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MECHANICAL AND CHEMICAL TESTS FOR THE FOUNDRY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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CHEMICAL AND MECHANICAL TESTS IN THE FOUNDRY.

The process of molding or of obtaining definite shaped pieces of a metal by pouring it while in a molten state into sand or earth molds, of the required shape, is very ancient, dating back without doubt to prehistoric times. From the savage of centuries ago with his precious bit of native copper melted in the hollow of a rock in the fire and poured into the impression of his stone spear head in the sand, to the modern foundry with its many tons of iron, made into huge castings daily, and its appliances for lessening labor, is a very long step; and one which was not made hastily. In fact, until within the last two decades, the improvement and development of the various phases of foundry operation have been extremely slow. While in other branches of engineering industry, development has been logical and rapid, the foundry has received but a small amount of the attention which it has deserved. This is especially true of the regulation of the quality of the iron. The usual method was to put the cupola in charge of a man experienced in judging the character of iron by the appearance of its fracture, and who depends upon the grades of iron as given by the iron makers and upon his knowledge of the results of former heats, in mixing his iron so as to obtain the required results.

During the last ten or fifteen years, however, committees of investigation appointed by such engineering bodies as the American Society of Mechanical Engineers, and the American

Foundrymen's Association, have conducted exhaustive experiments having as their object the development of methods of determining mixtures of iron before melting, so as to obtain a product having certain definite properties. Among the most prominent investigators in this field, are Messrs. T. D. West and W. J. Keep: and it is from reports of their work during the past fifteen years, that much of the information in this thesis was derived. Mr. West has devoted himself to a study of the relations between the chemical and physical properties of cast iron, and a regulation of iron mixtures by chemical analysis, while Mr. Keep has endeavored to devise simple mechanical methods for obtaining the same end. Both gentlemen have conducted a large number of tests and their reports comprise a very complete exposition of the subject.

It is the purpose of this thesis to present the more important conclusions reached by such authorities, to detail the equipment for a chemical laboratory such as might be installed for use in connection with a rather large foundry, to present as briefly as possible, the latest methods of chemical analysis, and to give an account of some tests conducted by the writer at the University of Illinois.

THE CONSTITUENTS OF CAST IRON, AND THEIR EFFECT ON ITS PHYSICAL PROPERTIES.

Cast iron contains about 92 to 96% of pure iron; the balance being impurities, of which silicon, sulphur, carbon, phosphorous and manganese are the most important. While these are essential to good cast iron, an excess of their total over 6% is generally injurious to the strength of the iron. The effects of these elements upon the character of cast iron are here given for each constituent under separate heads.

SILICON

Silica, SiO_2, occurs in all iron ores, and is reduced in the blast furnace to silicon, which is absorbed by the iron. It alloys with iron in all proportions up to 10%, and by special treatment up to 30%, forming ferro-silicon. Silicon's chief office in cast iron is that of a softener. It accomplishes this result by reducing the total amount of carbon which iron may take up and by causing the carbon to remain in the graphitic form instead of combining with the iron. Owing to this fact, silicon is a great element in cheapening iron mixtures, as by using a small quantity of high silicon iron, a large amount of scrap iron may be used and soft iron may be obtained. Four percent of silicon pig can often carry 80% of ordinary scrap to make soft castings in work over one inch thick. The use of very high silicon iron in small quantities should be avoided however, as a small error in the amount used would produce a great change in the properties of the resulting

iron. Silicon is seen to be a very good thing, but if carelessly used it can do more evil than good. It has found such favor with some, as to make them regardless of any other element in iron, which is a decidedly harmful practice from the fact that one part of sulphur can neutralize the effect of from ten to fifteen parts of silicon. TABLE V, taken from Mr. Thos. D. West's Metallurgy of Cast Iron, page 151, gives the necessary increase of silicon in a 2% silicon iron to preserve the same hardness in similar castings for each increase of .01% sulphur. Hence it is essential that sulphur should be as carefully watched as silicon; and the same may be said with regard to phosphorous and manganese, as all should be considered in mixing iron. Silicon and sulphur however, should be considered the bases for changing the character of the iron, phosphorous and manganese remaining practically constant under given conditions. The influence of silicon is indirect, as it acts through the carbon contained in the iron, and is modified by the various conditions attending remelting and cooling of the iron. The more total carbon or the less combined carbon, the less silicon will be needed for a given effect. Little silicon acting a long time as in large, slow cooling castings will have a similar effect to that of a larger amount of silicon acting quickly in small rapid cooling castings. From 2 to 3.5% of silicon will change all of the combined carbon into graphitic that can be changed. An increase in silicon will usually be accompanied by an increase in fluidity, and a decrease in shrinkage.

Remelting iron usually decreases the silicon by oxidation, the amount varying as the blast is stronger and the fire hotter. The loss of silicon in remelting varies from 0.1 to 0.3%.
Mr. W. J. Keep discovered in 1888 that the variation in shrinkage of iron test bars, indicated the variation in the influence of silicon in reducing combined carbon. The shrinkage decreases as silicon increases, other conditions being equal, as is shown in TABLE I, which consists of extracts from a table on page 48, of Mr. Keep's book, "Cast Iron".

SULPHUR

Sulphur is mainly derived from the fuel used in smelting the iron, and consequently charcoal iron is low in sulphur while irons smelted with coke or coal are higher.

Iron has a strong affinity for sulphur, and readily absorbs it from the fuel used in remelting, thus causing an increase in its percentage. Coke used in cupolas often contains as high as 1% of sulphur, the majority of which goes into the iron, increasing the percentage from .01 to .06%.

Sulphur is the most injurious constituent of cast iron with which the foundryman has to deal. This can be easily seen from the fact stated above, that an increase of .01% of sulphur can often neutralize the effect of from .10 to .15% of silicon.

There are however, three commendable qualities in it. One is its influence in increasing the strength, another in increasing its fusibility, and the third the effect in hardening or chilling

iron by increasing combined carbon. Aside from these its effects are evil. It makes light castings hard, molten iron sluggish, gives rise to blow holes, decreases elasticity and causes increased shrinkage.

CARBON

Carbon is the most important element in cast iron, and is present in larger amount than any other constituent, varying from about 2% to 4.25%. Without it iron could not be easily melted and poured into castings, and the degree of hardness and strength needed for various uses could not be obtained. The percentage of total carbon present determines the melting point. Iron has a strong affinity for carbon and absorbs it in the blast furnace, owing to the kind of fuel used in the smelting. The saturation point or amount of carbon the iron can take up, varies from 3 to 4.25% owing to blast furnace conditions.

A large amount of silicon in the iron reduces the power of iron to absorb carbon, and a large amount of manganese increases this power. Chromium has the same effect as manganese, and may cause iron to absorb as high as 12% or carbon. The more carbon the iron contains the greater influence silicon, sulphur, etc., have in changing its grade. When iron is melted, all of the carbon it contains is supposed to be dissolved or combined with it, as otherwise the lightness of the carbon would cause it to rise to the surface of the iron. When the iron is solidified the carbon will remain in the combined state, unless some influence is present to change it; the combined is the natural form for carbon to hold, and

if the iron has not absorbed more carbon than it will hold when cold, it will be white iron. If the iron does contain more carbon when molten than it can hold when cold, the extra amount will be crystallized and separate as graphitic scales lying between the iron crystals which form on cooling. The occurence of carbon in its different forms may be to some extent regulated by the way the iron is cooled. Rapid cooling prevents the formation of graphitic carbon by not allowing it sufficient time in which to crystallize, while slow cooling has the opposite effect. Fast cooling gives hard castings having a light, close grained fracture, while slow cooling gives softer ones, with a fracture much darker and large grained. This probable variation in the cooling of castings makes it impracticable to attempt to regulate mixtures by regulating the amount of carbon; the regulation by silicon and sulphur being more positive is much more to be advocated. Total carbon is generally increased by remelting, the amount of increase depending on the amount of fuel used and the time the iron remains in the cupola. Little fuel and a quick melt may reduce the carbon slightly, while enough fuel to produce hot iron with a slow melt will increase the carbon. Generally in remelting iron, combined carbon is increased and graphitic carbon is decreased.

PHOSPHOROUS.

Phosphorous occuring in cast iron, is obtained from the phosphoric acid which is found in the fuels and iron ores. It retards the saturation of iron for carbon and adds fluidity and

life to the metal. It has a bad effect in weakening iron if present in quantities greater than 1%. It is best to keep it below 0.8%. Phosphorous is a very essential element in successful founding, and as such needs to be watched as closely as silicon or sulphur. Mr. West on page 217 of his Metallurgy of Cast Iron, cites some experiences of Mr. James A Beckett of Hoosick Falls, N. Y., in experimenting with phosphorous as an agent to regulate foundry mixtures. Mr. Beckett has found phosphorous to greatly counteract the tendency of sulphur to increase combined carbon, and he has upon several occasions, when high sulphur was making castings hard, made them soft by increasing the phosphorous from .50 to .75%. Mr. Beckett's experience also shows, that 0.1 % increase in phosphorous, will produce the same effect as an increase of 0.25% of silicon, other constituents not varying, until the phosphorous reaches the safety limit of 1.%. The addition of phosphorous in the form of sticks, to molten metal increases its strength sometimes as much as two-fold. While the occurence in a natural way increases the fluidity and life of the metal as mentioned above, the addition to the molten metal as just cited has the opposite effect, the iron losing fluidity and solidifying rapidly. Mr. West found that phosphorous acted as a flux when added to the molten iron, driving out silicon, manganese, and total carbon. In the cupola phosphorous is slightly increased when occurring in the fuel. There is seldom any loss as all phosphorous in the cupola will usually be found in the iron. Phosphorous acts in a very decided manner in reducing shrinkage in castings, and consequently iron

having high phosphorous and high silicon should have but little shrinkage. Phosphorous has a very peculiar effect upon the fracture of cast iron, imparting a yellow tinge to the crystals. This yellow tinge is sometimes seen on the outside of high phosphorous irons that have been rapidly cooled.

MANGANESE

Manganese ranges from a trace up to 3.% in pig iron. It unites with iron in almost any proportion, but escapes to a certain extent upon remelting by volatilization and with oxidation with other elements, especially sulphur. Manganese can thus be used to counteract the effects of sulphur as it is very effective in reducing the latter. In making and remelting iron, manganese is affected in a manner similar to silicon. The higher the temperature in the cupola, the greater will be the decrease in manganese. When making iron, a hot furnace will send the manganese into the pig, while a cold furnace will send it into the slag, as a high temperature is required to make it combine with the iron. Manganese, like phosphorous, has very different effects, when occurring in the pig and when added to molten iron in the form of ferro-manganese. When occurring in the pig, it increases the saturation of iron for carbon; increases the combined carbon, although not to so great an extent as sulphur; deepens the chill, increases shrinkage, and to a degree, greatly strengthens iron. The effect of adding it to molten iron as ferro-manganese, is shown by the following extract from a paper presented by Mr. A. E. Outerbridge, Jr., before the Franklin

Institute, in February 1888. He said:

"A remarkable effect is produced upon the character of hard iron by adding to the molten iron a moment before pouring it, a small quantity of powdered ferro-manganese, about 1/6% and stirring with an iron rod. The result of several hundred experiments which I have made enables me to say, that the transverse strength of the metal is increased from 30 to 40%; the shrinkage is decreased from 20 to 30%; the depth of chill is decreased nearly 25%, while nearly one half of the combined carbon is changed into free carbon. The percentage of manganese in the iron was not sensibly increased by this dose, the small proportion of manganese which was added being found in the form of oxide in the scoria. When a casting which has been treated thus, and artificially softened, is remelted, the effects of the ferro-manganese disappear and hard iron results. In high manganese irons, an increase in the silicon can greatly neutralize the effects of the manganese; as is shown in TABLE II which consists of extracts from a table given by Mr. Keep, on page 100 of "Cast Iron". It will be noted that the increase in silicon is accompanied by an increase in strength, and by a decrease in shrinkage.

PIG IRON

Pig Iron is usually divided into the following brands:- Foundry, Charcoal, Bessemer, Gray forge, Basic, Ferro-silicon, Mottled and White Iron. The limits of the variation of the impurities are shown in TABLE III.

Foundry iron is made with coke or anthracite fuel, and is used for general casting.

Charcoal iron as the name indicates is made with charcoal, and is usually low in sulphur. It generally carries a larger percent of pure iron than other brands.

Bessemer differs from "Foundry" iron only in having less phosphorous, as may be seen in TABLE IV taken from Mr. West's Metallurgy of Cast Iron, page 215, and giving the analysis of Foundry and Bessemer irons. The four analyses could pass as Foundry excepting for phosphorous. Bessemer is used for making steel, and for general castings, not requiring extra fluid metal.

Gray Forge iron has a gray fracture with little or no grain, and is chiefly used as mill iron in puddling furnaces producing wrought iron.

Basic iron is similar to Gray Forge, with low silicon, phosphorous and sulphur, and finds its chief use in the open hearth process for making steel.

Ferro-silicon is made with coal or coke, from high silicon ores, and requires excessive fuel to cause the high temperature necessary in the furnace; as its name indicates it is high in silicon, ranging up to about 16%.

Mottled and White iron are made with coke, coal and charcoal fuels. These irons are high in sulphur and are used for hard and chilled castings.

GRADING PIG IRON

Until about ten years ago, almost all pig iron was graded

by fracture and piled according to the fineness of the grain; the coarsest grained iron being used for the softest castings and the fine grained for hard ones. It has been thoroughly demonstrated that grading by appearance is not reliable and is often deceptive, and the majority of founders now depend upon chemical analysis for their guide as to the quality of iron. There is much confusion at present in the numbering of different grades of iron, some furnace-men calling a soft iron #1, and others giving the same number to a hard iron. To correct this evil and to establish uniform methods for grading, Mr. Thos. D. West devised in 1901 a system of grading iron according to its chemical character which is shown in TABLE VI Metallurgy of Cast Iron, page 152, which decreases silicon 0.25%, and increases sulphur .01 to .06% in each grade. TABLE V already referred to shows the importance of variations of both silicon and sulphur upon the character of iron, and in establishing standards both should be included. As shown in TABLE VI, Mr. West depends entirely upon variations in these two elements for the determination of his grades. He says that it should not be thought that no attention is to be paid to manganese, phosphorous, or total carbon, as these elements have a very important influence as previously stated. He believes, however, that they will be best omitted from any universal system for numbering grades, and recommends that each foundryman, knowing his own conditions, should specify approximately the amounts of each when purchasing iron by grade.

PURCHASING, MIXING AND SAMPLING PIG IRON

The liability of errors by the makers of iron, in the number-

ing of piles of iron, etc., as well as in the chemical analyses furnished, makes it necessary that the founder who is regulating his mixtures by chemical analysis, should know positively the composition of the iron that he buys. In order to accomplish this with the highest degree of certainty, a thorough mixing of the pigs in one car, and intelligent sampling of the pigs for analysis should be assured. The importance of thorough mixing is due to the fact that in one cast of sand pig the silicon often varies as much as 1.5%, the last pigs cast being higher in silicon than the first, and sulphur varies in proportion, being higher at first than later. Assuming that alternate barrows, or trucks, of pig loaded at the furnace, are placed at opposite ends of the car; if the foundryman in unloading will follow the same scheme, the pigs should be pretty thoroughly mixed by the time they are piled. Each car of pig should be piled by itself.

In sampling, three or four pigs should be taken from near the ends and at the middle of the pile, broken, and drillings taken from the fractured ends. As it is essential that no sand or scale should contaminate the drillings, each pig should be well cleaned with a wire brush before being drilled. Strict precautions should be taken to prevent grease or dirt getting in the drillings. A flat drill is the best to use as the drillings will be finer that with a twist drill. The end of the pig should be drilled in from two to six places well distributed, and the drillings from each hole kept separate until all pigs are drilled, when equal weights from each hole should be mixed together. This method of sampling

will insure a good average of each car of iron. The part of the sample which will pass through a 20 or 40 mesh sieve should be used for analysis.

MIXING IRON IN THE CUPOLA

The day is past for the toleration of the ignorant methods followed by founders up to 1890, in mixing iron. When the deceptive appearance of the fracture of pig iron as indicating grade, as stated above, is considered, the wonder is that mixtures ever came out good. Since that date, however, many foundrymen have kept up with the progress in utilizing chemistry in mixing their iron, and with the furnaceman doing his part and furnishing iron as called for by the founder, the old cry of "bad iron" should cease. There is no really bad iron as all iron may be utilized for some sort of work or other. A knowledge of its chemical and physical properties is all that is necessary to enable both maker and user to handle their iron correctly.

Furnacemen can rarely furnish iron of the exact analysis for charging the cupola, and foundrymen, particularly those using a large amount of iron, must often accept two or more grades varying widely in their constituents, in order to obtain a mixture having the desired composition.

The thorough mixing of pigs from each car-load has been described above. Mixing irons containing a different percentage of impurities, in order to obtain the required percentage of an element is not very difficult, if reasonable care is taken. Say an iron carrying 2% silicon is desired, and the foundryman has two lots of

iron containing 2.6% and 1.4% respectively. The amount of each iron taken should be equal, as a simple calculation shows. If the charge is 800#, then the 400# containing 2.6 points of silico per hundred, and the 400# containing 1.4 points, give when mixed, 800# containing 16 points, or 2.0 points per hundred as required; or

$$(400 \times 2.6 + 400 \times 1.4) \div 800 = 2.0$$

In like manner a mixture of iron of any percentages may be calculated. Take two irons: A, having 1.% and B, having 2.5% of an element. Required a product containing 2.25%. The amounts of the two irons to be used are inversely as the difference between their percentages and that of the product.

Let (a) be the percent in the low iron:, (b), the percent in the high iron, and (c) the required percent.

Then $A : B :: b - c : c - a :: 2.5 - 2.25 : 2.25 - 1$,

or, $A : B :: .25 : 1.25 :: 1 : 5$.

Accordingly, in a charge of 600#, 500# of a 2.5% iron and 100# of a 1.% iron, would give a product having 2.25% of the element under consideration. $(500 \times 2.5 + 100 \times 1.0) \div 600 = 2.25$.

This is very easy when only one element is considered; but in trying to regulate several elements at once, the problem becomes exceedingly involved. If it were possible for the foundryman to obtain irons differing from each other in only one or two elements, he would have little or no difficulty; but when he has several brands of iron differing widely in all constituents, it will require considerable "cutting and trying" and the calculation of a large number of possible combinations before arriving at anything near the

desired result. Mr. West's recommendation as to the importance of silicon and sulphur for determining the grade of iron, is based upon the assumption that phosphorous and manganese will be fairly constant from any one furnace, and throws the responsibility on the furnaceman of living up to the foundryman's expectations in that respect. When the amounts of different irons charged are known, the composition of the resulting mixture may be readily calculated. For any element, the percentage occuring in any one iron, multiplied by the number of pounds charged, will give the number of "points" charged in that particular iron. The sum of these results for all irons charged, divided by the total number of pounds in the mixture will give the percentage of the element in the product. This method is shown by TABLE VII. (taken from page 256 of Mr. West's book previously referred to.)

The changes in the percentages before mentioned, due to remelting should be taken account of, in calculating any desired mixture. Silicon decreases from .20 to .30%; manganese from .05 to .15%; sulphur increases from.02 to .04%; Phosphorous from .05 to .15%, and total carbon may either increase or decrease slightly.

Scrap Iron, is iron which has been remelted one or more times, and hence fairly shows its grade in its fracture. This iron comes to the foundry in all conceivable qualities; ranging from sash weights made of cheap iron up to the best soft machine castings. It is, of course, impossible to obtain accurate analyses of all these varieties without an enormous amount of work, the cost of which would be prohibitive. In order to have some method of grad-

ing scrap so that a fair approximation may be obtained, Mr. West suggests that it be graded according to its fracture as compared with fractures of remelts of the various grades of pig of known chemical composition, taken as a standard.

In charging the cupola with irons of different composition when a definite mixture is to result, they should be in separate piles, known to the cupola tenders, and aggregating each charge in weight. Pieces should be taken from these piles alternately when thrown in the cupola and thus a thorough mixing will result.

EFFECTS OF FOUNDRY METHODS.

Iron which comes out of a cupola having a certain chemical composition as determined from test bars, may have its constituents so charged by the way it is heated in the foundry that the analysis will not indicate its true character.

The variation in temper or dampness of sand causes great charges in the amount of combined and graphitic carbon, in the contraction, and in the strength of small castings. As the moisture increases -within the limits required for sound castings-, the combined carbon, shrinkage, and strength increase. This is true to but a very slight extent in heavy castings.

A variation in the time of cooling, -as noted under "Carbon" above- can cause considerable change in the amount of combined carbon, and consequently in the strength of castings. The lighter the castings the greater will be the effect of "dumping" them as soon as sufficiently solid. This treatment also sets up contraction strains due to unequal cooling, which are very undesirable.

A casting to be easily machined should be left in the mold until almost cold enough to handle. This slow cooling aids the formation of graphitic carbon, and makes the casting softer and somewhat weaker, than if dumped while red-hot. The larger the casting the less, of course, will be the effect of quick dumping.

Rattling or tumbling castings has been found to increase their strength. Mr. A. E. Outerbridge has conducted exhaustive tests upon this subject, and has found many test bars to increase in strength as much as 15%.

MECHANICAL TESTS

Mechanical tests of cast iron are made use of in order to obtain information in regard to the physical characteristics of any particular iron, either for comparison and use in connection with the chemical analysis of that iron, or as a direct guide for the regulating of iron mixtures without making chemical analyses. Tests of the latter type constitute mechanical analysis. The characteristics usually noted are, tensile strength, transverse strength, shrinkage, hardness and chill.

The utility of tensile tests is manifest for castings having that sort of strain imposed upon them, as these tests give the ultimate strength per square inch of cross-section area. They are conducted by pulling apart in a testing machine, castings of such a form that the area of the cross-section at the break is easily determined.

Transverse tests, with the accompanying value of the deflection, are the most valuable, because iron castings are chiefly

subjected to this sort of stress. The ability of cast iron to withstand crushing loads is often of importance to the engineer and founder, and Mr. West affirms that the elements constituting a test in transverse strength, deflection and chill, are a good index to the crushing strength. An iron with high transverse strength and small deflection should prove best to withstand crushing.

Shrinkage tests are conducted by molding projections on a casting between chills which are a definite distance apart, and the difference between the distance inside the chilled portions when the casting has cooled, and the original distance between the chills, divided by the latter, gives the percent of shrinkage. Small bars are sometimes chilled on the ends; the original length being known, and the contraction measured.

Depth of chill is determined by fracturing the chilled portion of the casting in the shrinkage test, perpendicular to the surface. Depth of chill is affected by the time the chilling piece is in contact with the hot iron, by the thickness of said piece, and by the fluidity of the iron; hot iron chilling deeper than sluggish iron.

Hardness tests are useful in indicating the crushing strength and for other purposes. The method devised by Prof. Thos. Turner is now generally used, and consists in drawing a diamond (provided with an appliance for varying the weight upon it), over the highly polished surface of the material being tested, and determining the weight required for a scratch of given character.

In order to obtain a uniformity in testing, it is advisable

that the castings used should be of the same size and shape. This has been accomplished by using test bars, cast at the same time as the other castings, and from the results of tests conducted with them, the character of the other castings can be fairly determined. The size and shape of test bars varies greatly with different investigators, ranging from 1/2" to 3" in diameter, in both round and rectangular bars, and from 12" to 40" in length. It is evident that results obtained from one size of bar may differ materially from those obtained from other sizes, and accordingly the use of the same kind of bars by everyone conducting tests would be of advantage. The variation of shrinkage, as occurring in different sized bars of the same iron, is shown in TABLE I already referred to. It is easily seen that each size of bar will have properties which would be expected in castings of approximately the same size, but it is manifestly impracticable to have test bars for the many different kinds of castings made, owing to the large amount of work which would be required in obtaining results. The true utility of test bars is simply comparative, as they are of use only to define differences existing in different mixtures of iron; or in other words, all that the test bar will do is to denote the strength of the iron being poured into the mold; and what the influence of the shape and size of the mold will be in altering its physical qualities from those shown by the test bar, is largely left for experience to guess at, or for comparative tests of broken castings to determine. It is natural to look to the organization best representing those interested in this matter, for a solution of this

problem; and that such has been found, will be seen by the following extract from "Standard Specifications for Gray Iron Castings and Test Bars", as adopted by the American Foundrymen's Association in June 1901.:

" 4. Castings made under these specifications, the iron in which is to be tested for its quality, shall be represented by at least three test bars cast from the same heat.

5. These bars shall be subjected to a transverse breaking test, the load being applied at the middle with supports 12" apart. The breaking load and deflection shall be agreed upon specially on placing the contract, and two of these bars shall meet the requirements.

6. A tensile strength test may be added, in which case at least three bars for this purpose shall be cast with the others in the same molds respectively. The ultimate strength shall also be agreed upon specially before placing the contract, and two of the bars shall meet the requirements.

7. The dimensions of the test bars shall be as given herewith. There is only one size for the tensile bar and three sizes for the transverse. For the light and medium weight of gray castings the 1 1/2" bar is to be used, for heavy gray iron the 2", and for chilling irons the 2 1/2". ".

The tensile bar is shown in fig. 1, and sockets for using with them in the testing machine, in fig. 2. The transverse bars are round, 14" long, and 1 1/2, 2, and 2 1/2 inches in diameter. The latter are not finished.

The size and shape of these bars were determined upon after

a large amount of research by a committee of the A. F. A., composed of Dr. R. Moldenke, and Messrs. Thos. D. West, Jas. S. Stirling, Jos. S. Seaman, and Jos. S. McDonald. Much of this work was conducted by Mr. West at his foundry in Sharpsville, Pa., and his years of experimental work along this line were of much vale to the committee.

Square test bars have been much used in testing cast iron and were used almost entirely, prior to 1890. Mr. West first advocated the use of round test bars in 1886. Iron in cooling, arranges its crystals perpendicular to the bounding surfaces. In a paper read before the A. F. A., in 1894, Mr. Spretson speaks as follows regarding the two forms of bars:- "In the round bar the crystals are all radiating from the centre. In the square bar they are all arranged perpendicular to the four sides, and hence have four lines in the diagonals of the square, in which terminal planes of the crystals abut or interlock, and about which the crystallization is always confused and irregular."

In testing bars cast flat, it has been found that the cope side of the bar is less dense and consequently weaker than the drag or lower side. This is due to the lower side being cooled quicker than the upper side, and therefore, retaining more of the carbon in the combined state; making the iron dense and of finer grain. Mr. West in experimenting along this line found as an average of a large number of tests, for a bar 1" square, 100#, and for a 1 1/8" round bar 150# greater strength in transverse test when tested as poured, - that is with the lower side on the supports,- than when

tested with the drag side up. In a large bar the tendency of sulphur to rise to the top might neutralize the cooling effect to some extent, but not much in bars of the size given. With round bars cast vertical, Mr. West obtained results differing only a few pounds for two bars from the same flask, one broken with the cope side up and the other with the drag side up. He therefore, recommends that all test bars should be cast on end. In pages 512-527 and 579-580 of his Metallurgy of Cast Iron, methods of molding round test bars on end, and a full description of the appliances used may be found.

MECHANICAL ANALYSIS

Mr. W. J. Keep, as a result of a large number of experiments made by him as a member of the committee on Testing of the A. S. M. E., has developed a system of mechanical analysis, based upon Prof. Turner's discovery that the condition of the carbon depended on the proportion of silicon, and upon his own discovery that the shrinkage varies inversely as the silicon. (shown in TABLE I). The method is as follows:- Test bars 1/2" x 1/2" x 12" are cast between chills 12" apart; when cooled the bars are placed between the same chills, and the shrinkage measured with a taper scale. The following directions are given by Mr. Keep for the regulation of the quality of iron by his method:-

"Measure the shrinkage of a 1/2" square test bar from your mixture when you consider it satisfactory, and use it for your standard.

For stove plate and small castings, it should be .115" to

.190"; for ordinary machine castings .150" to .160".

If the shrinkage is greater than your standard, use more soft iron - (increase silicon). If it is less, use more scrap or cheap iron.

The strength of a bar 1/2" x 1/2" x 12" tested between supports 12" apart should be over 400#."

He also gives the following data as an additional guide:-

"With high shrinkage and high strength of a 1/2" bar heavy castings will be strong, but thin castings - (1/8" to 1/4") are likely to be brittle.

With low shrinkage and high strength of a 1/2" bar, large castings will be weak, and thin castings strong.

With uniform shrinkage, an increase in the strength of a 1/2" bar will denote a proportionate or corresponding increase in all castings.

For ordinary foundry work, and with all iron that runs gray in 1/2" square bars, that size gives better results than any other."

While this system offers a fairly good method for regulation when the castings are of the same general size and character, it is by no means as accurate nor is it susceptible to such regulations of quality and economy, as is the system of regulating by chemical analysis.

METHODS OF ANALYSIS FOR CAST IRON

Drillings of pig iron should be carefully taken as stated under "Pig Iron" above. Drillings from test bars should be taken from three different parts of the fractured surface, and the same care should be observed not to get grease or dirt of any kind in the drillings. About 15 grams should be taken for each complete analysis. The samples should be placed in a clean glass specimen tube and plainly labeled. Duplicates should be run for all determinations,and parallel determinations of A. F. A. standardized drillings should be run occasionally. See Chapter XXVl, 3rd Ed. "Metallurgy of Cast Iron", by Thos. D. West, for full information regarding the origin and use of standardized drillings. The methods given here are those taught in the Chemistry Department of the University of Illinois, and were compiled by Prof. S. W. Parr from the best and latest methods given by various authorities and modified by him as their improvement demanded.

Every foundry chemical laboratory should be provided with copies of the"Chemical Analysis of Iron," by A. A. Blair, "The Metallurgy of Cast Iron" by Thos. D. West, and "Cast Iron", by W. J. Keep.

SILICON

References:- Journal American Chemical Society. July '98, p. 547; Feb. '99, p. 215; Blair's Chemical Analysis of Iron, 4th Ed. pp. 72 to 78.

Silicon is present in iron as silicon (Si) and is determined as silica (SiO_2), which must be calculated back to Si. The process

is in brief the solution, and dehydration of the silica, weighing and volatilization by means of hydrofluoric acid (HF). The success of the operation depends chiefly upon the thorough dehydration of the gelatinous silica.

Weigh accurately about 1 gram. Dissolve in a casserole with 50 c.c. of solution prepared as follows:- 250 c.c. dil. HNO_3; (100 c.c. con. HNO_3, 150 c.c. water), 150 c.c. con. H_2SO_4, and 100 c.c. water. Pour the sulphuric acid into the water, then add the nitric acid. When the iron is dissolved, add 15 c.c. con. HCl, and boil down rapidly to SO_3 fumes. Repeat this boiling down, dilute and filter at once; burn carefully in a weighed platinum crucible; and after cooling in a desiccator, add a few drops of water, 5 or 6 drops of H_2SO_4, and 1 to 2 c.c. HFl. Distil over a hot plate and ignite in gas flame as usual. The loss in weight is SiO_2, which is calculated to silicon.

A method given in Blair p. 77 and developed by Mr. S. A. Ford of the Edgar Thomson Steel Works, seems peculiarly adapted to the foundry and blast furnace.

A small ladle is dipped into the molten iron as it runs out, and a little iron taken. This is then poured into a bucket of water with a circular movement from a height of about three feet, and forms in globules, the shape of which bears a close relation to the silicon content. With iron containing 2% or more the shot will be almost perfectly round, concave on the upper surface, and from 1/4" to 3/8" in diameter, while if the silicon be low the

drops will be very small, flat, and irregular in shape; and if the silicon is very low the shot will be elongated and have tails sometimes 1/4" in length. The shot are then dried and pulverized in a hardened steel mortar, sifted through a fine sieve, and about .5 gram of this siftings placed in a platinum evaporating dish. 10 c.c HCl (1.2 sp. gr.) are then added, the dish covered with a watch glass, and the iron dissolved by heat; as soon as solution takes place, the watch glass is removed and the solution evaporated to dryness over a bare flame; as soon as dry, dil. HCl is added and when all iron oxide is dissolved, water is added. The contents of the dish are then filtered by the help of a pump, and washed. The filter is then ignited in a platinum crucible, and as soon as the paper is burned a small jet of oxygen is driven gently into the crucible until the carbon is burned off. The crucible is then cooled and weighed, and the silicon calculated from the SiO_2 in the crucible.

By this method the silicon in pig iron may be determined in twelve to fifteen minutes from the taking of the sample, with accuracy enough for practical purposes.

SULPHUR

Blair pp. 60-72: J. A. C. S. Vol. 17, p. 891; Vol. 19 p. 114: Journal Iron and Steel Institute, 1899, Vol. 1, p. 319.

The popular method of determining the sulphur by evolution and absorption as H_2S is by no means accurate, but as it is widely used, and as when used with the A. F. A. standardized drillings a check is provided, the method is here given.

Weigh 1 gram. Use apparatus shown in fig.5 , A is a hydrogen generator, B a wash bottle containing a 5% solution of lead acetate to arrest any H_2S: C is a drop funnel of 300 c.c. capacity: D is a 500 c.c. flask: E a pipette used to avoid the drawing back of the liquid in H, and H and H' are absorption flasks containing about 100 c.c. each of a solution of caustic soda made by dissolving 10 grams NaOH in 100 c.c. water.

The iron is placed in the flask D, and a current of hydrogen from the generator is run through the entire system. The cock K is then closed and 150-200 c.c. of HCl (1/2 con. HCl, 1/2 water) placed in the funnel. The acid is forced down into the flask by the hydrogen, and a gentle heat applied. When the action is complete hydrogen is further run through until all danger of not getting all of the H_2S is past, and the soda solutions poured together, the bottles washed out with distilled water, the solution made strongly acid (litmus test) with a predetermined amount of HCl, and titration performed as given in Blair, pp. 69-72. The amount of sodium solution required to titrate is reduced to 1/100 normal iodine and the result multiplied by .016. This quantity is then divided by the weight of the sample and the result will be the percentage of sulphur.

PHOSPHOROUS

Blair pp. 92-104: J. A. C. S., Vol. 19, p. 93.

The solutions needed are:- Nitric acid 1.135 sp. gr. (2 water to 1 HNO_2 sp. gr. 1.42); sulphuric acid 1.84 sp. gr: dil. sulphuric acid (1000 c.c. water to 25 c.c. con. acid 1.84 sp. gr.): ammonia

sp. gr. .96: strong solution of $KMnO_4$, (12 -15 g. per litre). Molybdate solution prepared as in Blair p. 97. Standard solution of $KMnO_4$ prepared as in Blair p. 95. Hot acid wash made of 1000 c.c water, 40 c.c. ammonia (sp. gr. .90) and con. H_2SO_4, 25 c.c. Weigh about .3 gram of drillings into a 500 c.c. Erlenmeyer flask; add 100 c.c. HNO_3, sp. gr. 1.135, dissolve, and boil hard till red fumes cease. Add enough strong permanganate solution to cause a pink color, and boil until the pink color disappears and MnO_2 separates. Cool down slightly and add dilute solution of SO_2 until MnO_2 dissolves, and boil to drive off excess of SO_2. Filter through an asbestos filter into a 700 c.c. side neck flask, and wash. Return to original flask, boil down to about 100 c.c. and upon cooling add 40 c.c. of ammonia .96 sp. gr. Mix and heat as hot as can be borne by the hand. Add 40 c.c. molybdate solution, and shake hard for five minutes; allow to settle, filter through a 9 cm. filter, which has been accurately fitted to the funnel in order that any precipitate creeping above the paper may not be lost, and wash thoroughly with hot solution given above until test free from iron or molybdate. Dissolve precipitate by adding to flask 25 c.c. of dil. ammonia (1 NH_4OH sp. gr .90 to 4 water). Pour from flask onto filter; return again to flask and through filter, and wash with water until solution's bulk is about 150 c.c. Add now 10 c.c. con. H_2SO_4 and pass at once through the Jones reductor shown in fig. 6 (described Blair p. 93-94) at the temperature produced by the acid, about 75-80°C. Precede the reduction by passing through 100 c.c. of the dil. sulphuric acid warmed

to about 70° C. Always stop with a little solution in the funnel, so that no air will be drawn in, then pass the phosphate solution through, following it with 20 c.c. warm dil. nitric acid, and 50 c.c. hot water, and titrate with the standard permanganate solution. A blank should be passed through the reductor using the same quantities of acid and for the phosphate solution an equal amount of water with 25 c.c. 1 to 4 ammonia and 10 c.c. H_2SO_4, as above. The amount required to titrate this blank - about .1 c.c. - should be deducted from the readings for the phosphate. The action of the zinc is to reduce the MoO_3 to $Mo_{24}O_{37}$ which should be of a bright green color.

To calculate the percent of phosphorous, multiply the iron equivalent of 1 c.c. of the permanganate solution by .88163 and by .01794 and this product by the number of c.c. required for titration less the amount for the blank, and divide by the weight of the sample, the result will be the phosphorous in the iron.

MANGANESE

Blair p. 118-120.: J. A. C. S. Vol. 20, p. 504.

Weigh .5 gram into a small #3 or #4 beaker, add about 50 c.c. HNO_3 (sp. gr. 1.2) and boil down until less than one half bulk or nearly syrupy. Add another 50 c.c. HNO_3 (sp. gr. 1.4) and about 5 g. $KClO_3$ crystals and boil 15 minutes. Repeat addition of second acid and chlorate and boil till all yellow fumes are gone. The Mn. should now all be precipitated, but there will also be much gelatinous silica to interfere with the filtration. To remedy this add a few drops of HF and boil to remove the excess. A gram of $KClO_3$

may be added at the same time to make sure that all of the Mn is precipitated. Cool, filter on asbestos, wash two or three times with con. HNO_3 free from red fumes, and then wash thoroughly with cold water, until the nitric acid is removed, rinsing the beaker out well. Suck dry, transfer the asbestos and precipitate to the beaker again, and add 25 c.c. of standardized ferrous sulphate solution ($FeSO_4$) (Made up about 10 g. $FeSO_4 + 7H_2O$ to 900 c.c. water and 100 c.c. con. H_2SO_4, standardized against the regular $KMnO_4$ solution and kept in the dark and well stoppered). Stir till all the MnO_2 is dissolved and titrate with permanganate. The amount of permanganate required indicates (according to the standardization) the amount of $FeSO_4$ solution not taken up by the precipitate. The ratio is 2Fe to 1Mn. Hence the iron equivalent of the permanganate solution which would be required to titrate the amount of $FeSO_4$ solution taken up by the Mn, represents the Mn equivalent as 2 (56) is to 55. Then 55/112 times the iron equivalent divided by the weight of the sample gives the amount of manganese in the iron.

GRAPHITIC CARBON

Blair p. 169'

Weigh 1 gram. Dissolve in about 15 c.c. nitric acid (1.12 sp. gr.) best without heating. When solution is complete, add a few drops of HF to prevent formation of silica, and bring to the boiling point and boil for a few minutes. Dilute to about 100 c.c. and filter on a well fitted asbestos filter. A good method of filtration and method of preparation of filter is given in Blair p.156. Wash the filter with hot caustic soda solution, same as used in

analysis for Sulphur, then thoroughly with hot water, then with a little dil. HCl and again with hot water. Burn and calculate as given under Total Carbon.

TOTAL CARBON

Blair pp. 158-160.

Dissolve 1 gram of pig iron in a small beaker by adding 100 c.c. of a saturated solution of double chloride of copper and potassium ($CuCl_2.2KCl.2H_2O$, about 300 g. per litre). Stir and add 7.5 c.c. HCl (1.2 sp. gr.). Stir frequently as the solution of the iron and finally of the copper is hastened by stirring. When solution is complete, which may require standing over night unless some form of mechanical stirrer is available, filter as for graphitic carbon, using asbestos that has been ignited in a current of oxygen and wash thoroughly with hot water. If the interior of the beaker needs cleaning, do so with a small wad of asbestos pulp, and transfer it to the filter. The asbestos and carbonaceous matter is burned in the apparatus shown in fig. 7.

P' is an empty U tube, O is a tube containing silver sulphate dissolved in strong sulphuric acid. P contains anhydrous supric sulphate, Q contains granular dried calcium chloride. A Geissler's bulb R with attached drying tube constitute the absorption apparatus, S is a safety guard tube containing calcium chloride, and CC is a gravity arrangement for passing air through the apparatus. The air is freed from CO_2 by passing through the tube D containing fused potassium hydroxide. Transfer the asbestos and carbonaceous material to the flask A, insert the stopper carrying the drop funnel

B, close the stop-cock C and connect as shown. See that all joints are tight and then pour into B 10 c.c. of a saturated solution of chromic acid; admit it to the flask A by opening C. Close C and pour into B 100 c.c. strong sulphuric acid which has been heated almost to boiling with a little chromic acid. Allow this to run into A slowly, connect the air apparatus by the tube N, and start a slow current of air through. Light a low jet under A and increase it gradually until the liquid reaches the boiling point. Lower the light gradually while the current of air continues to pass, and when about 1 litre of air has passed through after the light was extinguished, detach and weigh the absorption apparatus. This contrivance contains caustic potash (1.27 sp. gr), the bulbs being filled about 2/3 full, the drying tube contains calcium chloride. The ends of the bulb should be closed with small pieces of rubber tube containing bits of capillary tube. The bulb should stand in the balance about 20 minutes and then be weighed. Care should be taken when filling that none of the solution gets on the outside, and the bulb should be clean and perfectly dry. In weighing after absorption, the increase is CO_2, which is calculated to carbon.

COMBINED CARBON

Combined carbon is best obtained for cast iron by the difference between total and graphitic carbon.

SULPHUR AND PHOSPHORUS IN COAL OR COKE

Blair pp. 279-282.

Sulphur

Mix thoroughly 1 gram of finely powdered dried fuel, with 1 gram of light and porous magnesium oxide and 1/2 gram of dry sodium carbonate in a 100 c.c. porcelain or platinum dish. Heat the dish over an alcohol lamp held in the hand at first. Gas must not be used because of the sulphur it contains. The mixture is stirred with a platinum wire and the heat slowly increased until in fifteen minutes the bottom of the dish is at a low red heat. When the carbon is burned transfer the mixture to a beaker, and rinse out the dish using about 50 c.c. of water. Add 15 c.c. saturated bromine water and boil for five minutes. Allow to settle, decant through a filter, boil a second and third time with 30 c.c. of water and wash till the filtrate gives only a slight opalescence with Ag_2SO_4. The volume of the filtrate should be about 200 c.c. Add 1.5 c.c. con. HCl and boil until the bromine is expelled, and add to the solution drop by drop stirring constantly, 10 c.c. of a 10% solution of Barium Chloride ($BaCl_2$). Digest on the water bath until the precipitate settles and the solution clears. Filter and wash thoroughly, and ignite moist in a platinum crucible. The sulphur is determined by calculation from the weight of the $BaSO_4$.

Phosphorous

Burn off 10 grams of fuel in a platinum or porcelain boat in a combustion tube in a current of oxygen. A boat 4" long and of a width to go in a 3/4" tube will hold 10 g very easily. Treat the ash with HCl to dissolve any calcium phosphate, filter and work well with water. Stand the filtrate aside, dry, ignite and fuse

the insoluble matter with sodium carbonate. Dissolve in water, filter from the insoluble matter, acidulate the filtrate with HCl, and evaporate to dryness. Redissolve in water with a little HCl, add this to the first filtrate, add a little ferric chloride solution, and a slight excess of ammonia. Acidulate with acetic acid, heat to boiling, boil a few minutes, filter and wash well with boiling water. Dissolve the precipitate in HCl, evaporate down, and precipitate the phosphorous by molybdate solution as for the determination of iron.

Directions for ignition, washing, weighing, etc., are not given in detail, as reference to text books and manuals will give full information regarding these operations.

THE EQUIPMENT OF A CHEMICAL LABORATORY FOR FOUNDRY ANALYSES

It is assumed that the foundry for which this equipment is proposed, is large enough to require the services of one chemist; that nothing in the chemical way has as yet been done, and that the laboratory is to be permanent.

The building may be either of wood, brick or stone; it should be about 20 feet square, with a flood of north light, with good water and gas supply, electric connections if possible, and with good sewer connections. A separate building is recommended as it can be built exactly to suit, and the laboratory should be removed from the foundry in order to avoid excessive dust and

smoke, and to enable firm foundations free from vibration to be obtained. The furniture should be plain but of good quality, and together with all wood work, should be painted three good coats of light gray zinc paint. The working portion of the top of the desks should be of white, glazed porcelain tile, and the desks should be provided with sinks of white ware, and with water, gas and electric connections, when convenient. A large hood about 3 feet deep by 6 feet wide with vertical sliding glass doors and glass sides, should be provided, having a good chimney outlet, and with gas, water and electric connections, as for the desks. As a supply of absolutely pure water is essential, some form of still must be provided which will give an ample quantity of it. A clean Carboy with glass siphon and pinch-cock is a good receptacle for the water. A small stock room, about 8 x 8 feet, should be partitioned off in one corner for use as a balance room, and for storing chemicals and apparatus. It is recommended that the balances be placed in this room, as they will not be so exposed to various fumes as in the laboratory. They should be placed on a heavy shelf fastened rigidly to the wall to reduce vibration to a minimum, and it would be well if they were placed before a north window.

In the list which follows are enumerated the material necessary for the equipment of a laboratory designed to follow the methods of analysis already outlined. The numbers preceding the names of the articles, refer to the 1897 edition of the catologue published by Eimer and Amend of New York and from which prices

were taken :-

5404	1	Troemner's #1 Balance, capacity 200 grams			$ 104.00
5448	1	set weights for above.	0.01 g to 100g		18.00
5426	1	Balance with weights			8.00
6137	1	500 c.c. glass graduated cylinders			1.10
6137	2	100 " " " " "		at .65	1.30
6137	1	10 " " " " "			.28
5788	2	50 c.c. g.s. burettes grad. 1/10 c.c.		at 2.00	4.00
5789	2	" " " " " " " " " "		" 2.45	4.90
6290	100	sheets filter paper #597	32 cm.		1.15
					142.93
				10%	14.29
					$128.64
	1	still (of some approved pattern)			$20.00
	1	mortar, hardened steel (about)			3.00
6972	3	Platinum crucibles #1 25 c.c. 75g		at .60	45.00
				net	$68.00
6487	1	Gas holder			$ 23.00
5207	1	Oxygen retort, copper	1/2 gal.		3.50
5215	1	Gas machine, Kipp's pattern	1 pt.		4.00
8413	1	Water bath	8"		2.25
6833	1	Glass mortar	3 1/4"		.25
6093	6	Porcelain crucibles	#7	at .17	1.02
6175	3	Porcelain evaporating dishes	#9-11-13		.95
5922	6	Casseroles	#4	" .85	5.10
5565	3	Vests glass beakers	#000-#0	" .25	.75
5568	2	" " "	#1 - #4	" .80	1.60
6345	6	Erlenmeyer flasks	24 oz.	" .40	2.40
6345	6	" "	8 oz.	" .25	1.50
6341	4	Flasks	32 oz.	" .35	1.40
6344b	4	Flasks, round bottom	16 oz.	" .25	1.00
6353	1	Measuring flask, g.s.	2000 c.c.		1.20
"	3	" " " "	1000 c.c.	" .90	2.70
"	3	" " " "	500 c.c.	" .75	2.25
"	2	" " " "	250 c.c.	" .60	1.20
"	2	" " " "	100 c.c.	" .35	.70
	4	Side neck Erlenmeyer flasks	32 oz.	" .85	3.40
6940	1	Pipette	50 c.c.		.40
"	2	"	25c.c.	" .30	.60
"	4	"	10 c.c.	" .20	.80
"	1	"	5 c.c.		.15
5802	6	Burette floats		" .25	1.50
6328	1	Glass funnel	8 in.		.50
"	6	". "	2 1/2 in	" .12	.72
6402b	3	Separating funnels	8 oz.	" 1.40	4.20

9137	4 Filter plates	4 cm.	at	.40		1.60
6152	2 Desiccators	6 in.	"	2.50		5.00
8405	6 Watch glasses	3 in.	"	1.25	doz.	.67
"	6 " "	5 in	"	2.50	"	1.25
8100	2 doz. specimen tubes	3" x 3/4"	"	.30	"	.60
8270	2 doz. test tubes	6" x 5/8"	"	.35	"	.70
"	1 doz. " "	7" x 7/8"				.50
5944	2 U tubes	6 in	"	[illegible]		.70
5952	6 " " side neck	6 in.	"	.35		2.10
7041	3 Potash bulbs		"	1.20		3.60
6540	4 lbs. glass tubing 1 lb #11,	1 lb. #5 2 lb. #4	"	.50	lb.	2.00
6537	1 lb. glass rod	1/4"				.50
8012	10 ft. rubber tube	1/4"	"	.10	ft.	1.00
"	10 " " "	3/16"	"	.07	"	.70
8010	1 lb. rubber corks, 2 holes,	asst #2-7				2.00
6003	2 Porcelain combustion boats	4 in.	"	.30		.60
6018	1 Combustion tube, porcelain	18 in.				1.00
9052	6 Bunsen burners		"	.50		3.00
6691a	1 Alcohol lamp	8 oz.				.50
6302	500 sheets filter paper #590	9 cm.	"	1.25		6.25
8314	6 Triangles		"	.75	doz.	.38
8213	2 Filter stands, iron		"	.65		1.30
8185	1 Burette stand, wood					1.50
8324	3 Tripods		"	.25		.75
6114	1 pr. crucible tongs					1.20
6314	2 Filter pumps		"	1.50		3.00
5970	6 Pinch-cocks		"	.20		1.20
	1 Beaker holder, wire					.18
	1 Tube holder, wire					.15
	1 gm. platinum wire					.60
6458	1 oz. glass wool					1.00
6053	6 cork borers	#1 to 6				1.00
	1 lb. asbestos wool					.30
	1 "Analysis of Iron", Blair					4.00
	1 "Metallurgy of Cast Iron", West					2.00
						120.97
				20%		24.19
						96.78
						$293.42

Bottles.

5709	2 doz. Reagent bottles g.s.	8 oz	at	2.25	4.50

2 H_2SO_4 2 HCl
2 H_2SO_4 dil 2 HCl dil.
2 HNO_3 2 NH_4OH
2 HNO_3 dil. 10 blanks.

5702	6 Reagent bottles g.s. 1 $HC_2H_3O_2$ 1 $BaCl_2$ 1 NH_4Cl 3 blank	4 oz.	at 1.75 doz		.88
5712	1 Reagent bottle $AgNO_3$	1 oz.	" 1.25 "		.11
5690	1 doz. Salt mouth bottle g.s.	16 oz.			1.83
	2 " " " " " "	8 oz	" 1.62 "		3.24
	1 " " " " "	4 oz			1.22
			net		$11.78

C. P. Chemicals. (prices include containers)

9 lb	H_2SO_4, sp. gr. 1.84	$1.84	1 oz.	Fe wire		.10
14 "	HNO_3 " " 1.42	3.52	1 lb	$FeSO_4$		.48
6 "	HCl " " 1.2	1.30	1/4 "	Fe_2Cl_6		.15
1/4"	HF	.35	1 "	$CuSO_4$ Anh.		.28
1/2	$HC_2H_3O_2$ " " 1.040	.15	1 "	[illegible]		.74
12 "	NH_4OH " " .90	1.52	1 oz.	Ag_2SO_4		1.15
1 "	NH_4Cl	.25	1/2 lb	MoO_3		1.31
2 "	KOH	.70	5 "	MnO_2		.20
1/2"	$K_2Mn_2O_8$	.15	1/2 "	MgO		.33
1/2"	$K_2Cr_2O_7$	.30	1 "	Cr_2O_3		.75
5 "	$KClO_3$ pure com.	.85	1 oz.	I		.35
1 "	KCl	.25	2 "	Br		.32
2 "	NaOH	.64	1/4 lb	$BaCl_2$		.08
1 "	Na_2CO_3	.27	1/2 "	$Pb(C_2H_3O_2)_2$		.11
2 "	$CaCl_2$ fused anhyd.	1.48	2 "	Jones Reductor	Zinc	.90
			5 "	Granulated Zinc		1.25
						$22.07

The total cost of the above equipment is $327.27; or in round numbers $325.00, as market prices may vary the above estimate 5% either way. The building mentioned above will cost with furniture, about $350.00, bringing the total cost of installation up to $675.00. The operating expenses per year, including the salary of one chemist at $75.00 per month should be about $1000.00.

REPORT OF TESTS.

The writer conducted two series of tests; one, series A, at the foundry of the University of Illinois; the other, series B, at the foundry of E. M. Burr and Co., Champaign, Ill. Each series consisted of six heats, and from four to six test bars were taken from each heat. Those in series A were all 1/2" x 1/2" x 12", and were made from patterns for "Keep's test". In series B three forms of test bars were used; the standard tensile bar, and the 1 1/2" round bar for transverse tests, as recommended by the A. F. A., and the 1/2" bar used in series A. All 1/2" bars were cast flat. All molds were made in green sand, by the writer.

Series A:- Taken at the University of Illinois foundry. All bars were poured by the writer, from a hand ladle, with good hot iron taken from the second or third tap. The cupola is a Whiting 22", and about 1500# of iron are melted each heat. Each tap draws from 250 to 300# of iron. Records of heats were kept on standard blanks, furnished by the University, and one of which, filled out for a heat in series B, will be found at the end of this report. The matter from these records for both series of tests is given in TABLES VIII and IX. From four to six 1/2" x 1/2" x 12" test bars, cast flat, were made every heat. These bars were all broken transversely between two supports 12" apart and with the load in the middle. As the bars were themselves only 12" long, the arrangement shown in fig. 4 was used. The ends of the bars were held in the square tubes t t, by the set screws s s. On the lower side of the

[illegible]

[illegible]

[illegible]

[illegible]

pieces tt, shallow notches were cut in order to facilitate placing on the supports, and the lines mm marked on the sides of t t, enabled the adjustment of the distance between the notches to be easily made. The bars were broken up in the small Riehle testing machine in the masonry laboratory of the civil engineering department. As this machine is usually used for breaking briquettes, an attachment furnished with the Olsen machine, for transverse tests of cement, was adapted to it and found to work very satisfactorily. As the bars were cast in the position shown at C fig. 3, the convention shown at a and b, fig. 3, was adopted for purposes of recording the position of the bar when tested; the position of the notch cast on the lower edge of the bar at one end, being as shown by the dotted lines when that end of the bar is looked at. This fact is recorded by the letters as in TABLE X, second column. The force was applied to the middle of the bar by a wedge attached to a vertical sliding screw, which was worked either by a hand wheel, constituting the nut, or by a worm which could be thrown into gear with a toothed part of the hand wheel, and which was used for slow speeds. There being 6 threads per inch on the screw and 50 teeth on the worm wheel, one turn of the crank attached to the worm raises or lowers the wedge 1/300 of an inch. The method of testing was as follows: The bar being clamped in the square tubes t t, and being marked at the middle, it was placed on the two supports, the wedge placed at the middle, and the screw was turned until a pressure of 20 pounds was produced, in order to take up slack in the machine.

The weight was then placed at 300 pounds and the screw tightened up to that amount as rapidly as the worm could be turned, the number of turns of the latter being counted. The pressure was then increased more slowly, the machine being kept balanced by running the weight out, until rupture occurred. The number of turns of the worm required to produce rupture, multiplied by 1/300 gave the deflection in inches. The fractured ends were measured and the dimensions recorded. The results of the tests in series A, and for the small bars in series B, are given in TABLE X. The "strength" given in the table was obtained by dividing the load by the area in square inches, as recommended by Mr. West.

Series B:- The small bars were poured with the same iron as the large ones and were tested as described above. All of the large bars, with the exception of Nos. 5a and 6a were cast vertical. The writer made all the molds for these bars at Burr's foundry, and they were all poured with hot iron from the 2nd or 3rd tap by moulders employed there, except for heat No. 4, which was poured from the middle of the heat with sluggish or slow iron. The 26" cupola at the foundry was made on the premises and from 1 1/2 to 4 tons of iron are melted each heat. Each tap draws from 400 to 700 pounds of iron. The molds were made from split patterns with the bars horizontal, and were set on end when finished; the two parts of the mold being held together by means of special bottom boards and bolts. The resulting bars were tested in the usual manner in the Philadelphia testing machine in the materials testing laboratory.

The sockets shown in fig. 2 were used for the tensile test, the bars for which were as shown in fig. 1. The tensile bars were uniformly bad; nearly all of them being weakened by flaws. This is believed to be due to the fact that the pattern for this bar was only 1" in diameter for the smaller portion, when it should have been at least 1/8 of an inch larger. It appears that the bars should be tapered from the end of the shoulder s,(fig. 1) to within an inch or so of the middle,instead of being reduced at that point and filleted, as one or two of those tested broke at the fillet. The bars should fit the the sockets loosely, so as to allow considerable side play.

The transverse tests were made in every case with the drag side of the bar down. The supports were 12" apart, load applied at middle, the amount of deflection was obtained by a rod clamped to the moving part of the machine, which touched the sliding arm of a vernier caliper which was clamped to the side of the machine. The first reading on the vernier was taken with a pressure of 60# on the test bar, and the machine being reversed at the moment of rupture, the rod receded from the arm of the caliper and the difference in the two readings, less the play in the machine (.01") gave the deflection with a fair degree of accuracy. Data was taken as in series A, and results are given in TABLES XI and XII. The iron in all of the bars of this series was of very good character judging by the fractures which were of a soft gray color, and of medium grain, varying only a very little from each other as far as the writer could tell.

Samples for chemical analysis were taken from the different irons and coke in the various mixtures and from the test bars for each heat, in the manner hereinbefore described, and turned over to the chemistry department. TABLES XIII and XIV show the relation between the heat numbers and brands of the iron from which the samples were taken, and the numbers or symbols on the bottles. The tables are left blank for the insertion of the results of the analyses.

11-2-00-300-R

MECHANICAL ENGINEERING DEPARTMENT SHOPS
UNIVERSITY OF ILLINOIS

FOUNDRY RECORD

Heat No. 2 AT E. M. BURR & CO'S. Date May 16 1902.

Make of Cupola Home made Size of Cupola 26"

Make of Blower Sturtevant Size of Blower 24"

Fire started 4. P M Blast put on 5:15 P M Bottom dropped 6:10 P M

First iron charged 4:45 First fluid iron appeared 5:25 Blast in inches —

Pig iron used { Kind #1 Soft; #2 Soft; Charcoal. No.
Analysis

Scrap iron used { Kind Machinery No.
Analysis

Coke used { Kind West Va.
Analysis

Flux used—Kind None Quantity

	Coke.	Pig Iron.	Scrap Iron.	Weighed by	Remarks.					
1st charge	90#	300#	300#	J W Stephenson	100# No 1,	50#	No 2;	150#	Charc	
2d charge	"	"	"	"	"	"	"	"	"	"
3d charge	75	150	450	"	"	"	"	"	—	—
4th charge	"	"	"	"	"	"	"	"		
Totals	50		600							

40 600
~~Total weight of iron melted~~ Ratio of iron melted to coke used

30 600
~~Weight of good castings~~ Weight of poor castings

10 400
~~Weight of sprues, gates, &c~~ Weight of iron lost in melting

Per cent. of iron lost in melting

General description of castings made—size, shape, weight, &c.

Test bar,
Analysis
Transverse test—size c. to c. Result
Tensile test—size Pounds per square inch
Hardness. By cutting or drilling
Microscopic features

Remarks— Test bars taken.

2 Tensile Standard. } cast vertical.
2 Transverse 1½ diam round.)

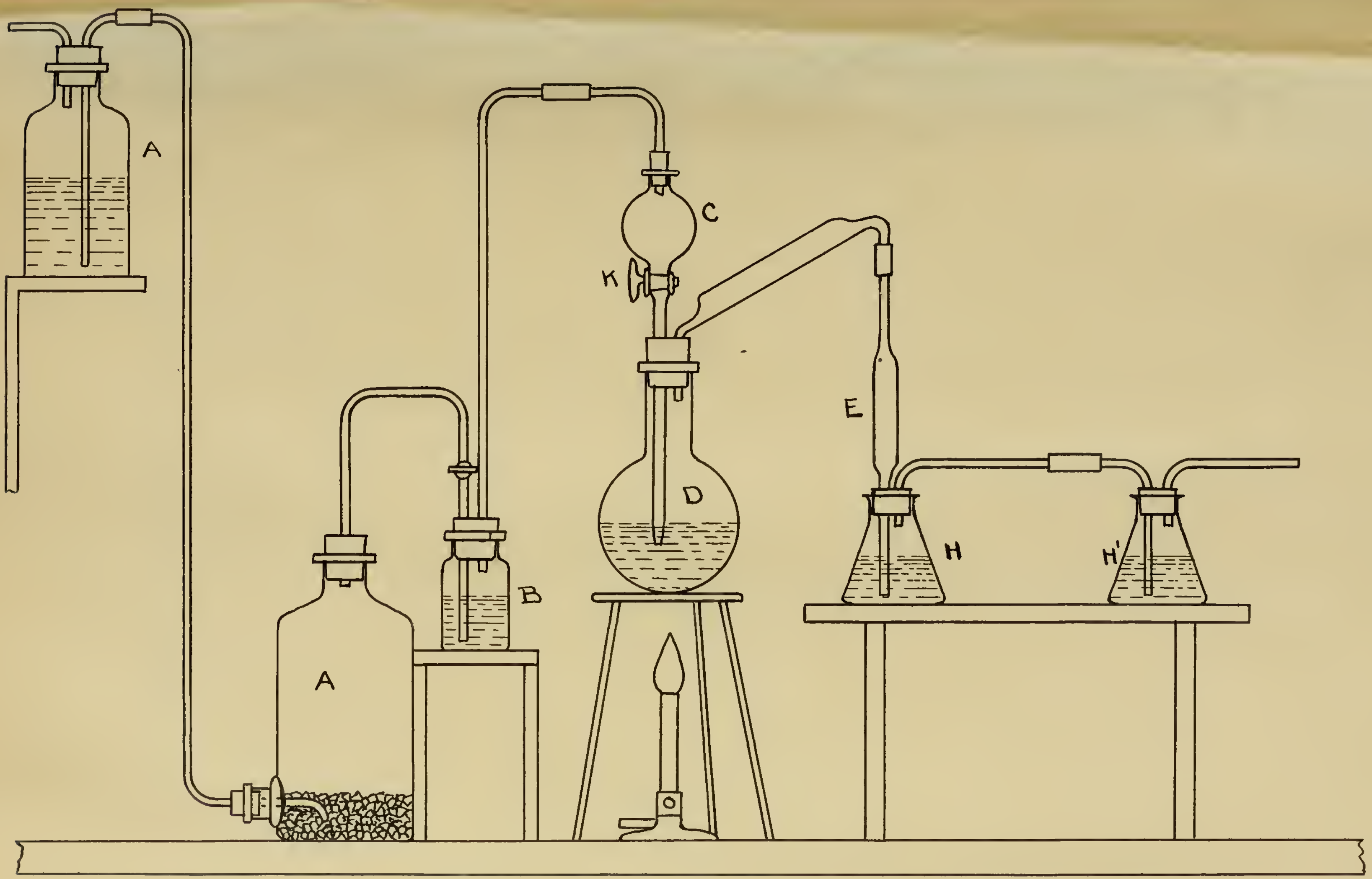


FIG. 5.

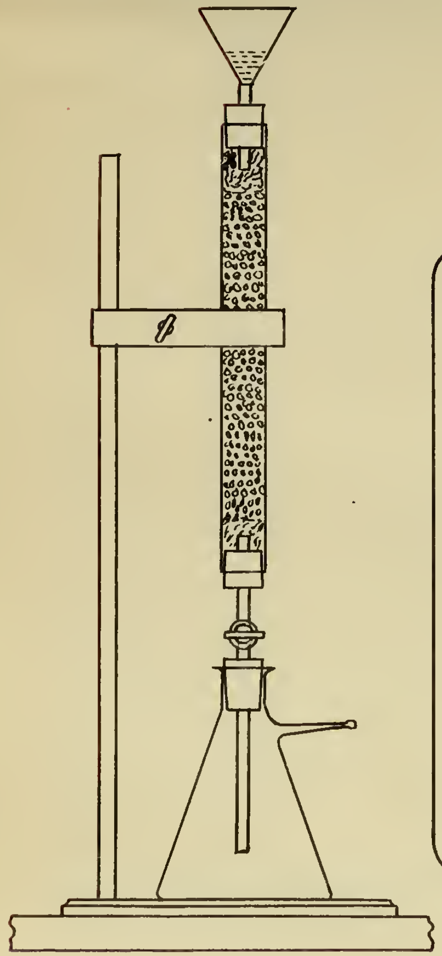


FIG. 6.

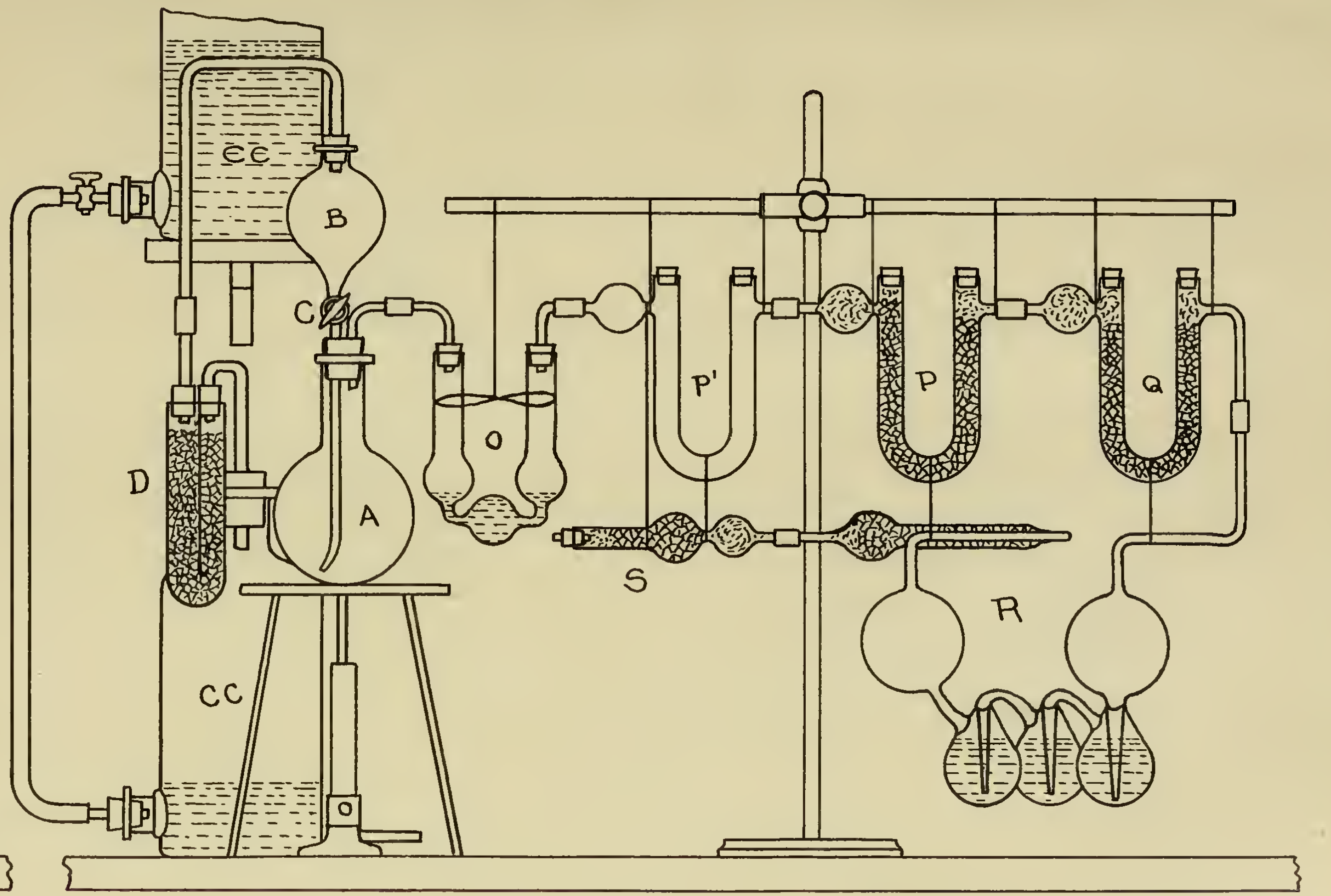
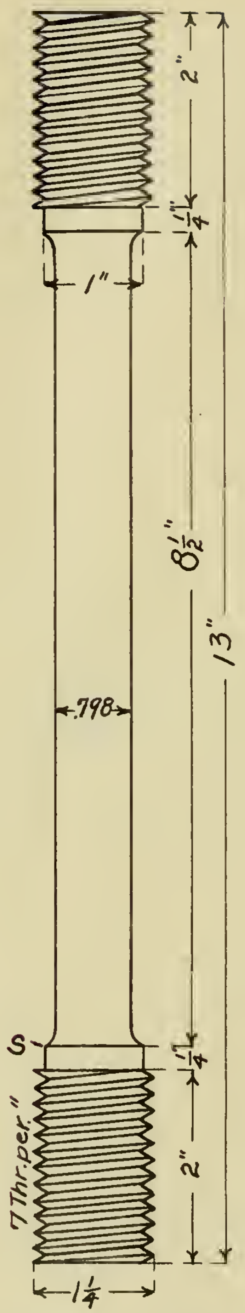
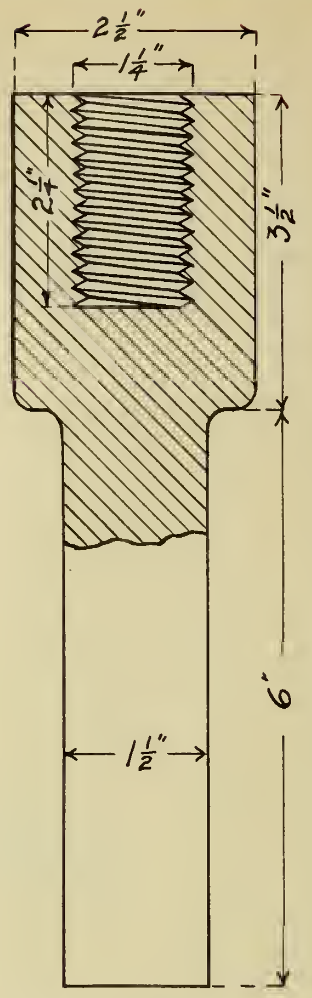


FIG. 7.



STANDARD CAST IRON
TENSILE TEST BAR.
FIG. 1.



STEEL SOCKET
FOR TENSILE TEST BARS.
2 REQUIRED.
FIG. 2.

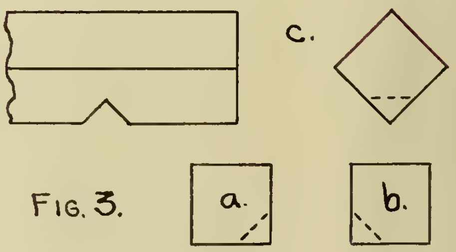


FIG. 3.

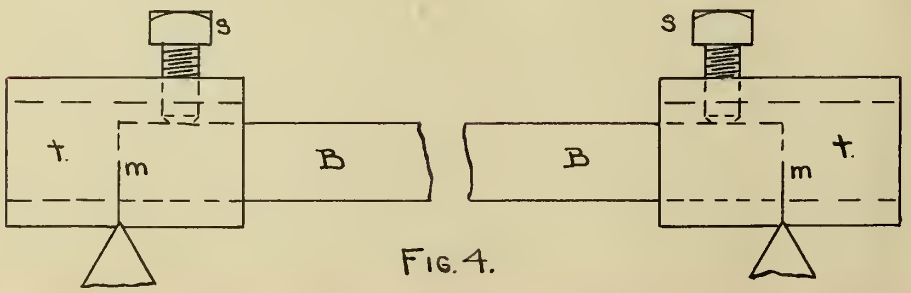


FIG. 4.

TABLE I.

INFLUENCE OF SILICON ON SHRINKAGE.

KIND OF IRON.	% SILICON	BARS $\frac{1}{2}$" □	1" □	1"x 2"	2" □	3" □
"IROQUOIS"	0.80	.183	.160	.148	.131	.116
"	1.21	.172	.150	.138	.125	.110
"	1.88	.166	.145	.130	.109	.069
"	2.01	.162	.145	.123	.099	.066
"	3.19	.157	.105	.094	.075	.067

TABLE II.

SILICON COUNTERACTING MANGANESE.

% MANGANESE	SILICON ADDED	DEAD LOAD STRESS	DEAD LOAD DEFL.	SHRINKAGE	HARDNESS
20.00	0.	150	.05	.272	185
"	1.66	168	.07	.266	186
"	3.00	179	.16	.240	146
"	4.84	230	.27	.222	115
"	6.20	326	.47	.218	123

TABLE III.

IMPURITIES IN PIG IRON.

BRAND	SILICON	SULPHUR	PHOSPHOR'S	MANGANESE	REMARKS
FOUNDRY	1.0 to 4.0%	.01 to .05%	0.2 to 1.5 %	0 to 1.50%	
CHARCOAL	0.5 " 5.0	0 " .08	.15 " .75	0 " 1.50	
BESSEMER	0.75 - 2.5	.01 " .05	0 " .10	.20 " 1.00	
GR. FORGE.	0.5 " 2.0	.05 " .20	.10 " 1.50	0 " 1.50	
BASIC	0. " 1.0	0 " .05	0 " 2.0	.30 " 1.50	P. desired low
FER.-SIL.	6.0 - 16.0	—	—	—	
MT'D.&WH'T.	0.1 - 1.0	.05 " .30	.10 " 1.00	.10 " 1.50	Carbon high.

TABLE IV.

ANALYSES OF FOUNDRY AND BESSEMER IRON.

	#1 FOUNDRY	#3 FOUNDRY	#4 BESSEMER	#7 BESSEMER
PHOSPHOROUS	.60	.50	.09	.09
GRAPH. CARBON	3.50	3.00	3.50	3.00
COMB. "	.15	.30	.35	.65
SILICON	3.00	2.25	2.00	1.25
SULPHUR	.01	.02	.025	.05
MANGANESE	.30	.40	.50	.45

TABLE VI.

GRADES OF PIG IRON BY % OF SILICON AND SULPHUR.

	#1	#2	#3	#4	#5
SILICON	2.75 to 3.00	2.50 to 2.75	2.25 to 2.50	2.00 to 2.25	1.75 to 2.00
SULPHUR	.01 " .04	.01 " .04	.01 " .04	.01 " .04	.02 " .05
	#6	#7	#8	#9	#10
SILICON	1.50 to 1.75	1.25 to 1.50	1.00 to 1.25	.75 to 1.00	.50 to .75
SULPHUR	.02 " .05	.02 " .05	.03 " .06	.04 " .07	.04 " .10

TABLE V.

CHANGE IN SILICON FOR EACH .01 % SULPHUR TO MAINTAIN QUALITY.

SULPHUR	.01	.02	.03	.04	.05	.06
SILICON	2.00	2.10	2.20	2.30	2.40	2.50

TABLE VII.

CALCULATING SILICON IN A CUPOLA CHARGE.

BRAND AND GRADE USED	WEIGHT OF IRON USED	×	PER CENT SILICON	=	TOTAL POINTS OF SILICON
#1, FLORA	600 lbs.		2.80		1680.00
#3, CLARA	400 "		2.26		904.00
#6, FRANK	300 "		1.50		450.00
SHOP SCRAP	200 "		1.80		360.00
YARD "	500 "		1.25		625.00
	2000 "		$\frac{4019.}{2000}$ = 2.00 %		4019.00

TABLE VIII.- RECORD FOR TESTS A AND B.

LOCATION OF FOUNDRY	NO. OF HEAT	IRON USED		COKE	DURATION OF HEAT	TOTAL IRON	TEST BARS MADE				REMARKS
		PIG	SCRAP				NO.	FORM	SIZE	HOW CAST	
UNIV. OF ILLINOIS	1	SOUTHERN	#1 SHOP	CONN'LSVILLE	25 min	1500#	4	SQ.	½"×½"×12(a)	HORIZ	IRON HOT
	2	"	"	"	40 "	1600	4	"	"	"	" "
	3	"	"	"	30 "	1500	6	"	"	"	" "
	4	"	"	"	35 "	1500	4	"	"	"	" "
	5	"	"	"	30 "	1500	6	"	"	"	" "
	6	"	"	"	20 "	1200	4	"	"	"	" "
E.M. BURR & CO.	1	#1 & 2 SOFT. CHARCOAL.	MACH'Y.	WEST VA.	50 "	5700	4 4	" ROUND	" 1½" d. (b)	" VERT	
	2	"	"	"	45 "	4600	4	"	"	"	
	3	"	"	"	50 "	3600	2 4	SQ. RD.	a b	HOR. VER.	
	4	"	"	"	1hr 15 "	6000	4	"	"	"	IRON SLOW.
	5	"	"	"	1" 0 "	3600	2 2 2	" " SQ	" " a	" HOR "	
	6	"	"	FRICK 72 hr.	45 "	3600	2 2 2	" RD "	" b "	" " VERT	

TABLE IX. CUPOLA RECORD.

TEST	CHARGE	HEATS																	
		#1			#2			#3			#4			#5			#6		
		COKE	PIG	SCR.	COKE	PIG	SCR.	COKE	PIG	SCR.	COKE	PIG	SCR.	COKE	PIG	SCR.	COKE	PIG	SCR.
A	1	6 bu.	400	600	6 bu.	400	600	6 bu.	400	450	6 bu.	400	450	6 bu	400	450	6 bu.	400	450
	2	2 "	200	300	2 "	150	450	2 "	300	350	2 "	300	350	2 "	300	350	2 "	300	350
B	1	90#	#1. #2. CH. 100 50 150	300#	90#	#1. #2. CH. 100 50 150	300#	80#	#1. #2. CH. 100 50 150	300#	90#	#1. #2. CH. 100 50 150	300#	80#	#1. #2. CH. 100 50 150	300#	70#	#1. #2. CH. 100, 50, 150	300#
	2	90	" " "	300	90	" " "	300	80	" " —	450	90	" " "	300	70	" " —	450	70	" " "	300
	3	75	" " —	450	75	" " —	450	70		600	70	" " —	450	60		600	60	" " —	450
	4	75	" " —	450	75	" " —	450	50		600	60		600	50		600	40		600
	OTHER	220		3300	130		2200	30		1200	180		3600	50		1200	40		1200

TABLE X

TRANSVERSE TEST OF $\frac{1}{2}$"X$\frac{1}{2}$"X12" BARS, SERIES A AND B.

No. OF HEAT	POSITION OF BAR	MICROMETER SIZE		BREAKING LOAD	DEFLECTION	STRENGTH PER SQ.IN.
		DEPTH	WIDTH			
A. 1	a	.508"	.534"	442#	.256"	1630#
1	"	.519	.496	410	.235	1590
1	b	.509	.531	406	.233	1500
1	"	.517	.501	474	.264	1830
2	"	.533	.500	434	.228	1630
2	"	.507	.515	480	.300	1840
2	a	.515	.533	442	.237	1610
2	"	.523	.510	450	.235	1690
3△	"	.509	.518	430	.256	1630
3△	"	.521	.497	416	.243	1610
3	"	.494	.532	432	.290	1645
3	"	.522	.508	460	.273	1730
4	"	.503	.528	436	.260	1640
4	"	.516	.499	458	.266	1780
4△	"	.519	.499	416	.262	1605
4△	"	.525	.501	450	.265	1715
5	"	—	—	450	.256	(FLAW)
5	"	.507	.523	456	.275	1720
5	b	.503	.523	452	.247	1715
5	"	.500	.524	482	.295	1840
5△	a	.523	.516	524	.292	1940
5△	"	.506	.536	490	.282	1810
6	"	.504	.526	454	.247	1715
6	"	.540	.508	490	.250	1780
6	b	.510	.525	468	.280	1745
6	"	.536	.514	446	.227	1615
B 1	"	.516	.522	360	.227	1655
1	a	.522	.501	360	.215	1185
3	"	.508	.514	414	.268	1585
3	b	.504	.515	360	.216	1385
5	a	.507	.530	440	.247	1640
5	"	.524	.510	450	.236	1680
6	"	.520	.517	452	.258	1680
6	"	.507	.499	424	.247	1675

TABLE XI.

TRANSVERSE TEST OF $1\frac{1}{2}$" ROUND BARS. SERIES B.

NO. OF BAR.	SIZE		BREAKING LOAD	DEFLECTION	STRENGTH PER SQ. IN.	REMARKS
	DEPTH	WIDTH				
1 a	1.41"	1.53"	5320#	.104"	3130#	ALL 12" BET. SUP.
1 b	1.45	1.49	4520	—	2660	
2 a	1.45	1.47	4810	.123	2880	1 small flaw.
2 b	1.44	1.49	4370	—	2600	2 medium " .
3 a	1.49	1.50	4450	.105	2540	
3 b	1.48	1.49	4060	.084	2350	
4 a	1.48	1.51	5730	.111	3240	
4 b	1.48	1.51	5000	.100	2830	2 small flaws.
5 a	1.50	1.50	5460	.126	3090	CAST FLAT
5 b	1.45	1.47	4650	.104	2780	TUMBLED
6 a	1.49	1.48	5200	.098	3000	CAST FLAT.
6 b	1.46	1.47	4940	.106	2940	

TABLE XII.

TENSILE TEST OF STANDARD BARS. SERIES B.

NO. OF BAR.	DIAMETER.	BREAKING LOAD.	STRENGTH PER SQ. INCH.	REMARKS.
1 a	.832	10370	18880	2 very small flaws
1 b	.799	7250	—	1 large flaw. About $\frac{1}{4}$ a.
2 a	.800	12150	24250	
2 b	.800	10090	20150	1 " " " "
3 a	.789	10330	20660	BROKE AT FILLET.
3 b	.800	10250	20450	1 medium flaw. $\frac{1}{10}$ a.
4 a	.814	9950	—	1 large " . $\frac{1}{5}$ a.
5 a	.801	11050	21920	2 very small flaws.

TABLE XIII

CHEMICAL ANALYSES OF PIG IRON AND COKE

KIND	MARK	SILICON	SULPHUR	PHOSPHOROUS	MANGANESE	TOTAL CARBON	GRAPHITIC CARBON
SOUTH'N	C						
#1 SOFT	D						
#2 "	E						
CHARCOAL	F						
CONNELSVILLE	K						
WEST VA.	L						
FRICK.	M						
SHOP SCRAP.	G						
MACH'Y "	H						

TABLE XIV

ANALYSES OF TEST BARS.

NO. OF TEST	MARK	SILICON	SULPHUR	PHOSPHOROUS	MANGANESE	TOTAL CARBON	GRAPHITIC CARBON
A 1	A 1						
2	A2						
3	A3						
4	A4						
5	A5						
6	A6						
B 1	B1						
2	B2						
3	B3						
4	B4						
5	B5						
6	B6						