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## Cast Iron.

CONTRIBUTED BY A MEMBER.

READ

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CHAIRMAN: MR J. T. MILTON (Vice-President).

The HON. SECRETARY: The paper which is before us to-night was received with a view to printing it in the Transactions direct, as a contribution from a member. Its manifest value and importance made it extremely desirable to have the paper read at a meeting, in order to obtain the best value from it, with the opportunity of discussing the subject and placing on record questions which will, no doubt, arise in the minds of members as the subject is unfolded. The writer of the paper, on being communicated with on the question, kindly consented that I should read it to-night, and I am quite sure that we shall all agree in thanking him for this concession. I have much pleasure in reading it on his behalf.

VERY considerable interest is at present being taken in the qualities and properties of cast iron. For instance, one of our daily papers (1) recently devoted more than a column to the

subject of cast iron "growth," and papers on cast iron, especially in regard to its use for special parts of internal combustion engines have recently been read before the Engineering Societies, (2) (3) and it has been publicly announced that a research into cast iron is to be undertaken by the Engineering Section of the National Advisory Council for Scientific and Industrial Research. The present paper contains many extracts from the published works of experts on the subject, and in every case the writer has endeavoured to record the sources from which they have been taken, both from the desire to render credit where it is due, and also in order that our members who may wish to have more detailed information may know where to obtain it.

#### INTRODUCTORY.

Before proceeding to discuss the subject of "cast iron," a few explanatory remarks as to some of the terms used will not be out of place. They are in common use, and therefore are clearly understood by metallurgists, physicists, and other scientific persons, but are strange to many engineers, iron founders, and others who are engaged in the more practical work of making, machining, and using iron castings.

The origin of the art of "founding" goes back to antiquity. In the so-called "Bronze Age" the ancients made bronze, an alloy of copper and tin, each of which metals was known in its separate form. They therefore were aware that metals would "alloy," or combine, forming a new metal with properties entirely different from those of either of the constituents. When "brass" was first introduced, i.e., an alloy of copper and zinc, in contradistinction to bronze, which is an alloy of copper and tin, it is singular that zinc as a separate metal was unknown. The "brass" was produced by heating together copper and "calamine," which is an ore of zinc. The zinc became reduced from the ore and alloyed with the copper in the process, but was not obtained as a separate metal.

When chemistry became an exact science, it was known that chemical combination took place only in definite atomic proportions, and it was evident that the compositions of alloys, which could be made to vary in any desired proportions, could not be accounted for by chemical combinations only, although in many cases chemical combinations do take place between the individual metals comprised in alloys. We must look further to ascertain what actually occurs in alloys.

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It is known that some liquids will not mix with others. For instance, take oil and water. Mix them together as thoroughly as possible by mechanical means, they will not really mix, but if left undisturbed will separate into two portions, the lighter floating above the heavier." On the other hand, some dissimilar liquids will thoroughly mix : as examples we may take alcohol and water. These will mix in all proportions, and will not of themselves separate again. In fact, the tendency to mix is so strong that if the lighter alcohol is floated over the heavier water, then, without agitation of any kind, some of the water will permeate the alcohol, and some of the alcohol will descend into the water, and this will go on until each of the dissimilar liquids has so mixed with the other that the mixture throughout will be of homogeneous composition. This process, familiar to all of us, is called diffusion. When speaking of the resulting diffused liquids, we may consider them to be either a solution of alcohol in water or a solution of water in alcohol.

Again, it is a matter of every-day knowledge that water will dissolve a very large number of different substances; as examples we may cite sugar, salt, alum, lime, etc., the results of the process being termed solutions. There is a marked difference, however, in these cases from that previously noticed, where one liquid dissolves in another. In that case solution takes place in any desired proportion from the smallest to the very largest. In the cases of solution of, say, alum in water, it is found that at a given temperature the quantity of alum which will dissolve in water will not exceed some definite proportion. If less is put into the water it will all dissolve; if more than the critical proportion is put in, so much of it will dissolve as will bring the solution up to that proportion, but the remainder will not dissolve. The amount which will dissolve depends upon the temperature. In many cases a greater proportion will dissolve in hot than in cold water; in some cases the contrary occurs. In the case of alum, which we have referred to, if a solution which is saturated when it is at a given temperature has its temperature raised it will be capable of dissolving a further quantity. If, however, its temperature is reduced, it will be unable to retain all its previous content in a dissolved form, and the excess will solidify out in the form of solid crystals. Marine Engineers generally know that sulphate of lime is a salt which has the opposite qualities, viz., it is less soluble in hot than in cold water. A

certain (although small) quantity of this salt is present as a solution in all sea water. At higher temperatures than the normal it becomes less soluble, and at the very high temperatures at which steam boilers are now worked it becomes insoluble, and if sea water containing it is introduced into a high-pressure boiler it comes out of solution and forms the crystalline, objectionable boiler scale.

These illustrations familiarise us with a conception of what a *solution* is, but so far, in both cases, whether the components are both liquids, or one liquid and one solid, the solution is a *liquid solution*.

We have seen that at a given temperature water will dissolve certain salts up to a given proportion. This in each case supposes the water to be pure. If, however, the water in which it is desired to dissolve a specific salt, instead of being pure has already a quantity of another salt in solution. it will be found that, although it may dissolve some of the specific salt, it will not dissolve so much of it as it would do if it were pure. It will be found that an analogous result obtains when dealing with cast iron.

Now let us turn to metals, and take as examples two which are commonly known, viz., Lead and Tin. Both metals melt or become liquid at temperatures below red heat. The metals have no chemical action upon each other, but if we take them at such a temperature that both of them are liquid we shall find that these liquids, like the alcohol and water previously referred to, will diffuse into one another in any proportion. A mixture of them can then, while liquid, be termed either a solution of tin in lead or one of lead in tin. If in solidifying by cooling such a mixture did not tend to separate out into its component parts, the resulting solid would possess the similar property to a liquid solution that each particle of it, however small, would possess the same composition as the whole. Such a solid would be called a solid solution. As a matter of fact, the mixture of tin and lead which we have taken as an instance will under very slow solidification tend to separate out into two distinct layers of lead and tin, but if the solidification is fairly rapid the result is a solid solution.

In taking the illustration of Lead and Tin, it was purposely mentioned that in mixing the metals we took them at temperatures at which both of them were liquid. Another aspect of this mixture will now be considered. Lead melts at a temperature of, say, 620° Fahr., tin at 450° Fahr. It may readily be expected that if we dissolve a little tin in lead the melting point of the solution will be lower than that of lead. This is found to be the case. It might, however, be thought that by dissolving a little lead in molten tin the melting point of the resultant alloy will be higher than that of tin. This, however, is the opposite to the fact. It is found that each addition of lead to the tin, down to a certain proportion, lowers the melting point.

The melting point, when a solid metal has its temperature raised until fusion occurs, is, of course, the same temperature as that at which the molten metal by cooling solidifies or freezes. Whether, therefore, we commence with pure tin, and add gradually increasing amounts of lead to it until the ratio of lead and tin becomes a certain amount, or commence with lead and gradually add tin to it, the melting point becomes lower and lower until the proportion of lead and tin comes to the same critical proportion as in the previous method. This definite proportion that constitutes the alloy with the lowest melting point is called the Eutectic of the mixtures in question. In the case of lead and tin to which we have been specifically referring, the *Eutectic* is the alloy known as "soft solder," or "tinman's solder," and, as is well known, is composed of, approximately, 67 per cent. tin and 33 per cent. lead. Its melting point is about 340° Fahr., which is considerably below that of either of its constituents.

*Eutectics* are not necessarily confined to compounds containing only two constituents, but similar properties, viz., that of *lowest melting point*, may occur in compounds of more than two. A familiar example of this is an alloy of lead, tin and bismuth, in which the melting point of the triple eutectic is lower than the temperature of boiling water. Such a triple eutectic also occurs with iron, carbon and phosphorous, and plays an important part in "cast iron." It is generally referred to as the "phosphorous eutectic," and must not be confused with the "phosphorous eutectic," which is of scientific interest only.

Owing to the mobility of the particles of a liquid it is not difficult to understand that diffusion can take place in liquids with comparative facility, and that the results of chemical action taking place at one part can be readily transferred to other parts, but it is not so easy to comprehend how chemical action necessarily involving the transference of atoms of solid substances through solid metal can take place, yet we know

that such action does occur. As instances may be mentioned the process of case-hardening. In this process articles of wrought iron or of exceptionally soft steel, consisting practically of pure iron, are imbedded in a mass of carbonaceous substance, and kept at a high temperature for a considerable The outermost layer of the iron combines with some time. of the carbon, and thus becomes converted into high-carbon The depth to which the conversion proceeds depends steel. upon the temperature at which the articles are kept and upon the length of time given to the operation. In this way a thin laver of hard steel, forming an excellent wearing surface, is produced, whilst the central portion of the article retains the toughness of the original wrought iron. In the process of " cementation." or the conversion of wrought iron bars into steel, practised in the manufacture of steel for high-class cutlery, a similar occurrence takes place, but in this case the process is continued until the bar becomes converted into steel throughout the whole of its mass.

When carbon combines with iron it does so in the proportion of one atom of carbon combining with three atoms of iron forming the carbide of iron, the chemical symbol of which is  $\text{Fe}_3\text{C}$ . This substance, in metallography, is called *Cementite*. When the carbon is in this form it is called "combined" carbon.

In ordinary "grey" cast iron there is always some carbon which is not combined. It is usually in flakes, very minute, but easily discernible under a low power of magnification. This *uncombined* or *free* carbon is termed *Graphite*, because it is apparently of the same structure and has the same properties as *graphite*, the so-called *black lead*.

Carbon, however, sometimes exists in iron in another form. Iron containing "cementite" or with its carbon combined may be subjected to such heat treatment as will break up the chemical union between some of the carbon and iron; the carbon thus separated is *free* carbon, but it is in such minute subdivision as to bear little resemblance to the flakes of "graphite" in ordinary grey cast iron. Such carbon is sometimes termed "temper" carbon, and sometimes "annealing" carbon. In reality, with different treatments of cast iron, the size of the flakes of graphite can be made very small, so that there is not a hard and fast line to be drawn between *graphite* and *temper carbon*. Professor Turner prefers to call this form of carbon " secondary graphite " (4, page 250). If in an ironcarbon alloy, such as mild steel, there is a total content of carbon less than 0.9 per cent., then at temperatures above  $700^{\circ}$  C. (say 1,300° F.) the carbon will be about equally diffused throughout the mass, which will then be a solid solution of carbon (or Iron Carbide) in iron. If such a mass is slowly cooled, the carbon (or carbide) segregates into some of the crystals, leaving the other crystals free from carbon. The crystals which are free from carbon are called ferrite. Those which contain carbon are found each to contain 0.9 per cent. of that element. When examined under a high power of magnification these crystals are found not to be homogeneous, but to consist of minute portions of carbide (cementite) intimately mixed with pure iron (ferrite). These crystals are called *pearlite*. If the iron-carbon alloy is fairly pure, the cementite and ferrite in the pearlite crystals are found to be, in alternate laminæ or layers; if, however, there is manganese present the cementite may be described as nodular rather than lamellar, but it is still found to be in very small particles intimately intermixed with ferrite.

#### Composition of Cast Iron.

The term " cast iron " is usually given to the metal after definite castings are made from it; that is, after it has been melted in a cupola, and used in a foundry. The material as it comes from the blast furnace is called " pig " or " pig-iron." The composition of " pig " is very varied even when made the same day in the same blast furnace with the same qualities of ore, coke and flux. Usually, the iron contains some portion of every element which is contained in the ore, fuel or flux used, and which is capable of being reduced in the blast furnace, but the proportions of each element so reduced will vary with the conditions of working of the furnace.

As examples, Professor Turner (4), gives tables showing in the case of Hæmatite Pig, a total proportion of elements other than iron, ranging from 5.23 to 8.03 per cent., and in the case of Cleveland Pig a similar range, varying from 6.14 to 9.10 per cent.

With such a large proportion of elements other than iron in cast iron there need be no wonder that there are great variations in the properties of cast iron. Further, it may be stated, that the properties of the iron constituting a casting depend upon some other considerations besides those appertaining to the composition of the pig used.

When iron is reduced from its ores in the blast furnaces, mixed, of course, with any other elements reduced at the same time, such as silicon, manganese, sulphur, phosphorous, etc., it flows down over intensely heated coke, and must, therefore, be saturated, or nearly saturated, with carbon, which will dissolve in it. That is to say, it is combined with the largest amount of carbon which it can take up at the temperature at which it then exists. Professor Turner (4, page 247), gives a diagram which illustrates what would happen if pure iron and carbon only were in question, and this will give some idea of what will actually occur when small quantities of other elements are also present. At a temperature of about 1,350° C (2,462° Fahr.) the iron will contain about 6 per cent. of carbon in the form of "cementite" (Fe<sub>3</sub> C) in solution. As the temperature falls some of this " cementite " decomposes, and its carbon separates out, until the "eutectic" point of the iron and carbon series is reached. This is at the temperature of 1,130°C (2,066° Fahr.). At this time only 4.25 per cent. of carbon, still in the form of "cementite," will be in solution,  $1\frac{3}{4}$  per cent. of carbon having then separated. At this temperature the mass will be still liquid. When cooling takes place below the "eutectic" point of 1,130°C graphite will commence to separate out, and will be retained in the mass of cooling iron. This will continue until the "combined" carbon content is reduced to 2.2 per cent., after which the solidification proceeds without further decomposition. The final result would, therefore, be in the case of a pure iron carbon alloy.

Iron		 	95.75	per cent.
Graphite		 	2.05	,,
Combined	carbon	 	2.20	,,

The presence of the other elements, however, in actual cast iron very considerably modifies these proportions. As was mentioned in describing the analogous case of saturation of water with more than one salt, the fact that the molten iron has already a comparatively large quantity of silicon dissolved in it greatly influences its capacity for also retaining carbon in solution, and it is found that the larger the amount of silicon gresent the greater will be the separation of free carbon (graphite), and the less the amount of combined carbon. As an example, the composition of the hæmatite pig, previously referred to (4) as containing only 5.23 per cent. of elements other than iron, includes silicon 1.35 per cent., graphite 2.3 per cent., combined carbon 0.79 per cent. In the iron containing

8.03 per cent. of other elements, these figures are 2.85 per cent., 3.52 per cent., and .18 per cent In general, the influence of silicon upon cast iron is to increase the graphite, and at the same time to decrease the combined carbon. Sulphur is thought to have an opposite effect.

It will now be advisable to state the conditions in which the various elements are found in cast iron, and how they can be recognised.

Carbon can always be distinguished. It appears either as "free" carbon (graphite), or as carbide (cementite, either free or as laminæ or nodules in pearlite). It is never found in solid solution in the iron under normal conditions of cooling. If phosphorous is present, part of the carbon will be found in the phosphide eutectic.

Silicon can never be recognised by itself. It exists in cast iron, most probably in solid solution in the ferrite.

Manganese in cast iron is thought to be always present as a carbide  $(Mn_3 C)$ , which is intimately mixed with the cementite, either the free cementite, or the cementite which is found in the pearlite.

Sulphur in the proportions in which it is found in east iron is considered to be in the form of Ferric Sulphide (Fe S), which goes into solid solution in the Ferrite. In microscopic examination, however, there are often seen minute globules of slag, which from their colour, are recognisable as Sulphide of Manganese (Mn S), so that part of the sulphur probably will always exist in this form.

The position of phosphorous is of considerable importance. Dr. Stead has shown (8) that where iron is alloyed with phosphorous only, i.e., no carbon being present, the phosphorous combines with the iron as a phosphide with the composition  $Fe_3 P$ . Up to a content corresponding to 1.7 per cent. of phosphorous, this phosphide exists in the iron as a solid solution. When the proportion of phosphorous exceeds 1.7 per cent., but does not exceed 10.2 per cent., an amount which is never reached in practice, the metal consists of a mixture of crystals or grains of the saturated solid solution of  $Fe_3P$  in iron, and of a eutectic containing 10.3 per cent. of phosphorous.

When carbon is present, as it always is in cast iron, the conditions become changed. Dr. Stead (8) has shown that where carbon and phosphorous are both present the phosphorous has a greater affinity for iron than carbon has, and that the

whole of the phosphorous combines with iron, absorbing sufficient to bring its composition to Fe<sub>3</sub> P, and so lessens the amount of iron left to combine with the carbon. In cast iron, therefore, containing phosphorous there will be less total carbon proportionately to the amount of phosphorous. When carbon is present, instead of the phosphide of iron entering solid solution in the iron, as above referred to, into it combines with iron carbide, forming a tertiary iron-phosphorous-carbon eutectic with a still lower melting point than the iron-phosphorous eutectic, viz., about 900°C (about 1,650° Fahr.). This is apparently not capable of entering into solid solution with the iron, as when the phosphorous content of a grev iron is only 0.03 per cent., the eutectic can be detected by the microscope. When the phosphorous exceeds this amount, as it does, in all foundry iron, the eutectic is in great evidence.

Dr. Stead (8) gives the following description of what happens when grey phosphoretic cast irons solidify from the molten condition —At first plates or shells of graphite fall out of combination with the iron, leaving the remaining portion in a plastic state. As cooling proceeds solidification also takes place, commencing at the solid borders of the graphite flakes. The part to solidify next to the graphite contains all the silicon, part of the manganese, and a large part of the iron, leaving all the phosphorous and some of the iron and manganese, still liquid, occupying the spaces between the already solidified portions. The last to crystallize is the phosphide eutectic, which is found between and at a distance from the graphite plates. Even in iron containing combined carbon the same phosphorousiron-carbon eutectic is found in the same position between the graphite flakes.

The eutectic is very hard, but not so hard as cementite.

The following are recognised as being in general the influences of the various elements upon the properties of cast iron. It must be remembered, however, that both the rate of cooling and the temperature at which the metal is poured has considerable effect upon the properties, as also has the thickness or size of section of the casting, the latter probably mainly owing to the influence it has on the speed of cooling, and on the separation of graphite from the carbide.

Carbon in the "combined" condition hardens and strengthens cast iron. In the "graphite" form, however, it has the reverse effect, rendering it soft and weak and more easy to machine. The influence of "graphite," moreover,

depends not only upon the quantity present, but also upon its method of distribution. Other things being the same a casting in which the graphite is fine and evenly distributed, is stronger than one in which it exists in coarse flakes. If all or nearly all the carbon exists in the combined form we have what is termed "white" iron, which is always hard and brittle, and in general is not strong. An iron which under ordinary casting conditions would produce a grey casting, will be white if the cooling in very rapid, as the carbon then has not time to separate from the combined condition. This was the principle upon which the "Palliser" cast iron armour piercing shot were made. These shot were cast point downwards, the bottom of the mould was made of iron which, being cold, rapidly "chilled" the point of the shot, which thus became intensely hard, the hardness gradually lessening along the length of the shot.

Silicon is the next element of importance which is always found in cast iron, its amount varying from under 0.5 per cent. to over 4 per cent. (4). Its most important effect is its influence in causing more of the carbon to separate out into the graphitic state, and, therefore, to soften the iron. Although it softens cast iron, it is generally considered to also strengthen it, and consequently a proportion of iron, rich in silicon, is often advantageously mixed with other iron in foundry practice.

Manganese is also always found in cast iron. Turner states (4, page 267) that the physical properties of cast iron are not greatly altered by manganese, unless that element exceeds 1 per cent. Its presence up to that limit is, however, rather beneficial than otherwise, but the benefit ceases if it is much greater than 1 per cent. When manganese exceeds 1.5 per cent., the iron becomes very appreciably harder to machine, and if the amount of silicon is relatively small the iron will become "white." Manganese increases the shrinkage during cooling. It tends to eliminate sulphur by combining with it forming a sulphide of manganese, which separates into the slag.

Phosphorous is an element very much in evidence in the irons of some districts, but present only in small quantities in Hæmatite iron (4). When a large proportion is present such as from 2 to even 5 per cent., the metal is very fluid when melted, and takes an excellent impression of the mould. Such iron is very brittle. It is employed for making thin castings, such as stoves, rain water pipes, etc., where great strength is not required. For the general run of foundry

work, in cases where fluidity and softness are of more importance than great strength, from 1 to 1.5 per cent of phosphorous may be used. Highly phosphoric irons are unsuitable for articles exposed to high temperatures in use, such as ingot moulds and fire-bars (4).

Sulphur is always an objectionable element in cast iron. It tends to keep the carbon in a combined form, and in this way to make the iron hard and brittle. Good foundry iron will not contain more than 0.15 per cent. of sulphur (4).

Arsenic is sometimes found in small quantities in cast iron, but it is rarely found to exceed 0.1 per cent. (4). Its influence is said to be similar in character, but less marked in degree than that of phosphorous.

Other elements are found in cast-iron, but the above are those which are most usual, and which are sought for in making ordinary analyses for practical work.

It has been mentioned that there is very considerable variation in the composition of pig iron, even when made on the same day, at the same blast furnace, from the same quality of ore, coke and flux. These differences in the pig are due to the variations which take place in the working of the furnace, and are mainly caused by the variation in the reduction of silicon, which, as has been stated, so materially affects the proportion of graphite and combined carbon. The other elements are also affected, but not to the same degree. For instance, in the various grades of Cleveland pig, whose analyses are given in Turner's work(4, page 280), whilst the total elements other than iron vary from 6.14 to 9.10 per cent., a range of nearly 50 per cent., the phosphorous varies only from 1.55 to 1.69 per cent. In general, the pig from certain districts can be relied upon as containing comparatively large amounts of some one impurity, and less amounts of others, so that by mixing irons from several districts it is possible to produce castings having no special element in excess. It is for this reason that in foundry practice it is usual to employ a mixture of several brands of pig, as well as to use a quantity of scrap, which presumably has originally been made from several other brands. By suitably chosing brands, either a soft iron or a specially hard and strong iron can be obtained, according to what may be required for special purposes.

It is generally known that remelted iron becomes harder and stronger each time it is remelted, and this fact is generally given as a reason for using a good proportion of scrap when a specially strong casting is required. The change of property is not due to the remelting itself, but is due to the change of composition thereby effected. It has been proved conclusively (4, page 297) that in a series of tests where iron was remelted 18 times, whilst the total carbon did not appreciably alter, yet the silicon was reduced by oxidation during the remeltings from 4.2 per cent. to 1.88 per cent., with the necessary consequence of increasing the combined carbon from 0.25 to 2.2 per cent. This of itself converted a very soft into a very hard iron, but the influence of the remelting extended to the other elements as well. The manganese was reduced by oxidation from 1.75 to 0.12 per cent. The sulphur, most probably by absorbing more sulphur from the coke, increased from 0.03 per cent. to 0.20 per cent., whilst the phosphorous was also increased from 0.47 to 0.61 per cent., the latter, no doubt, being due to this element being concentrated into a smaller amount of iron, due to the oxidation of the silicon, etc., and of part of the iron in the repeated remeltings.

It has been proved that by melting the metal in a carefully covered crucible, where no change of composition takes place, the properties of the iron are unaltered by frequent remelting. (4, page 296).

When extra strong castings are required, it is sometimes the practice to introduce wrought iron or mild steel scrap into the cupola. This, compared with pig or cast iron scrap, may be considered to be pure iron. In passing through the cupola in a molten condition it picks up or dissolves its quota of carbon from the coke, but its main effect is that the pure iron thus added correspondingly reduces the proportion of the impurities which would otherwise be contained in the charge. The reduction of the amount of silicon increases the proportion of combined carbon which can be retained in the metal, and thus strengthens the iron, whilst the reduction of the sulphur phosphorous and manganese all tend to the improvement of the quality. It is generally considered that 30 per cent. of wrought iron or steel scrap is the limiting amount which can be thus used, but larger quantities have been successfully Boiler plate scrap is a suitable form to use, whilst employed. old steel rails cut into suitable lengths for handling are sometimes employed. The increase of strength obtainable by using wrought iron or mild steel scrap, is said to be as much as 30 per cent., and even more than this is sometimes claimed. It

is sometimes feared that the use of so much scrap will reduce the fluidity of the molten metal, and render it difficult to cast, but in cases where it is regularly employed no difficulty of this kind is met with.

Iron castings are always smaller than the patterns from which the moulds were made. When cast iron first solidifies as it cools from its molten condition, it expands slightly. This property enables it to take and retain a sharp impression of the mould. At the moment of solidification it is red hot, and subsequently as it cools it gradually contracts. Careful experiments show that some irons have a second slight expansion when cooling after solidification, due to the formation of some of the special constituents (pearlite and phosphide eutectic), but, on the whole, there is a considerable contraction. This varies from 1-10th to 1th of an inch per foot of lineal measurement. The actual amount varies not only with different irons, but also with the same iron in accordance with the dimensions, shape, etc., of the casting. Thick castings contract less than thin ones when made of the same iron, partly, perhaps, because with thick castings it is possible to "feed" them during solidification, either by special "feeding" heads or from the casting gates. These being made of larger section than the casting, cool more slowly, and the contents in their centres remain fluid, and are thus able to partially compensate for the contraction taking place in the casting.

The contraction of large castings necessitates a considerable amount of care in the construction of their moulds. These must be made sufficiently strong to withstand the wash of the metal as they are being filled, and also to resist the fluid pressure due to a considerable head of fluid metal more than seven times as heavy as water. At the same time they must be so made as to yield to the contraction of the casting as it cools down from the red heat at which it solidifies, otherwise the rigidity of the mould will lead to a fracture of the casting.

The contraction also leads to other difficulties, called *contraction strains*. This is especially the case with castings of complicated forms, and those in which there are wide variations in the thicknesses. In some parts which can readily part with their heat, say thin parts near the outside of the castings, the metal will solidify before other portions which take longer to cool owing to their being thicker and exposing less cooling surface in proportion to their mass, or to being in closer proximity to other hot parts of the casting. These parts which solidify first will naturally commence to contract, their shrinkage will somewhat compress the hotter portions, which, being still fluid, will yield. When these hotter portions in their turn solidify and contract the colder portions will have cooled so much as to have become strong and rigid, and will not yield to the contraction which is taking place in the hotter portions. The consequence is, either there will be a tendency for "draws," that is to say, actual ruptures at the junctions of the two portions, or, if such do not occur, the metal will be in such a state of stress as to be less able to bear the loads which will come upon it in use. The designer should, therefore, strive to arrange that the cooling should be as uniform as possible throughout the casting, whilst the founder must arrange that the mould must be able to yield to the contraction of the casting without setting up undue strains on it during the cooling.

Cast iron is used for a very large number of different purposes. For some, the chief property required may be resistance to corrosive influences, other desirable properties are strength, either tensile, compressive or resistance to cross breaking, hardness or resistance to wear, rigidity which might be considered to include permanence of form and dimensions when subjected to the working conditions. Sometimes softness is desirable, as in cases where much machining has to be performed. These various qualities afford considerable scope to the founder to employ irons which are suitable for the purpose. They also give much anxiety to the engineer, who has to depend upon cast iron, and who is often perplexed in deciding upon a reliable method of testing whether the castings supplied are really such as comply with his requirements.

At first sight it might appear that questions regarding strength could easily be settled with precision. This, however, is not the case. A thick part of a casting never possesses exactly the same qualities as a thin part, both thick and thin, therefore, never can be represented by a single test piece. Then, again, a test piece which has been cast attached to, and therefore, near to a large casting, will necessarily be subjected to cooling conditions differing from those of a similar test piece cast separately. In general, engineers who have to deal with large castings which have to be subjected to strenuous use, prefer to rely upon past experience as to the composition of the iron best suited for the purpose, and then, in order to ensure that the required quality is used, to require the test pieces to be cast in a separate moulding box, in a definite manner, care being taken that these

pieces are cast from the same charge of molten iron from which the important casting is made. It is generally stipulated that the iron for the test pieces is to be taken from the casting ladle when the charge has been about half poured.

The influence of the thickness of section of a casting upon its strength has been appreciated for many years. So long ago as 1847 (11) a Commission was appointed by Parliament to enquire into the application of iron to railway structures. Their report, which was made in 1849, is most interesting and instructive. It contains an immense amount of information about iron, including accounts of what were probably the first experiments ever made upon the effects of often repeated impacts and other applications of stress. As regards the influence of size of section upon the strength of cast iron, it says that if the standard of strength is assumed to be that of 1 inch square bars, then bars of 2 inches square and those of 3 inches square in section will have only  $\frac{2}{3}$  and  $\frac{3}{5}$  respectively of their computed strengths. It records that by planing  $\frac{3}{4}$  inch square bars out of the centre of 2 inch and 3 inch bars, the central portion was found to be only  $\frac{7}{12}$  as strong as a similar  $\frac{3}{4}$  inch bar planed from one 1 inch square. It follows that the strength of castings should be computed from bars as thick as the thickest part of the casting.

The next question which arises is as to how the strength is to be tested. If crushing strength is required there is no special difficulty, but where a definite tensile strength is required very exceptional care is necessary to ensure that the test piece is so made, and so put into the testing machine that the pull put upon it is accurately central throughout its length. Owing to the unyielding nature of cast iron, a slight inaccuracy in this respect, which would be of no practical importance when testing a ductile material, such as wrought iron or mild steel, will give a result much less than the actual strength. It may be noted that errors of this description invariably show a deficiency of strength, never an excess.

The most usual tests for cast iron are cross bending tests. These can be made with reliability without the excessive care needed for making tensile tests, but even with these tests it is important to note that the knife edges upon which the ends of the bars rest are perfectly parallel, and that the bars bear equally across their width, otherwise a twisting, as well as a cross breaking stress, is set up in the test bars. Such test bars are usually tested as cast, that is to say, they are not machined, but machined bars are occasionally specified. A

usual size of bar is 3 feet long, with a cross section of 2 inches deep and 1 inch broad. Sometimes shorter bars—1 inch square in section—are used.

The recorded tensile strengths of cast iron are many and are very varied. Some experiments have given as low as 5 tons per square inch, whilst others have yielded figures as high as 18 and 19 tons. Probably 9 tons per square inch is as high a strength as may be relied upon for ordinary castings, but where special iron is used much higher results can be regularly obtained.

As a general rule the higher tensile strength and greater hardness of cast iron is accompanied by a loss of toughness; or, in other words, an increase of brittleness, but this is not necessarily always the case. Special cast irons are being regularly made for specific purposes which require high tensile strength and great toughness. In these cases, it need hardly be mentioned, very special attention has to be paid to the chemical composition of the iron used. The chemist is here of at least as great importance as the founder.

In testing for hardness, new conditions arise. A very interesting and instructive report has recently been made by the "Hardness Test Research Committee " of the Institute of Mechanical Engineers (6). This Committee reported upon several methods used for determining the hardness of materials. They found that, although various methods of testing for hardness gave useful information, yet the results of different methods did not always agree amongst themselves, inasmuch as they really tested different things. For instance, the Brinell Hardness test measured the comparatively large indentation made by a hard steel ball 10 m/m diameter, loaded with 3,000 kg, whilst the Shore scleroscope record depended upon the minute deformation produced by dropping a diamond point loaded to only 40 grains through a height of not more than 2 The rebound is observed, and it is considered that the feet. work done in making the indentation is proportional to the difference of the heights of the drop and of the rebound. It may easily be appreciated that the Shore scleroscope, however useful it may be for testing a homogeneous metal, is unsuited for dealing with a heterogeneous mass, such as cast iron is seen to be when a smooth or polished surface is viewed under a microscope. If the diamond point falls upon such particles as the cementite or the phosphide eutectic, the result will be a

higher rebound than if it falls upon the softer ferrite, and especially so than if it should happen to fall upon a graphite flake.

The subject of hardness as affecting the wearing of cast iron has recently been discussed by Mr. J. E. Hurst (3) at a meeting of the Manchester Association of Engineers, and by Messrs. P. H. Smith and H. Primrose (7) in The Petroleum World. In both cases the wear of cylinder liners and piston rings was dealt with. Mr. Hurst, after pointing out that cast iron is a conglomerate of graphite, ferrite, cementite, and phosphide eutectic, states that on microscopic examination of worn cylinder liners the surface is found to be more or less covered with small pits or holes, and that it is invariably found that the harder constituents (phosphide eutectic and cementite) stand out in He says that the pits or holes are often thought to be relief. holes from which the coarse plates of free graphite have been detached, but that this is not the case, for careful microscopical examination shews that they are the result of the detachment of whole grains of a constituent torn out of that particular portion of the surface of the liner. He attributes this tearing out of the grains to the very low inter-crystalline cohesion of the mass. He points out that it is possible that the hard projecting portions serve as a direct support of the load coming on the surface, and the minute hollows between them serve as reservoirs for evenly distributing the lubricant over the whole surface, but eventually the hard grains are loosened, and then detached from the surface. The debris resulting from the surface disintegration of the liner is a contributory cause of fur-He considers that the cast iron having the highest ther wear. inter-crystalline cohesion, otherwise the highest tensile strength, will possess the greatest resistance to surface disintegration, and consequently to wear.

Messrs. Smith and Primrose (7), dealing with the same question, have come to conclusions in some respects in accord with those of Mr. Hurst; but they think that the hardness or softness of the iron *per se* is not so important as the micro-structure. They say that excellent results have occasionally been obtained with liners made of soft iron. They advocate the use of an iron in which there is a minimum of structurally free graphite in large separate flakes. They, however, are convinced that the wear in Diesel engine cylinders, in which very stringent heat conditions are met with, is intimately connected with the "growth" of cast iron, which growth is itself largely dependent upon the graphite content of the iron. This subject of "growth" will be dealt with later on.

Mr. Hurst (3) gives some reasons for discounting the value of the Brinell hardness test when applied to cast iron. When no one test appears to give universal satisfaction, it may be wise to adopt either the one which gives the least controversial results, or the one most readily applied. The Brinell hardness test appears, on the whole, to be a very useful one to employ in the workshop and in the foundry, when a suitable iron for a specific purpose has been determined upon, even although the results it gives are not absolutely concordant with resistance to wear in ordinary use. The work in a foundry must necessarily always be mainly the manufacture of articles for definite use, in contradistinction to those required for scientific research. When the latter has settled the best iron to be used for any definite purpose, the Brinell test will readily indicate any serious departure from the desired standard.

It is surprising that tests for "toughness" of cast iron have been so little used in this country. They have, however, been in regular use in important works in France and Belgium. In France the Railway Administration has standardized a form of impact-testing for this purpose.

Test pieces are cast separately, 40 m/m square in section, and having a length of 20 c/m. These are placed upon two rounded knife edges, spaced 16 centimetres apart, contained in a heavy anvil block, a guided weight of 12 kilos, having its striking portion rounded, is allowed to drop from a height of 28 c/m upon the centre of one face of the test piece. The blow is then repeated until fracture occurs, each successive blow being from a height exceeding by one c/m that previously given. All the blows are given upon the same face of the test The number of blows which have to be given to produce piece. rupture are specified in accordance with the purpose for which the material is intended to be used. For ordinary work they commence at 28 c/m drop, and must sustain the number of blows necessary to include a final drop of 31 c/m without rupture. For very special purposes the blows, still commencing at a drop of 28 c/m, must not cause rupture until a drop of 45 c/m has been withstood. This method of testing by a succession of blows of increasing intensity has not as yet become common in this country. A somewhat similar impact test, by a number of blows, has, however, been used for steel forgings,

but in this case the blows are all of the same intensity, and are delivered alternately upon opposite sides of the test pieces.

Amongst the qualities which have been referred to as being desirable in iron castings, one was mentioned as rigidity, or power of maintaining form and dimensions permanently when subjected to its ordinary working conditions. This was incidentally alluded to when referring to the remarks of Messrs. Primrose and Smith upon the wear of Diesel engine cylinder liners, they referring to what is generally known as the "growth" of cast iron.

The fact that cast iron, under certain heat treatments is found to grow has been known for very many years. Mr. W. H. Hatfield (9), who has devoted a chapter in his book to the subject, states that the fact of considerable growth occurring in crude iron whilst being annealed was communicated to the Royal Society so long ago as 1791. He also states that Dr. Percy, in his classical book on the metallurgy of iron and steel, mentions a practical application of the phenomenon, as advantage was taken of the permanent increase of volume which cast iron acquires by long exposure to high temperature in rendering cannon shot serviceable which had been cast too small. The matter was brought to serious notice by Mr. A. E. Outerbridge, of Philadelphia, in 1904, and was very exhaustively investigated by Professors H. F. Rugan and H. C. H. Carpenter (10) in 1909.

The latter authors made their experiments at a higher temperature than 600° C. They state in a footnote " that, although " they found no permanent expansion of cast iron after heating " for three hours at 600° C, they are aware that if the heating " is sufficiently prolonged a growth has been found to take " place at much lower temperature; e.g., cast iron valves, sub-" jected to superheated steam at 366° C, increase in size per-" manently. The length of time required for this, however, is " such as to suggest that the phenomena are different." Both the excessive growth at high temperatures, and the much less growth at lower temperatures, will be referred to. The latter is by far the more important, as it is only this which comes into operation in ordinary engine constructions.

As regards the larger growth at the high temperatures, many experiments were made by the Professors with bars of several kinds of cast iron. It was found that with an ordinary grey cast iron no change was observed after three hours' heating at 600° C. At 650° C no alteration was observable after one hour's heating, but a very slight expansion was observable after two

hours. At about  $730^{\circ}$  C the maximum growth took place in about three hours; at higher temperatures up to 900° C no greater rate of growth was observed than at  $730^{\circ}$ , and at any particular heating the growth was not perceptibly greater in 17 hours than in two hours. It appeared that for continuous growth, cooling and heating alternately were required. After 99 heatings the iron in five different sets of experiments increased in volume by amounts varying from 35 to 37.5 per cent.

The experimenters found that white iron did not grow. They explained their view of the cause of the phenomena observed. The grev iron experimented upon was composed structurally of

1. Ferrite, consisting of a solid solution of iron silicide in iron and manganese.

2. Graphite.

- 3. Some combined carbon in pearlite.
- 4. Phosphide eutectic.

With repeated heating the carbon of the pearlite tends to pass into graphite. The phosphide eutectic apparently has no action in the matter.

The explanation suggested is that, during the first heating, gases penetrate to a certain depth, but get no farther in 17 hours than in three. They probably pass along slits existing between the graphite plates and the adjacent solid solution of silicide in iron, but they are not actually absorbed or combined with the metal until the cooling. When this takes place the oxides of carbon present in the gases oxidize the metal at the boundaries of the crystals, forming silica and oxide of iron, and thus initiating growth and incipient disintegration of the iron. At the next heating the gases penetrate a little farther, and on cooling the reactions are repeated, and further disintegration and growth occur. These operations are repeated continuously, with the result that the enormous growth which has been stated occurs. Some of the graphite becomes burnt The disintegration is caused by the formation of iron off. oxide and silica, which occupy more space than the metal from which they have been formed. It was observed that not only was the volume increased, but the weight also was augmented by about 8 per cent., this being due to the combination of oxygen with the iron and silicon.

It may be mentioned that iron which has "grown" in this manner is utterly ruined for structural purposes.

Reference will now be made to the "growth" which is said to take place although to a much less extent when cast iron is subjected to much lower temperatures, such as may occur in steam engines using high pressure or superheated steam.

It was stated in the newspaper article referred to (1) that a case is known where a cast iron steam turbine casing had grown 7 per cent.

Mr. Hurst (3) states that cast iron fittings, such as pipes and valves, on superheated steam mains, after considerable service, have been found to deteriorate seriously, the tensile strength falling off, permanent distortion and changes of volume occur, and sometimes cracks become developed.

Mr. Hatfield (9) devotes a chapter to this subject. His conclusions are that the case of growth at these temperatures is not proved. He points out that, although tests taken from fittings that have failed after use have shewn surprising irregularities of strength in the same castings there is nothing to prove that the fittings when new did not possess an equal lack of homogeneity. He mentions that small increases of temperature appreciably reduce the strength of cast iron, which, however, returns to its normal strength when it cools again, and that at high temperatures, therefore, fittings might be too weak, although tests made when they are cold would indicate that they were sufficiently strong. He gives instances where cast iron fittings have given prolonged satisfactory service under a high degree of superheat, and he therefore concludes that such fittings will not develop flaws if they are of correct configuration and cast sound. He points out in this connection that anyone accustomed to practical foundry work will appreciate the severe internal strains that are set up in castings of certain configurations during cooling alone.

Professor Carpenter (1 and 2) pointed out in his recent lecture that even at the high temperatures at which he and Professor Rugan had previously experimented, the growth depended upon the composition of the iron, and he said that with cold blast low silicon iron the growth would probably be not more than one quarter of the amount which would occur in high silicon hot blast iron. Possibly some differences of this kind have occasioned the divergency of views as to the growth and change of properties of cast iron at the superheater temperatures under consideration. When we are considering the probable effect of "growth" in internal combustion engines, we are again met with a divergency of opinions amongst those who have considerable experience.

Messrs. Smith and Primrose (7) are quite convinced that the wear of cylinder liners in oil engines is partly due to "growth." They adopt the theory that the hot gases penetrate between the graphite plates and the adjacent grains of metal, oxidizing the latter, the increase of volume of the oxidized portion tends to loosen the grains, which are thus more easily torn out; and when they are detached these serve to further abrade the surface. To reconcile this with Professors Carpenter and Rugan's idea, it would be necessary to suppose the surface temperature to rise above 700° C. Mr. Hurst (3) attributes the wear to a similar tearing out, or detachment, of metallic grains, but he does not give credit to "growth" for any part of this action, attributing it entirely to low inter-crystalline cohesion.

As regards the temperature which the cylinder surface actually attains during working, Mr. Hurst states that the liner itself does not become unduly heated, owing to the efficiency of the cooling arrangements. At the same time, its inner surface is approximately from 200° to 300° C, which figures are very considerably below the temperatures which the Professors previously quoted consider to be critical.

Whilst referring to Diesel engines, it may be mentioned that Mr. Hurst states that the crowns of the pistons of gas engines become raised to a dull red heat, and that those of Diesel engines attain still higher temperatures. (This must refer to air-cooled pistons only, as these temperatures cannot be attained where water-cooling is used.) When pistons are thus overheated they become pitted and scaled in the overheated area, and then frequently fracture by star-shaped cracks, which radiate from the centre of the heated areas.

In this case he is of opinion that the phenomenon is not the same as the "growth" which Professors Carpenter and Rugan dealt with, because it is found that the metal, although weakened at the graphite plates, does not become oxidized, except in a superficial layer. He considers that the cracking is mainly due to the phosphorous contents, and states that if this is kept low, cracking is practically eliminated; and further, he remarks that it is certain that at high temperatures high phosphorous cast iron is considerably weaker than low phosphorous cast iron.

The influence of temperature on the strength of cast iron has not been thoroughly investigated. Mr. Hurst (3) gives a table, taken from *Stahl and Eisen*, from which it would appear that the strength is not very materially reduced at temperatures up to  $300^{\circ}$  C, but falls to one half at  $620^{\circ}$  C and to about one quarter at  $800^{\circ}$  C; but the kind of iron to which the table refers is not stated. Part of the same table is quoted by Mr. Hatfield (9), who also has omitted to give any particulars of the composition of the iron tested.

Contraction strains in castings have been more than once referred to in this paper. In the case of mild steel castings, in which the shrinkage is considerably greater than in cast iron, these strains are very severe, and occasionally cause ruptures before the casting has been put into the annealing furnace. As has been mentioned, they are caused by different parts of the casting cooling at unequal rates. When the casting has been put into the annealing furnace, its temperature is slowly raised to that desired for annealing, care being taken that the heating is so gradual that it is always practically uniform throughout the casting. The high temperature is maintained for some time; the source of heat is then shut off, and the casting is allowed to slowly cool down. This process of annealing is necessary to improve the quality of the material, altogether irrespective of the desirability of removing contraction strains; but incidentally, if it is properly carried out, it entirely removes When the steel is at the highest temperature it is soft them. and yielding; any portion subject to stress has the stress relieved; and the subsequent uniform cooling is necessarily accompanied by a uniform contraction, which will leave no initial stresses in the casting.

With east iron the same causes produce strains in the castings as they would in similar castings in steel, and possibly in some cases, owing to the less extensibility of cast iron than mild steel, the strains may even be more severe. The question arises —can they be relieved in a similar manner by annealing? Unfortunately, the answer is in the negative.

Castings for engineering purposes must be more or less grey; that is, they must contain graphite. White irons, in which all the carbon is combined, would be too brittle to employ, even if they could be cast sound in the intricate forms in which they have to be used. Mr. Hatfield (9) records experiments in which annealing of grey irons has been carried out, with disastrous effect so far as strength is concerned. He states that the microstructures of the treated samples afford a complete explanation of the considerable loss of strength, and emphasise the detrimental effect of annealing such irons. The strength of grey cast iron depends largely upon the pearlite it contains; by annealing, part at least of the carbide in the pearlite becomes dissociated. Its carbon, thus rendered free, is drawn into positions alongside the already existing graphite plates, the consequent swelling of which further weakens the iron, already rendered weaker by the loss of its pearlite. Any advantage, therefore, which might occur by the lessening of initial stresses is more than counterbalanced by the severe deterioration of the quality of the material which takes place.

Some attempt is made to "anneal" important castings, such as large turbine casings, by subjecting them, by the means of steam, to as high a temperature as, or to a slightly higher temperature than they will be subjected to in use before the final machining is done. It is found that by this means they do slightly change form, and so relieve some initial strains, and it is, of course, advisable that any change which will take place on heating should be dealt with before the final boring out, especially in view of the great precision of form which is required in turbine engines to permit sufficient, but not excessive, clearances of the numerous blades.

Enough has been given to shew the very great importance of a knowledge of the properties of cast iron to engineers, and not only a knowledge of what is possible, but also of how to obtain it with certainty. It is very remarkable that, although cast iron is one of the oldest constructive materials used in large engineering undertakings, yet the knowledge of its capabilities is no greater now than it was a century ago; whereas with the newer material, mild steel, increased knowledge of its properties, and with it, of course, increased capabilities for its advantageous use, are being continually obtained through the attention given to it by steelmakers, constructors, and scientists. The stress of war conditions is leading to more attention being given to cast iron, and much is to be expected from the research which it is understood is to be undertaken by the Engineering Committee of the National Advisory Council for Scientific and Industrial Research, under the guidance of the President of the Institution of Civil Engineers.

# Appendix.

The following are some Analyses of Pig Iron, which may be taken as typical of the iron made in the different districts (9):—

				Graphite.	Comb. C.	Silicon.	Sulphur.	Phosph.	Man- ganese.	Copper.
No. 1				3.75	0.30	2.60	0.02	0.045	0.20	0.04
No. 2				3.20	0.46	2.40	0.03	0.045	0.20	0.04
No. 3				3.25	0.54	2.10	0.04	0.045	0.50	0.04
No. 4				2.80	1.00	1.65	0.10	0.045	0.20	0.04
No. 5				2.40	1.60	1.20	0.20	0.045	0.20	0.04
Mottled				1.6	1.95	0.90	0.25	0.045	0.20	0.04
White				Trace	3·25	0.65	0.30	0.045	0.10	0.04
н	Æ	М	ATI	TES, SC	сотсн,	WELSH	H AND	EAST	COAST.	
No. 1				3.725	0.30	2.50	0.02	0.05	1.00	0.05
No. 2				3.525	0.45	2.25	0.03	0.05	1.00	0.05
No. 3				3.150	0.56	2.00	0.04	0.05	1.00	0.05
No. 4				2.750	1.00	1.50	0.10	0.05	1.00	0.05
No. 5				2.450	1.55	1.00	0.20	0.05	0.75	0.02
Mottled				1.500	2.05	0.75	0.25	0.05	0.50	0.05
White				Trace	3.15	0.65	0.30	0.05	0.50	0.05
Special No	. ]	L		3.525	0.30	2.50	0.015	0.03	1.00	0.05
No.	. 2	2		3.350	0.40	2.25	0.020	0.03	1.00	0.05
,, No.	. 3	5		3.000	0.20	2.00	0.025	0.03	1.00	0.05

WEST COAST HEMATTLE	<b>MATITE</b>	HÆM	COAST	WEST
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#### DERBYSHIRE IRONS "RENISHAW."

	Graphite.	Comb. C.	Silicon.	Sulphur.	Phosph.	Manganese.
No. 1	3.41	Trace	2.94	0.04	1.68	0.36
No. 2	3.26	1.79	2.15	0.03	1.62	0.71
No. 3	3.85	0.11	2.33	0.05	1.58	0.57
No. 4 Foundry	3.30	0.22	2.10	0.05	1.77	0.65
Close Forge	2.80	0.33	1.82	0.08	1.73	0.52
Mottled	1.55	1.56	1.20	0.20	1.50	0.35
White	2.65	0.10	0.45	0.25	1.35	0.25
Glazy	3.45	Trace	4.20	0.02	1.60	0.61

#### NORTHAMPTON AND DISTRICT "HOLWELL."

No. 1 Foundry	 3.35		2.61	0.02	1.19	0.49
No. 2 ,,	 3.65	_	2.47	0.04	1.17	0.40
No. 3 ,,	 3.85		2.38	0.04	1.19	0.40
No. 4 ,,	 3.35	*	2.33	0.02	1.25	0.39
No. 4 Forge	 2.97		2.33	0.06	1.09	0.48
No. 5	 1:75		1.37	0.06	0.93	0.24
Mottled	 1.54		1.26	0.22	0.97	0.22
White	 0.84	-	1.05	0.30	0.94	0.19
Glazy	 2.50	-	4.85	0.03	1.28	0.53

## APPENDIX.

## YORKSHIRE COLD BLAST.

	Graphite.	Comb. C.	Silicon.	Sulphur.	Phosph.	Manganes
No. 1	3.42	0.58	1.71	0.07	0.63	1.61
No. 2	3.15	0.58	1.65	0.07	0.63	1.47
No 3	3.36	0.39	1.38	0.06	0.60	1.47
No. 4	3.31	0.32	1.38	0.08	0.60	1.17
STAF	FORDSHIF	E COLD	BLAST '	GLAZEB	ROOK."	
	1	1	1	1		1
No. 1	3.07		1.48	0.03	0.43	0.96
No. 2	3.04		1.27	0.04	0.34	0.80
No. 3	3.12	-	1.16	0.02	0.44	0.94
To. 4	3.03	-	0.83	0.04	0.31	0.27
No. 5	2.81		0.57	0.06	0.53	0.13
	YORKSH	IRE IRO	N "CL	ARENCE.	,	
7. 1	0.02	0.20	9.17	0.02	1.00	0.50
10.1	3.03	0.30	0.17	0.03	1.00	0.50
0.3	3.05	0.30	2.80	0.03	1.97	0.60
o. 4 Foundry	2.99	0.43	2.24	0.06	1.94	0.52
o. 4 Forge	2.75	0.55	1.85	0.10	1.96	0.20
lottled	1.49	1.65	1.27	0.18	1.21	0.40
Vhite	0.10	3.10	0.88	0.28	1.57	0.38
	SCOT	TCH PIG	"CAR	RON."		
Jo 1	3.50	0.14	2.80	0.03	0.88	1.45
Jo 2	3.37	0.25	2.97	0.04	0.91	1.45
Jo 3 Soft	3.98	0.18	2.65	0.04	0.90	1.40
Jo 2 Foundary	0 20	0.20	2.05	0.05	0.91	1.21
to 2 (lloss	0.00	0.20	1.75	0.05	0.00	1.49
to. 4	3.16	0.29	1.57	0.08	0.90	1.45
	LINCOL	Neilide	" DEDE	OUDNE ?		1
	LINCOL	NSHIRE	" REDE	OURNE.		
Io. 3 Foundry	3.10	0.56	2.75	0.04	1.33	1.68
In 4	2.82	0.75	2.61	0.04	1.32	1.59
rev Forge	2.52	0.89	2.51	0.06	1.32	1.46
In A Close	2.46	0.94	9.45	0.06	1.30	1.34
Lottlad	1.19	1.59	1.39	0.10	1.30	1.12
White	0.67	1.02	0.45	0.15	1.90	1.10
vinte	0.01	2.70	0 40	0.10	1.29	1.10

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- (11). Report of Commissioners appointed to enquire into the application of Iron to Railway Structures, 1849.

The CHAIRMAN: In opening the discussion on this paper, I should like to supplement the remarks of the author upon our lack of precise knowledge of the effects of superheated steam upon cast iron. It will be observed that very opposite opinions are held by Mr. Hurst and Mr. Hatfield. It is quite possible that both are right. Professor Carpenter points out that "growth" of cast iron depends upon the composition of the iron, and possibly Mr. Hurst's experience has been obtained with irons peculiarly susceptible to "growth," and, therefore, to deterioration at high temperature. It may be of interest to know that in 1912 a paper was read at the Sixth Congress of the International Association for Testing Materials at New York, by Messrs. Wm. Campbell and John Glassford of the Columbia University upon "The Constitution of Cast Iron, and the effects of Superheated Steam." The first paragraph of their paper is as follows:—

"It has been repeatedly observed that cast iron fittings in superheated steam pipe lines have been subject to a form of corrosion which causes them to swell, become brittle, and fail. The worst specimens completely disintegrate, breaking down to a friable mass which may be crumbled in the fingers. It is also known that other cast iron fittings have been used in superheated steam pipe lines for years without showing signs of corrosion."

This paper draws attention to the work of other investigators. It quotes statements made at Boston by Mr. Ira. N. Hollis in 1909 at a meeting of the American Society of Mechanical Engineers, which are as follows:—

(a) Fittings have developed cracks and small changes of shape after a few months of actual service.

(b) Fittings exposed separately to superheated steam at a temperature exceeding  $500^{\circ}$  Fahr. have shown a permanent increase of some dimensions.

(c) The tensile tests of pieces cut from fittings that had failed in service indicate in some cases the possibility of permanent loss of strength.

He gave the results of six tensile tests taken from different parts of a failed fitting, the strengths as found varying from 5.65 to 12.26 tons per square inch. Mr. Hollis concluded that the failures were due to *strains* caused by expansion and contraction of long pipes, and that the superheated steam had nothing to do with the matter.

Mr. A. S. Mann, at the same meeting, stated that after a short time cast iron fittings used for superheater work grow in size and cracks appear in them, and even steel fittings fail with superheated steam.

He has, however, come across an iron which gave satisfaction in every respect for four years under 300° of superheat. Thinking that the "growth" of iron under repeated heatings had

something to do with failure under superheat he tested a sample of high-grade cast iron which had proved itself capable of carrying superheated steam and one of ordinary cast iron, and he found that the good high-grade cast iron actually "grew" more than the ordinary iron. His ultimate conclusion was that the remedy for the trouble is in the use of a high quality of cast iron.

The authors of the paper made some very elaborate experiments by taking sets of samples of 23 varieties of cast iron, heating them in superheated steam at 800° Fahr. for 30 and for 90 days. Some were also taken and heated in air at the same temperature, being cooled down and reheated 72 times. The conclusions they arrived at were that (1) corrosion of cast iron in superheaters is due to the metal becoming oxidized, following the planes of the graphite plates; (2) with white cast iron, malleable cast iron and medium carbon steel, surface oxidation alone occurs; (3) with cast iron containing silicon there is penetration of oxidation, this following the coarsest of the graphite plates, the penetration increasing with the amount of the silicon; (4) alternate heating and cooling in air results mainly in surface oxidation.

In 1903 a paper was read at the Institute of Civil Engineers by Messrs. Milton and Larke upon "The Decay of Metals." In that paper reference was made to the decay of cast iron when in contact with sea water. They pointed out that sometimes cast iron will resist corrosion in sea water for many years, but some cast irons in these conditions become converted into something more like plumbago than metal. They give representations of microscopic sections of cast iron, one which had re-. sisted corrosion for 22 years, others in which corrosion had In these latter it was seen that the corrosion been acute. travelled along the graphite plates, in a manner similar to the oxidation which occurs when cast iron "grows." No one, as yet, has given a satisfactory explanation of the causes why some cast irons behave so remarkably differently from others when used for sea water purposes, yet this is a matter of vital importance when we consider the very large sea inlet valves used on large vessels, which are always exposed on their inside inaccessible parts to the action of sea water. The failure of one of these would be a very serious matter.

The author of the paper to-night points out the greater attention which is given in France compared with this country to the systematic testing of cast iron. The British Engineering Standards Committee have left cast iron severely alone.

The Admiralty in their specifications require the testing of only such castings as their officers select and give nine tons per square inch as a minimum tensile strength.

The Bureau Veritas has specified both tensile and percussive tests for two qualities of cast iron used for engine purposes. For "superior" quality they require a tensile of 11 tons per square inch; and for "common,"  $7\frac{1}{2}$  tons. Their impact tests are after the plan adopted by the French railways, but not so severe. The other Registration Societies and also the Board of Trade have no regulations regarding cast iron tests. In Germany there are standard cross breaking tests for cast iron for engine castings, and also for castings for buildings, for pillars and for pipes. In America special tests are recognised for locomotive cylinders, for pipes and for ordinary gray iron castings.

The author gives the information that a standard test bar in this country is one 3 feet long 2 inches by 1 inch in section.

Dr. Stead presented a report on behalf of the British section to the New York Congress previously mentioned upon the testing of cast iron. From this report it appears to be important for the English standard cross breaking test to be cast on edge, not on the flat. The German standard cross breaking sample is 30 m/m diameter, the length between supports being 650 m/m  $(23\frac{5}{2}$  inches). It has to be tested with the mark due to the separation of the mould horizontal. For ordinary engine castings the test pieces have to sustain a load of 495 kg., high quality cast iron a load of 600 kg., and the iron used for pillars 460kg. The American practice is to use round test bars  $1\frac{1}{4}$  inches diameter, but with a length of only 14 or 15 inches. For locomotive cylinders a length of 14 inches is used, and the load which has to be carried is 3,000 lbs. For ordinary castings the 15 inch length is used, and the minimum load is 2,500 lbs. both German and American practice a minimum deflection is Experiments made by Messrs. Kirkaldy & Son, and specified. quoted by Dr. Stead, show that with the same iron all three types of test bars, when calculated out by the usual formula, give identical results, but Dr. Stead recommends that, owing to the difficulty of accurately measuring the deflection in the cases of short bars, the length should not be less than 24 inches.

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It is remarkable that, seeing that cast iron is the only material we use for steam cylinders, etc., exposed to high temperatures and high stresses, we have such a small amount of information as to the effect of high temperatures upon its strength and its resistance to deformation. It is hoped that as attention is now being given to the subject we shall soon know more about this useful metal and especially know how to secure the higher qualities in our ordinary work.

The discussion on this subject is open for contributions by correspondence, and Members are invited to forward their views for publication in a subsequent issue. It is also hoped that iron-founders and others who are interested in the subject will express their opinions.

### BOILER EXPLOSIONS ACTS, 1882 AND 1890.

REPORT OF PRELIMINARY INQUIRY (No. 2440.)

(By Mr. D. W. STEPHEN).

## Explosion from a Steam Stop Valve Chest.

The explosion occurred about 9 p.m. on Sunday, the 24th September last, at a colliery. No person was injured.

The chest was made of cast-iron, the body being  $11\frac{1}{4}$  inches in diameter externally, and  $19\frac{3}{4}$  inches in height over the flanges; at the fracture the metal showed a uniform thickness of  $\frac{15}{16}$  inch. There was one branch 7 inches in diameter to which the steam pipe was attached. The valve, spindle and seat were made of brass, the valve being loose on the spindle and 7 inches in diameter. Two wrought-iron columns secured to the cover supported a crosshead through which the spindle worked by a screw having an ordinary thread. No. 9 boiler, together with its mountings, was purchased by the Company in 1907, but I have been unable to obtain any reliable information regarding the previous history of the valve chest. The name of the maker and age of the chest cannot therefore be stated. No repairs to the chest have been required.

All the boiler mountings were examined annually by an inspector for the Insurance Company, the last occasion being on the 28th December, 1915. They were also under the daily supervision of the engineer at the colliery. The valve chest was insured with the Vulcan Boiler and General Insurance Company, Limited, Manchester.

The body of the valve chest fractured circumferentially through the solid metal, immediately below the top flange. The cover, together with the valve, spindle and wheel, were projected through the roof of the shed, and fell on top of the adjoining boiler. The steam pressure at the time is stated to have been 70 lbs. per square inch. The explosion was due to water-hammer action in the steam pipes, caused by the opening of a drain cock when the pipes were partly filled with the water of condensation, and steam at boiler pressure. The steam plant at the colliery consists of three boilers of the Lancashire type, known as Nos. 4, 8 and 9. At 3 p.m. on Saturday, the 23rd September last, No. 9 was laid off for cleaning, the main stop valve being kept closed, as the remaining boilers

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were under steam. On completion of the cleaning the boiler was again got ready for use, and shortly before 6 p.m. on Sunday, the 24th, the fire was lit. At 9 p.m. there was a steam pressure of 70 lbs., and as this corresponded with the pressure on the two other boilers, the fireman on duty prepared to connect up No 9. Before doing so, he opened the drain cock attached to the steam pipe, in the position shown on the plate; he stated in evidence that he did this very gently, but apparently he must have opened the cock wider than he intended, as he immediately heard what he described as two loud "thumps" in the pipe, and simultaneously with the second, the cover of the stop valve was blown off. The main range of steam pipes ran at right angles to the boilers, and about 2 feet 6 inches above them, short branches connecting up with Nos. 4 and 8. On No. 9 boiler, however, owing to the position of the stop valve, a considerable length of pipe was necessary to make the connection; this pipe drooped gradually towards the stop valve which was about 1 foot 2 inches below the level of the main range; a drain  $\operatorname{cock} \frac{3}{4}$  inch diameter was fitted at the lowest part of the pipe. As already stated the stop valve on No. 9 boiler was shut at 3 p.m. on Saturday, the 23rd September, so that 30 hours elapsed before the drain cock was opened by the fireman. The condensation in the steam pipe during that time must have been considerable; this water would remain in a state of rest until disturbed by the opening of the drain cock, when it would be set in motion, causing waterhammer in the pipe, the full effect of which would be felt at the stop valve.

The new stop valve, fitted since the explosion occurred, has been raised to the level of the main range, thus avoiding the fall in the line of pipes which would always have remained a source of danger.

#### Observations of the Engineer Surveyor-in-Chief.

The explosion was clearly due to water-hammer action set up by draining the pipe while under steam pressure, the danger of which procedure does not appear to be generally realised by men of the class usually charged with the manipulation of valves and cocks in steam pipe installations, and the owners of the plant in the present instance have prudently altered the piping in such a manner as to reduce the chance of water accumulating in the pipe, thus minimising the danger which might arise from the ignorance or carelessness of the boiler attendant. Thos. CARLTON.

### BOILER EXPLOSIONS ACTS, 1882 AND 1890.

REPORT OF PRELIMINARY INQUIRY (No. 2443.)

(By MR. ROBT. STEVENSON.)

## Explosion from a Steam-Heated Cast Iron Press.

The explosion occurred about 11.30 p.m. on the 5th October last, at works near Manchester. No person was injured.

The press was made of cast-iron. It was 7 feet in length, and 3 feet 7 inches in width, depth of body and jaws 1 foot 2 inches, and depth over compression screws 3 feet 3 inches. The body was in one piece, the lower portion being hollow, while the upper part consisted of two jaws, with a division piece between which formed two spaces wherein the material was placed, when being moulded. The ends and sides of the hollow part were  $1\frac{1}{2}$  inches thick at the thinnest part, the flat surfaces being of the same thickness and supported internally by one longitudinal stiffening bar 11 inches thick, and seven transverse stiffening bars 1 inch thick, the centres of the stiffeners having cored holes 2 inches deep, and  $6\frac{1}{4}$  inches and 1 foot  $2\frac{1}{4}$  inches long respectively. The jaws and division piece were 6 inches in depth and 3 inches thick, each jaw had twenty-four  $\frac{1}{2}$  inch screwed holes in the side for the use of set-pins to screw the material when being moulded against the division piece. while to press the material against the flat surface of the machine were eight strong backs, each composed of two iron bars, 1 inch thick and 4 inches deep, bolted together with distance pieces between and supported by screwed stays  $1\frac{1}{2}$ inches in diameter. Four compression screws,  $1\frac{1}{4}$  inches in diameter, were supplied for each strong back, these screws being swelled at the top end to 3 inches diameter, and having a hole  $1_{\frac{1}{16}}$  inch in diameter for the use of a toggle; they were each passed through a flanged nut which was fitted between the bars composing the strong back. An inlet and an outlet, 1 inch in diameter were provided, and by means of a T-piece so arranged that steam or water could be passed through the machine together, or separately as desired.

The press was made by the owners at their works, about October, 1913. It was therefore about three years old. No repairs have been made to the press. It was tested by waterpressure to 300 lbs. per square inch before being put into use

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about three years ago. It has been examined superficially almost daily by the works engineer. The press was not insured.

The bottom of the press was almost completely blown out, and broken into four or five pieces, the force of the explosion being sufficient to cause the machine to partly turn round until it rested on its side. The constant heating and cooling, and consequent expansion and contraction of the cast-iron of which the machine was made, no doubt caused fatigue of the metal which ultimately failed under ordinary working conditions.

The hot-press which failed was used for moulding fullerboard and mica cells used in connection with the insulation of electric It appears that the time taken to complete the operplant. ation of moulding depends altogether on the depth of the material, the greater the depth, the longer it has to remain in the press before it is properly set. The material to be treated is placed between the jaws with bars of iron between each unit and held in position by means of the side and strong-back Steam is then turned on, passing through the body screws. of the press, and escapes by the waste pipe at the end opposite When the material under treatment that at which it enters. has been thoroughly heated, the steam is shut off and cold water is passed through the press until it is cooled, the operation being then complete.

It appears that on the night the explosion took place, the man in charge of the press, started to charge it about 9.30 p.m.. It was charged about 10.30 p.m., when steam was turned on. It was still under steam at 11.30 p.m., and he states that he was standing about three yards distant from it when he heard two distinct bumps which sounded as if coming from the press; he stepped towards the press and, without further warning, it burst with a loud report. The escaping steam prevented him from seeing what had happened until he had turned it off at the control valve of the department. On returning to the press, he found that the bottom had been blown out by the force of the explosion, that it was broken into four or five pieces and was lying under the press, the body of which had been partly turned over and was resting on its supports on its side.

The steam is supplied to these works by six Babcock and Wilcox boilers, the working pressure of which is 180 lbs. per square inch. The press in question is some considerable distance from the boilers, and it is stated that the maximum pressure at the press is 160 lbs. per square inch. Records of

### EXPLOSION FROM A CAST IRON PRESS. 37

the steam pressure carried in the boilers is kept, and, from the diagram shewn to me when I visited the works, the boiler pressure at the time of the explosion was apparently 175 lbs. per square inch. It is stated that the design of the press was one which had been in use in these works for over 14 years, and prior to that time was in common use in the firm's American works for a great number of years. The press was built to withstand a working pressure of 160 lbs. per square inch, and when new about three years ago, was tested by hydraulic pressure to 300 lbs. per square inch.

When I visited the works almost a month had elapsed since the explosion had occurred. The owners, it appears, were unaware that the accident came under the Boiler Explosions Acts and consequently did not report the failure of the press until after it had been scrapped. I am, therefore, unable definitely to state what was the cause of the explosion. The machine, however, was subjected to very severe working conditions by the constant heating and cooling, and it seems probable that the fatigue of the material, due to the consequent expansion and contraction, in time caused its failure. I am informed that it is the firm's intention periodically to test all their steam presses by water to double their working pressure at least once in every 12 months.

### Observations of the Engineer Surveyor-in-Chief.

As the ruptured press appears to have been destroyed without a careful examination of the material where fractured, it is uncertain whether its failure was hastened, as it may have been by latent defect. Although it is said that presses of this type have been successfully employed for several years, danger from the unreliability of the castings under the treatment to which they are subjected is incurred by their use, and this is not entirely eliminated by a periodical test, which nevertheless is a wise precaution.

THOS. CARLTON.

## Notes.

In connection with the remarks made in the course of Mr. J. H. Anderson's contribution to the discussion on Mr. MacArthur's paper, the following is a copy of the advertisement *re* By-products from Coke Ovens :—

Otto Coke Ovens.—By-product ovens erected at the Company's own cost, taking in payment the by-products for an agreed period. For further particulars, address the Otto-Hilgenstock Coke Oven Co., Ltd., 4, Southampton Row, London, E.C.

The following-named papers have been contributed on the subject of fuel, and indicate the widespread interest taken in the economical use of it. The papers are referred to here so that members who wish to study any of the details may know where to obtain them :—

"Use of Powdered Coal as a Fuel," by Mr. Jos. Harrington, read before the Chicago Section, American Society of Mechanical Engineers.

"Coal and Its Economic Utilisations," by Mr. John S. S. Braine Howard (Prof. Chem. R.N. College, Greenwich), lecture, Royal Society of Arts.

"Use of Peat in Gas-producing Plants," by Professor E. C. C. Balby, Liverpool Section, Society of Chemical Industry.

"A Few Words on Coal," by Mr. John H. Anderson, "Grays Co-operative Industrial and Provident Society Journal."

## Election of Members.

Members elected at a meeting of the Council held on Tuesday, February 13th, 1917:---

### As Members.

Henry Limon Ford Dring, "Clydesdale," Augustine Street, Grimsby.

Charles L. Fyfe, 39, Park Road, South Wanstead, E.

Joseph Esau Spurgeon, No. 8, Rue Marine, Alexandria, Egypt.

James Stirling, 22, Milner Road, Jordanhill, Glasgow.

David Malcolm, 2, Lynford Gardens, Seven Kings, E.