carbon content to that required in the ultimate product. At the same time ferro-manganese (6 per cent., 70 per cent. Mn) is added to bring up the manganese to the required percentage. In working this out the bath is assumed to contain 0.2 per cent. of manganese, as earlier stated.

Finally, about five minutes before pouring, about 8 lbs. of ferro-titanium (20-25 per cent. Ti) are added, partly as a deoxidiser and partly because it appears to give better mechanical properties to the steel.

The metal is then poured into the ladle, which is previously well heated on a special stove. The final slag is poured with the metal so as to give it a neutral covering in the ladle. For this reason bottom teeming ladles are invariably used in the basic process.

Finally, a small quantity of aluminium (which is a most powerful deoxidising agent) is thrown into the ladle. The quantity should not exceed about 8 ozs. per ton of metal, as otherwise it is liable to adversely affect the mechanical properties of the steel, as stated later. It is a good practice to have the metal in the ladle for five minutes before teeming, as this offers an opportunity for any entrapped gases and slag to rise. Stage III. usually lasts about an hour.

## 3. Influence of the Constitutents on the Mechanical Properties.

The influence of the various constituents found in steel has been the subject of a great deal of research and there are still a good many points open to controversy. The tendency amongst engineers is to get over the difficulty by insisting upon a material as free as possible from every constituent other than the carbon required to produce the requisite hardness, and sufficient manganese to prevent red shortness. The objection to this course is that such a material is necessarily very costly when manufactured on a commercial scale, and it becomes necessary to compromise in everyday practice.

	U.T.S. i Per se	n Tons. q. in.	Elongation.	Bending Tests.	
	Not more than	Not less than	Not less than	Not less than	
Intricate	37	30	Per cent. 12	45°	
Ordinary castings.	35	28	15	60°—90°	

The Admiralty requirements for steel castings are as follows :---

The tensile tests at Portsmouth Dockyard are made on test pieces 2 inches long by 0.5642-inch diameter, and bend tests on test pieces 1 inch square over a radius not greater than  $1\frac{5}{2}$  inch.

The influences of the following constituents will be considered :---

Carbon, silicon, sulphur, phosphorus, manganese, and aluminium and various gases.

Carbon.—The influence of carbon (other constituents being normal) is best shown by the curves on Fig. 3. These are taken from a paper presented by Professor Dalby on "Strength and Inner Structure of Mild Steel" before the Institution of Naval Architects in 1917. These curves are only approximate but have been most useful. They only hold good if the carbon is in the form of "pearlite," in other words, if the heat treatment has been properly carried out and not unduly prolonged.

It will be observed that the curve of ultimate tensile strength is a straight line, and in connection with this it is of interest.



to note that the hardness of the steel, as shown by the Brinell hardness test, is practically proportional to the ultimate tensile strength.

After considerable experience it has been ascertained that the Admiralty requirements can be met by a carbon content of 0.30 to 0.35 per cent.

The lower the amount of carbon in the steel the higher the melting temperature, as is shown by the iron-carbon equilibrium diagram. Also, the lower the carbon content the more intensely oxidising must be the conditions of manufacture and consequently the more difficult the deoxidisation becomes. These two factors **make** it desirable to maintain the carbon content as high as is possible, compatible with the material meeting the stipulated tests.

Silicon.—Up to 0.35 per cent. Silicon has practically no influence on the mechanical properties of the steel. Above this percentage it is liable to adversely affect the bend test.

It is always desirable to retain a little silicon and also some manganese in the bath of metal to prevent over-oxidisation. The exact manner in which silicon and manganese act in this respect is not thoroughly understood, but there is little doubt that considerable portions are oxidised to  $SiO_2$  and MnO by some of the oxidising gases present and so by removing these gases, prevent blowholes. This is only a partial explanation. There are strong reasons for believing that silicon and manganese and also aluminium increase the solvent power of steel for gases, and thus prevent the dissolved gases being liberated on the steel cooling.

The amount of silicon aimed at to meet the above conditions is 0.25 per cent. to 0.35 per cent. Some of the Sheffield steel makers deliberately aim at 0.5 per cent. to ensure sound test pieces.

Sulphur.—Sulphur exists in steel as sulphide of iron or sulphide of manganese and these substances may be found in three forms :—

- (1) As globules.
- (2) As thin irregular laminæ.
- (3) As a meshwork round the crystals of the steel.

When in the form of globules these sulphides are comparatively harmless, and as the laminæ can be "balled up" into globules by suitable heat treatment, the effect of (1) and (2) need not be important.

When the sulphide is present as a meshwork round the crystals it is in its most objectionable form as it causes inter-crystalline weakness, which no known heat treatment will remove. It is well established that in sound materials the process of fracture, whether under steady load or under shock, proceeds across the body of the crystal. Where inter-crystalline fracture occurs, it is a certain sign of some abnormality in the composition or condition of the metal, as is the case when the sulphide is present in the form of a meshwork.

If sulphur is present in excess, it makes the castings "red-short," *i.e.*, they are liable to develop cracks on setting; also, it adversely affects the elongation and bend tests. As previously mentioned, owing to a high sulphur content, due to bad fluor-spar, a great deal of difficulty was experienced at Portsmouth Yard in obtaining the required mechanical properties until the reason was located.

The upper safe limit for sulphur appears to be about 0.04 per cent. At Portsmouth Dockyard a sulphur content of not more than 0.03 per cent. is aimed at and usually obtained without difficulty.

Phosphorus.—Of all the impurities usually present in steel, practical experience has established the fact that phosphorus is the one that most prejudicially influences the physical properties of the metal by producing brittleness under shock, and general cold shortness. There is no doubt that the lower the phosphorus content the safer is the material, but it is not possible to assess the definite maximum limit beyond which this undesirable feature may arise. In Portsmouth Dockyard under 0.02 per cent. is aimed at, although there appears to be but little danger below .04 per cent.

It is perhaps somewhat difficult to credit the fact that such a small proportion of phosphorus could produce such a serious change in the strength characteristic of steel. Two factors must, however, be borne in mind. In the first place, the phosphorus is present, not in the free condition, but as "Fe<sub>3</sub>P," so that every 0.10 per cent. of phosphorus involves the presence in the steel of 0.48 per cent. of Fe<sub>3</sub>P. Further, Fe<sub>3</sub>P is not uniformly disseminated throughout the steel, but resides in the peripheral parts of the first large crystals which are formed on cooling. It is these higher local concentrations which lead to failure under test or in service.

Manyanese.—The influence of manganese on the properties of steel has already been dealt with to a certain extent under the heading of silicon. It is not an impurity present which metallurgical treatment has failed to remove, but an essential constituent especially added to deoxidise the metal so as to prevent its being red short. For mild steel, the less manganese a steel contains above that required to ensure solid castings and freedom from red-shortness, the better.

The general tendency of manganese is to increase the tensile strength and somewhat to reduce the ductility. At Portsmouth Dockyard, the most satisfactory results appear to be obtained with a manganese content of about  $\cdot 60$  per cent.

Aluminium and Gases.—All steel when in a molten state contains a certain amount of iron oxide which has the effect of lowering both its fluidity and the strength of the casting, making it "red-short." As oxidised metal cools, the oxide, under the action of carbon is partially reduced, forming carbon monoxide gas. The gas so evolved causes a more or less violent ebullition in the molten metal, giving rise to blowholes. The addition of very small amounts of metallic aluminium to such metal is found to stop the violent ebullition of gas and allow of the production of sound castings without blowholes. The explanation of this action appears to be that aluminium has a far greater affinity for oxygen at high temperatures than iron; the oxide is consequently reduced, while the alumina formed passes out of the metal as slag.

A small addition of aluminium is found to stop also the evolution of other occluded gases, nitrogen and hydrogen. It is supposed that the reason for this is that the deoxidation of the molten metal increases its power of retaining occluded gases and the metal retains in solution gases that otherwise would be expelled.

Blowholes, in the case of steel, may be due either to the mould or to the material. Those from the mould, as shewn by fracture, are stated to be coloured or oxidised, while those from the metal are clear and bright, but no practical proof of this has been obtained at Portsmouth Dockyard.

Aluminium should be added cautiously (about 8 ozs. to the ton of metal) as, if added in large quantities, it seems to have the curious effect of causing segregations of impurities in the metal, resulting in poor resistance to shock tests.

The amount of aluminium in the finished castings should certainly not exceed  $\cdot 02$  per cent.

Table I. shews the chemical compositions and the results of mechanical tests of some recent products from this furnace.

Sample No.	C.	Si.	s.	Р.	Mn.	Ultimate tensile strength.	Elonga- tion.	Bend angle
						Tons per	1 1	
		1.5				sq. in.	Per cent.	0
G. 16	.27	· 39	·030	·036	.77	34	24	106
G. 19	·30	·29	·032	·025	.80	36	20	138
F. 22	· 30	·29	·017	·008	.68	31	35	62
F. 6	·31	·40	·029	·008	.66	31	33	86
H. 2	.31	·40	·025	·020	.76	34	26	90
H. 3	.32	.37	.024	·028	.76	34	31	85
E. 18	.33	.27	·017	.015	.66	31	28	109
G. 13	·33	·45	·022	·020	.63	32	31	67
G. 12	·34	.39	·018	·028	·81	35	29	105
G. 17	.36	.34	·024	·023	.73	35	22	93
H. 4	.38	.36	.024	·039	.75	35	22	80

TABLE 1.

Results of Chemical Composition and Mechanical Properties.

### 4. Moulding Methods.

Steel castings can be made either in "greensand" or "dry sand" moulds, the former being used for light and unimportant castings and the latter for high-class work and articles of heavy section. There is a great saving of time in "greensand" moulding and it is adopted wherever possible, *e.g.*, for such articles as boiler feet for Yarrow boilers, etc.

The pouring temperature of steel is much higher than that of iron or brass; consequently special sands of a highly refractory nature are required for facing the moulds. The following sands are used at Portsmouth Dockyard:--" Yorkshire, steel," "Mansfield, steel," "Silica sand," etc. They are bonded with "treacle," "linseed oil," "spermolin," etc., the object being to have a bonding material which will char on heating and give way on contraction of the metal so as to avoid cracks in the castings.

Silica is always the base of all steel moulding sands, in fact the "silica sand" used contains about 98 per cent. of silica. The following is a typical composition of a sand used for "greensand moulding":—

 $SiO_2 - 92.5$  per cent;  $Al_2O_3 - 4.5$  per cent.; FeO - 2 per cent.; CaO - 0.4 per cent.; MgO - 0.3 per cent.

The position of the runners and feeding heads is, if anything, even of more importance than in iron and brass work. Generally, the feeding heads are larger and more numerous owing to the more rapid solidification of the metal. The position and number can only be determined by experience.

The defects chiefly met with in steel castings are blowholes and cracks. Blowholes have been dealt with briefly already. Provided the molten material is properly made, the presence or absence of blowholes in the castings is chiefly dependent on the skill of the moulder; this aspect is, however, rather beyond the scope of these notes.

Considerable trouble was experienced recently with cracks in castings. As the contraction of the steel is equal to from 3/16-inch to  $\frac{1}{4}$ -inch per foot, it is obvious that special means have to be adopted to allow for it; wherever possible freedom is given both in the moulds and cores to allow for contraction by the use of collapsible cores and sections of the moulds. Such means as using sawdust and ashes with the sand have been adopted with advantage, and lately very few castings have developed cracks.

The pouring temperature plays an important part in the production of sound castings. It is only necessary to heat the molten metal to a temperature which will secure successful running. Higher temperatures tend to cause over-oxidisation, thereby producing unsoundness and hot cracks. It also overtaxes the refractoriness of the facing sands, which makes fettling difficult. Influence of Design.—The foundryman frequently has to contend with difficulties in moulding which would be avoided if there were more co-ordination between him and the designer. Castings with long thin sections, thick and thin sections and heavy bosses attached to very thin general sections, are regularly met with, and each of these cases requires special treatment.

Where a thick section adjoins a thin section the latter cools first and on contraction is liable to cause cracks at the junction because the thick section is still in a very weak condition when the thin section has set. Such difficulties are overcome sometimes by the use of chills (external and internal) at the thick sections or by casting temporary webs at positions where the castings are found liable to crack.

In many of these cases a little forethought on the part of the designer would make these precautions unnecessary. Even sections with well-rounded corners and gradual changes of thickness where variation is necessary should always be aimed at.

## 5. Heat Treatment.

The object of heat treatment of steel castings is to eliminate any internal stresses due to casting, and to bring about a definite alteration in the structure by a re-arrangement of the constituents.

The heat treatment is carried out in two stages at present in Portsmouth Dockyard, as follows :---

(1) The casting is heated relatively rapidly (in about four hours) in a closed steel muffle to  $1,050^{\circ}$  C., kept at this temperature for about four hours and cooled in the furnace during the night to about 100° C.

(2) Re-heated to from  $815^{\circ}$  to  $870^{\circ}$  C., retained for two hours at this temperature and cooled in the muffle with furnace door open.

This method was adopted about a year ago with very satisfactory results, as compared with the old method which consisted in heating the castings for about 72 hours at 820° C.

In the following remarks use will be made of two metallurgical terms, viz., ferrite and pearlite. Ferrite crystals are crystals of practically pure iron. Pearlite consists of laminæ of iron carbide (Fe<sub>3</sub>C) embedded in ferrite. An increase of pearlite results in a progressive hardening of the steel, as is shewn in Fig. 3. A 0.9 per cent. carbon steel in its normal condition is entirely pearlitic.

A typical micrograph of unannealed or overheated steel is shewn in Fig. 4. The steel has a typical coarse and angular structure and is in a poor condition to resist the propagation of fracture with a consequent adverse effect on its mechanical properties. Further, as shewn by Fig. 5, photomicrographs of un-heat-treated steel sometimes reveal the sulphides in the form of detached films in its structure. These films have a weakening effect on the steel, as is shewn principally by the poor results under elongation and bend tests. The object of the first part of the heat treatment is to ball up the sulphide films into globules as shewn on Fig. 6. The sulphides are then in a relatively harmless condition, being present more or less as a microscopic dust in a matrix of sound metal.

The second portion of the heat treatment is to refine the structure of the steel by breaking up the large crystals into small ones, with an even distribution of the pearlite over each section as shewn by Fig. 7.

Effect of Grain Size on Mechanical Properties.-There is little doubt that the mechanical properties of steel are better, the smaller the constituent crystals from which it is built up. Under the tensile test, coarseness of structure usually results only in a slightly lowered yield point, while ultimate stress and elongation are little impaired. Under both shock and fatigue tests a coarse structure gives unsatisfactory results. The reason is easily understood. As stated previously, in all sound material the path of fracture is across the body of the crystal and not along the intercrystalline spaces; thus the crystal boundaries act as a species of strengthening skeleton. At each boundary a crystal is supported by its neighbour, probably of different orientation, and a fracture must change its direction where it passes from one crystal to another. In other words, the weakness of one crystal will be balanced by the strength of the other. Where the crystals are large, single surfaces of cleavage extend unbroken through relatively large areas and fracture-particularly under shock or fatigue-may be brought about under conditions which a fine-grained structure would have resisted.

Effect of Thermal Treatment on the Structure of Steel.-On heating steel containing less than 0.9 per cent. carbon above the upper critical temperature, which varies from 900° to 720° C., according to the carbon content, the ferrite crystals at once undergo an allotropic change. The new crystals when first formed are smaller and more numerous than the pre-existing ones. These newly-formed crystals, if maintained at a temperature above the upper critical one, will begin to grow, and the growth will be more rapid the higher the temperature. If therefore, the steel is kept at temperatures above the critical range for any considerable time, a coarse structure is developed; also, if the temperature is raised above 900° C. it develops rapidly. On cooling, the events are to a certain extent reversed but not nearly to the same degree. Thus, by "overheating" steel, i.e., by exposing it to unduly high temperatures, or for too long a time, a coarse structure results. Not only this, but the arrangement and forms assumed by the pearlite and ferrite is characteristic, viz., in elongated and sharply defined angular patches, as shewn on Fig. 4. "Overheated" steel must not be confused with " burnt " steel. The former can be restored to a normal structure by suitable heat treatment, while the latter cannot be, and the only remedy is to remelt it.

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FIG. 4



FIG. 5.



FIG. 6.



FIG. 7.

If a steel is cooled unduly slowly, or if it is exposed to prolonged heating at a temperature approaching  $700^{\circ}$  C., the laminæ of iron carbide gradually ball up. The resulting structure consists of ferrite with some iron carbide scattered amongst it. The steel then becomes practically pure iron with a coarse crystalline structure and with correspondingly poor mechanical properties. Finally, when a material has been subjected to a low red heat (about  $600^{\circ}$  C.) for a very long time, there is a tendency for the iron carbide to form a meshwork round the ferrite crystals. This structure is decidedly objectionable, as it causes intercrystalline weakness in the same way as the sulphide meshwork mentioned previously.

The above mentioned three conditions of the steel can always be corrected by heating the steel to a temperature just above the upper critical one, maintaining it there for a time only just long enough to allow the whole mass of material to attain the temperature and then cooling as quickly as practicable. Thus the maximum refining effect is obtained and this is the object of the second portion of the heat treatment of castings.

For comparison, the mechanical properties of heat treated and non-heat-treated test pieces cast under the same conditions at the same time are given below :---

	Ultimate Tensile Strength. Tons.	Elongation.	Bend test Angle.	
Untreated specimen - Heat-treated specimen -	-	35 32	19°,0 28°,0	55° 105°
Composition		C. Si. •32 •33	S. P. •02 •018	Mn. • 60

The photomicrograph of the untreated specimen is shewn in Fig. 4, and of the heat-treated specimen, Fig. 7.