

making allowances, of course, for the changes that occur in melting the metal.

(7) As a final question in this line, I would like to ask what elements you use in estimating the strength of your test bars, and the general method of doing this work; that is, the amounts per unit for the elements that you consider, and how these figures are modified, owing to the relation of one element to the others.

I think the above information would make a very fair starting point for our young men, and also for a good many of the older ones here present. I do not mean to impose on Mr. Outerbridge's good nature too much, or ask him to give away any of their trade secrets, but if the foundrymen are going to instruct the young men, they must give them the best information they have on these subjects, and I believe that in the end all would be gainers by doing so.

In 1895 I gave the following proposed scheme* for the study of the physics of casting to the American Institute of Mining Engineers, and knowing that there has been considerable advance in the process since that time, I would

*NOTE ON A PROPOSED SCHEME FOR THE STUDY OF THE
PHYSICS OF CAST IRON.

BY WILLIAM R. WEBSTER, PHILADELPHIA, PA.

In view of the great interest now taken in the tests of cast iron and details of foundry practice, with the number of investigators at work and recent improvements in the methods of research, it would seem that the time is ripe to attempt the solution of some of the many problems with which iron founders have to contend. Recent papers and discussions on these subjects have opened up a large field for investigation, and have emphasized the importance of many considerations generally overlooked. With the view of promoting a comprehensive and systematic discussion, I have attempted to tabulate, in convenient form, some of the most important points for investigation, on the general plan suggested, with such good results, by our former President, H. M. Howe, for the discussion on the "Physics of Steel," at the Virginia Beach meeting last year. This table can, no doubt, be modified or enlarged to advantage, and put in shape to serve as a guide or reminder to all who are interested in this line of work.

SUGGESTED LINES FOR DISCUSSION AND INVESTIGATION.

I. Correspondence between chemical composition and melting point, fluidity, shrinkage, fracture, chill, micro-structure and other physical properties.

ask Mr. Outerbridge if he would be kind enough to bring these suggested lines for discussion and investigation up to date. I will not take the time to read this short paper, as several copies have been distributed to the members, but would be greatly obliged to any of them who would assist in bringing this matter up to date in all respects.

In my list of questions to Mr. Outerbridge, I omitted the following:

What is the best check test you know of, that can be made quickly before pouring the metal, that will show if it is suitable for the castings for which it is intended? In this I refer to some simple test that will show the physical character of the metal, similar to the ladle test used in melting steel in the open-hearth furnace.

In steel there is always more or less trouble from the oxide of iron. This also gives trouble in cast iron, and I would like to ask, what is the best method of getting rid of the oxide of iron in cast iron, and how long has it been in use?

II. *Influence of:*

- (1) Cupola mixture, use of steel and other scrap, oxidized or clean material,
- (2) Manner of melting, flux, etc.,
- (3) Casting temperature,
- (4) Manner of handling melted metal and method of casting,
- (5) Size and form of casting,
- (6) Kind of mould, green sand (under different conditions of ramming, amount of moisture, and skin-dried), dry sand, loam and chills,
- (7) Rate and mode of cooling castings,
- (8) Manner and temperature of heating for annealing,
- (9) Additions of nickel or aluminum,

on

- A. Fracture.
- B. Micro-structure.
- C. Physical properties.
- D. Shrinkage.
- E. Chill.
- F. Residual stress.
- G. Condition and quantity of carbon and other elements.

III. *Segregation as affected by:*

- (1) Composition.
- (2) Casting temperature.
- (3) Rate of cooling.
- (4) Size and shape of casting.

MR. OUTERBRIDGE:—For the sake of brevity I think it will be advisable to group several of Mr. Webster's questions together in my replies thereto. With regard to his deduction from the records of annealed and unannealed test

IV. *Blow-holes, their volume and position as affected by :*

- (1) Composition.
- (2) Casting temperature.
- (3) Casting pressure.
- (4) Rate of cooling.
- (5) Size and shape of casting.
- (6) Special additions.

Instead of giving a review of what has been written on the most important of the above headings, I have induced several investigators and experts to contribute the results of their work and opinions. If these are fully discussed, and followed up by the results of others who are working in the same line, we shall soon accumulate a large amount of valuable material. That such material already exists there is no reason to doubt.

Several works have employed chemists, and struggled with these problems for years, but each one carefully guards the results ; and at the present time many seem disinclined to add theirs to the common store. But, if they could be induced to make their methods and results public, by freely discussing them before this Institute, they would be well repaid by the assistance they would receive through such an interchange. Nobody is as wise as everybody ; and nobody loses, as a general rule, by a generous frankness which secures the criticism and help of others. The possible loss through giving to competitors a few shop secrets is really trivial in comparison.

I am fully convinced that the relations between the chemical constitution and physical character of cast iron are much closer than is generally admitted to-day. If proof of this is wanted, we have it in the success of those who have given up the old rule-of-thumb methods in running their foundries. There is no doubt that, in a full discussion and investigation of this kind, new data will be brought to light which, in connection with the results of the valuable researches already made, would enable us to make tables and lay down rules for the founder's guidance that would be of the greatest value to the makers and users of cast iron. In other words, from a cupola or furnace mixture, of known chemical composition, we could predict with certainty the physical properties of castings of any given size or shape (due allowance being made for change of composition in melting). Or, when certain physical properties were required in a casting of given size and shape, the chemical composition of the different mixtures that would produce these results could at once be given without any of the "cutting and trying" that we now have. This is not too much to expect ; and it is not too much to hope that each will do his part in bringing about a result so beneficial to all. [*Transactions of the American Institute of Mining Engineers*, Vol. XXV, 1895.]

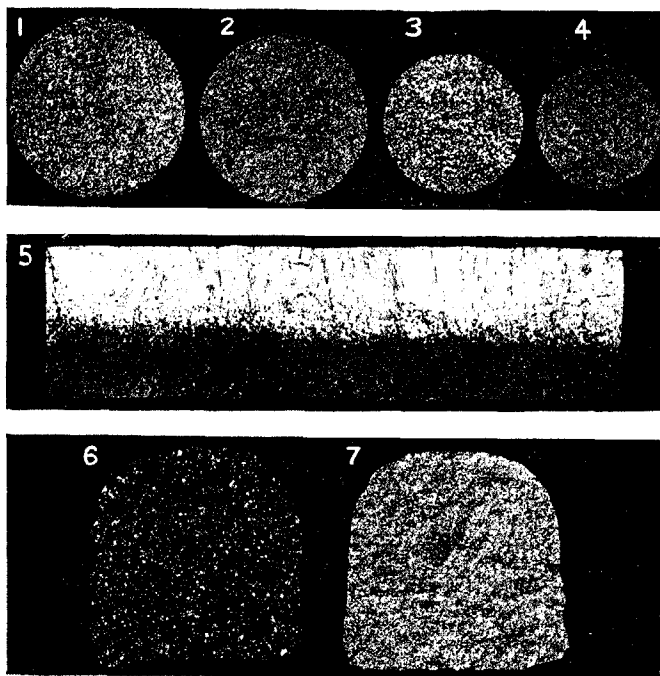
bars of cast iron, given in my first communication, that, notwithstanding the decrease in strength of the annealed bars, they were better able to withstand shocks, as indicated by an increase in deflection, I would say that a calculation of the "resilience" of the bars, made by Prof. J. B. Johnson's rule, shows a large decrease in resilience of the annealed bars, due to the fact that the increase in deflection was far less, relatively, than was the decrease in strength. With regard to Mr. Webster's next point, I would simply call attention to the wording of my original discussion, in which it appears that, in referring to the great difference in grain, or fracture, of cast iron in large and small castings, I said, "no such great difference exists in steel castings," but did not say that there is no difference in grain in large and small castings made from one ladle of molten steel.

Replying to questions 1 and 2, I may say that for many years past it has been my aim to produce castings, day after day, varying from the smallest sized pulleys with rims about a quarter of an inch thick, up to immense machinery castings weighing 40 or 50 tons, and requiring very different mixtures of iron, in which the test bars shall not vary in strength more than 5 per cent. from the predetermined standards of strength (transverse and tensile) for castings of any given kind. I am sure, from a review of records extending over a good many years, that the average variation is less than 10 per cent., and such variations would probably be still less if it were practicable to melt only one grade of metal in a cupola in one heat. Commonly, three different grades of iron are melted in one heat, viz., soft iron for pulleys and light work, moderately strong iron for "medium" work, and very strong iron for special castings, generally of large size. The transverse strength of 1-inch square test bars 15 inches long, broken with supports 12 inches apart, varies from about 2,000 pounds for soft iron to 4,000 pounds (center load) for strong iron, and the tensile strength ranges from about 20,000 pounds to about 40,000 pounds per square inch.

(3) The fracture of the pig iron is carefully noted when the iron is received in the yard, not so much as a guide to

subsequent mixtures in the cupola, but because it is an indication of the working condition of the furnace from which the iron was purchased. It may be stated, however, that more attention is paid to the fracture of the pig iron in making charges for pulleys and small work than in making mixtures for large castings.

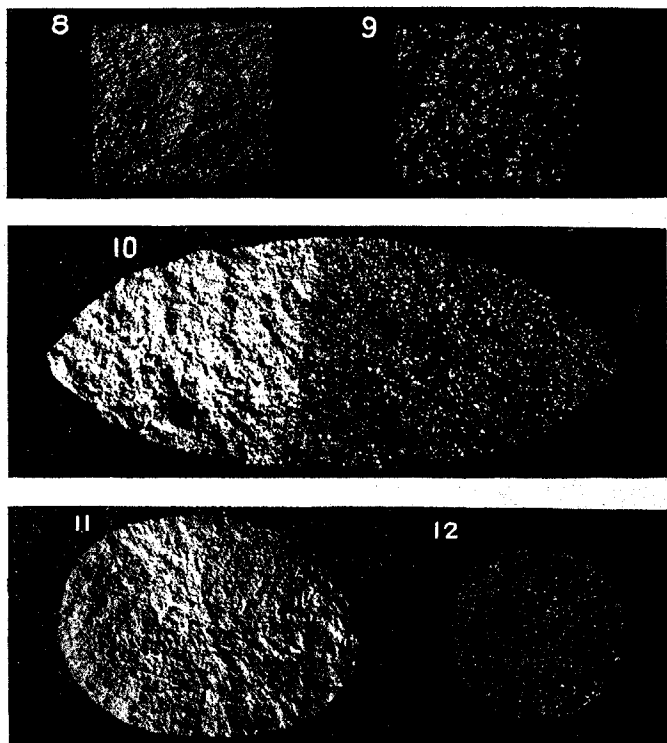
(4-5) The resultant castings ordinarily agree very closely with the composition of the mixture charged in the cupola,



as a certain allowance is always made for burning out of the metalloids in melting. For example, a casting, such as a car wheel, which should contain by calculation from the mixture 0.7 per cent. of silicon, will rarely, if ever, be found to vary more than $\frac{1}{10}$ of 1 per cent. either way from the standard. In like manner, a casting made from a mixture of different kinds of pig iron having very different proportions of silicon, but averaging $2\frac{1}{4}$ per cent. of that element, will

rarely be found to vary more than $\frac{1}{4}$ of 1 per cent. from the standard.

(6) The strength of test bars depends largely upon the size of the bars. Two bars cast in the same mould from the same ladle of iron, from a good mixture, one bar being $1\frac{1}{4}$ inches diameter and the other $1\frac{3}{4}$ inches, both turned to the same size, say 1.129 inches (= 1 inch area), will show a variation



of about 20 per cent. in the tensile strength of the two bars, the larger bar being the weaker, assuming, of course, that both bars are gray iron. I have already stated that the strength of the test bars can be approximately estimated from a knowledge of the composition of the mixtures.

(7) I regard the element silicon as the most important of all in determining the question of strength of foundry

iron, not because this element imparts strength or weakness to iron *per se*, but because it controls the condition of the carbon, whether graphitic or combined.

Other elements, such as phosphorus, sulphur, manganese, etc., all exert their influence, but it is not very difficult to guard against the danger of introduction of any of these elements in injurious proportions, while some of them, when present in moderate amount, are beneficial.

In reply to Mr. Webster's final questions, I would say that the kinds of foundry tests which shall show the physical character of the metal before pouring depend so largely upon the character of the castings to be made and kind of metal melted that the methods adopted in one establishment may not be at all suitable to another. So far as I know, there are few general foundries where rapid tests are made during the run of iron, and the consequences of such neglect are sometimes serious, for castings are poured from metal unsuitable for the work, this fact not having been known at the right moment to prevent the error.

Finally, I may say that I am convinced that the presence of iron oxide dissolved in the molten metal is a factor which is commonly overlooked, and is to be feared, especially in strong iron mixtures. The best deoxidizer with which I am familiar is ferro-manganese, a metal containing about 80 per cent. manganese, which may be added either in the ladle or in the cupola in the proportion of about 1 pound to 600 pounds of iron. The effect is to increase the strength and ductility, to decrease the chill, and to darken the gray color of the fracture in high-chilling iron mixtures. This discovery was first brought to the attention of metallurgists in an address given at the Franklin Institute in February, 1888, on "Pig Iron, Including the Relation Between Its Physical Properties and Its Chemical Constituents."*

Since that time the beneficial effects of ferro-manganese as a deoxidizer and desulphurizer in certain iron mixtures have become quite generally known, and its extensive

* *J. F. I.*, March, 1888.

use, especially in car wheel foundries, has followed thereupon.*

DESCRIPTION OF PLATES.

FIG. 1 shows the fracture of a test piece cast from a regular melt of fairly strong iron for machinery castings. The rough dimensions of the bar were $1\frac{5}{8}$ inches diameter by 15 inches in length, turned on a lathe to a diameter of 1.129 inches for a length of $7\frac{3}{4}$ inches between shoulders, and pulled on an "Emery" 100,000-pound hydraulic testing machine. The tensile strength was 33,740 pounds per square inch.

FIG. 2 shows fracture of fine-grained, soft iron, made in a special manner for special work. The rough dimensions of the piece were $1\frac{1}{4} \times 1\frac{3}{4} \times 13\frac{1}{2}$ inches, turned to a diameter of 1.06 inches for a length of 8 inches. The tensile strength was 29,794 pounds per square inch.

FIG. 3 shows comparatively coarse-grained fracture of soft iron for pulleys and small work. Rough dimensions $1\frac{5}{8}$ inches \times 15 inches, turned to a diameter of .935 inch for a length of 7.25 inches. Tensile strength, 19,708 pounds per square inch.

FIG. 4 shows fracture of a square bar cast from nearly the same grade and quality of cast iron as Fig. 1. Rough dimensions, $1 \times 1 \times 15$ inches. This bar was first broken transversely on a testing machine with supports 12 inches apart. The transverse strength was 4,200 pounds, center load. One of the broken pieces was then turned to a diameter of .813 inch for a length of 4 inches between shoulders, and pulled. The tensile strength was 40,116 pounds per square inch. The greater strength as compared with Fig. 1 test piece was due to the smaller dimensions of the bar.

FIG. 5 shows fracture of a "chill test piece" cast in a green sand mould, with an iron "chill-block" on one face. This casting was made from the same ladle of iron as Fig. 1 tensile test bar. The metal has sufficient chilling property for making chilled cast-iron car wheels and contains no charcoal iron.

FIG. 6. shows fracture of a pig of foundry iron, graded "2", made with mixed anthracite and coke fuel. It contained 1.7 per cent. silicon.

FIG. 7 shows fracture of a pig of foundry iron, graded "2 plain," made with coke. It contained 2.75 per cent. silicon. These samples of pig iron show the risks which foundries incur when relying upon furnace grading of pig iron by fracture.

FIG. 8 shows fracture of a test bar $1 \times 1 \times 14$ inches cut from the outer portion of a cubical block of cast iron $15 \times 15 \times 15$ inches. This block was first planed on all faces and then cut into eight slabs, $1 \times 14 \times 14$ inches; these slabs were each cut into eight strips, or bars, making 64 test bars in all, $1 \times 1 \times 14$ inches each. The bars were numbered serially and all

*The speaker illustrated his remarks with an interesting collection of specimens of pig iron, test bars and castings. By the aid of a "megascopé" the physical characteristics of freshly fractured surfaces of different grades of metal were shown by casting their images, greatly magnified, upon a screen. A few of the more striking specimens have been photographed, and are here reproduced by the half-tone process.—EDITOR.

were broken transversely on a testing machine with supports 12 inches apart. The piece marked *Fig. 8* was taken from the bottom row. It shows a fine-grained fracture and gave transverse strength of 2,878 pounds, center load.

FIG. 9 shows fracture of a test bar cut from near the middle of the cast-iron block; it shows a very coarse-grained fracture and dark color; the transverse strength was 1,800 pounds, center load. The average strength of the eight test bars cut from the middle of the block was little more than one-half the average strength of the eight bars cut from the lower part of the casting.

FIG. 10 shows fracture of an arm of a pulley, cast from soft iron similar to *Fig. 3* test piece. A card was laid upon a portion of this casting and the exposed part was briskly brushed with a whisk for about three minutes. The loose graphite lying between the crystals of iron was brushed away like dust, thus changing the color of the surface of the casting from dark gray to almost white, and giving the metal an extremely hard appearance, which, of course, was entirely deceptive. This interesting experiment may be readily repeated upon any freshly-fractured surface of gray cast iron.

FIG. 11 shows fracture of an ingot of white iron, rough dimensions $2 \times 1\frac{3}{4} \times 10$ inches. This metal was exceedingly brittle and too hard to machine; the white iron bar was placed in an annealing oven, in a closed case containing sand and charcoal, to prevent any decarbonization, such as occurs in making "malleable" iron castings. The combined carbon of the white iron was gradually changed into graphite interspersed in the interstices of the metal. The bar then became quite "tough" and dark gray in color.

FIG. 12 shows fracture of a test piece turned to 1.129 inches in diameter, from the bar *Fig. 11* after annealing. The tensile strength was 47,760 pounds per square inch. A brief description of this interesting and rather novel treatment of white iron castings may be found in the *Journal of the Franklin Institute*, May, 1900, in the discussion of Mr. Kreuzpointner's paper on "Riddles Wrought in Iron and Steel."

MR. ASA W. WHITNEY:—In agreeing recently with Mr. Outerbridge's statement concerning the weakening of the metal of chilled cast-iron wheels by the annealing, which strengthens them as castings, through the relief of the unequal strains of gray plate and chilled tread, I was misled at the time by the correspondence of merely similar tests of mine on 2-inch square bars of gray wheel metal with his 1-inch square bars of low chilling or nearly non-chilling iron. In spite of Mr. Webster's criticism, Mr. Outerbridge's position is apparently correct, as the averages of the two sets of bars give a reduction of resilience of about 13 per cent.

But judging from the fact that ordinary wheel annealing decidedly improves in resistance to drop tests even gray iron centers for steel-tired wheels, it is evident that the

testimony of square bars is not final. I regret that I have never tested by flat bars the point now raised by Mr. Outerbridge. But it seems probable that the kind as well as the degree of effect of annealing depends upon the method and completeness of the process as well as upon the character of metal and of the cross-section treated. A flat bar, even of the same sectional area as a square one of the same iron, does not figure out to the same modulus of rupture and resilience unless cut from a larger casting. Even in gray castings, as pointed out, and illustrated by photogravures, in my paper on "Transverse Strength of Chilled Car Wheel Metal,"* the effect of a difference in the relations of the direction of quickest cooling to that of stress can be shown without a change of cross-section. It is likely that the effects of annealing on flat bars of different gray compositions will be found more or less beneficial in reasonable agreement with the indications of practice. Estimating from the calculated modulus of elasticity of Mr. Outerbridge's bars and from my tests on unannealed square, flat and hexagon section wheel iron bars, it appears that a gray iron only slightly harder than his will increase at least 5 per cent. to 10 per cent. in resilience by ordinary wheel annealing if cast $\frac{3}{4}$ inch deep by 2 inches wide and tested flat. In wheel iron bars chilled solidly white from opposite sides, even if of $1\frac{1}{2}$ inches square cross-section, the difference due to a change of relation of stress to the direction of quickest cooling is far more notable than that caused by the annealing of the 1-inch square bars in question. Averaging the two 1-inch bars in each condition referred to, it appears that annealing effects a loss in transverse strength of 19 per cent., and in resilience of 13 per cent., in spite of increase of elasticity of 30 per cent. (E or factor for modulus of elasticity being reduced from 10,555,000 to 8,074,000). But the greater importance of the effect of a more rapid dissipation of heat in the direction of the depth rather than of the breadth (referring to position of bar in transverse test) is shown by the results of change of position in testing ten

**Journal of the Franklin Institute*, April, 1897.

aforesaid $1\frac{1}{2}$ square bars. Five were tested with the direction of *slowest* cooling as the depth, or direction of load, and the other five with the direction of *quickest* cooling as the depth. A comparison of the average results of each set shows that changing the direction of depth or load from that in line with slowest to that of quickest cooling effects a gain of 81 per cent. in transverse strength (modulus of rupture) and 175 per cent. in resilience in spite of a decrease of 19 per cent. in elasticity (E increased from 9,173,500 to 10,892,000).

The effect of subsequent moderate annealing would probably reduce the value of E more than the modulus of rupture in the original direction of quickest cooling, thus showing improved resilience.

The great effect of the original rates of cooling upon E , in wheel iron, owing to shapes and sizes, is shown by the following: In a 1-inch square bar, tested with direction of chill as the depth, $E = 15,988,000$ and modulus of rupture 46,836; while a bar of hexagon section and 4-inch area from same ladle, totally gray (cast entirely in sand), showed $E = 6,081,500$ and modulus of rupture 60,240, which, with but 11.3 per cent. increase of transverse strength and 3 per cent. decrease of specific gravity over flat chilled bar of same area tested the strong way, gave it a resilience of 103, or 71 per cent. greater. This effect of the direction of quickest cooling is so great that the flat chilled bar referred to above will break, if tested edgewise, at about 2 per cent. less instead of 70 per cent. more than if tested flat, or in direction of quickest cooling. Consideration of the above points leads to the conclusion that wheel iron at least, cast in flat bar or plate form, even though gray in fracture, is given a higher resilience by ordinary annealing because the reduction in the value of E is more important than the reduction of modulus of rupture in the direction tested, which is that of the most rapid dissipation of heat.

Incidentally, it is therefore evident that, in calculating strength and resilience of one form of section in cast iron from another by the proper engineering formula, reference to the modulus of elasticity and to specific gravity is also

necessary. For different compositions reference to relative grain and capacity for chill is required, as these are also affected by the same changes in rates of cooling due to change of section or its relation to stress. As calculation directly from the approximate analysis already gives a measure of success in prediction of relative strength and capacity for chill for standard conditions, I presume further study and experiment will develop formulæ, based on chemical composition, which will more directly give the proper corrections on modulus of elasticity and specific gravity to be made for change of composition as approximately known from the chemically calculated cupola charge.

Mr. Francis Schumann has already given formulæ by which the contraction of any shape or section can be calculated when rate of contraction of any standard test bar is known.

Systematic work on these laborious lines would presumably result in valuable tables and short formulæ.

Resolving of ordinary analysis into a metallographic analysis of the terms cementite, etc., referred to by Professor Howe, would probably at once simplify formulæ for standard conditions.

In regard to wheels that "break asunder with a loud report" if allowed to cool outside the mould without annealing, I can state that a proper application of foundry chemistry has proved such quality to be of unsuitable composition for best results even if annealed, and has made it very rare. For wheel annealing it is not the time of cooling, but, as Mr. Schumann has stated in regard to glass, the uniformity of rate of cooling, which is important for the *relief of strains*, whereas for the *formation of graphite* time is doubtless important. Where the latter occurs to a marked degree the effect upon the physical qualities depends upon the original character. For instance, the white iron bars recently shown by Mr. Outerbridge were improved greatly both in tensile and transverse strength and in resilience by such annealing, which fact also tends to indicate that flat bars of moderately hard iron would be improved rather

than weakened even by severe annealing. In fact, I have obtained best results in annealing of light wheels by using a much higher initial temperature with uniform but quick cooling, two days being sufficient, instead of our former practice requiring three, or that of other makers, who use no fire in pits, and require as many as five or six days.

Concerning Mr. Outerbridge's answers to Mr. Webster's questions 4 and 5, I disagree with the idea that the correspondence is close or uniform between the cupola charge and the casting. In a crucible melt the variations are important, in a cupola much greater, and in an air furnace enormous. Even to the untechnical founder this difference is one of the salient features of foundry experience. And the measure of this difference is, naturally, the very considerable percentage of new iron necessary to continue the same quality. Constant experience for many years with mixtures calculated from complete analyses, and compared with analyzed and physically tested castings, has shown the actual differences for different kinds of casting and conditions. Moreover, the exact average kind of pig required to balance given scrap or pig on hand is easily calculated from such differences, and then subdivided by reference to the kinds and prices of available stock on the market. The results have never indicated any notable amounts or importance of dissolved oxides even in air furnace-melted mixtures for cast iron.

But the impracticability of making up mixtures wholly by calculation from complete analyses of the stock, without a knowledge of the kind of chemical change and the approximate amount of total oxidation which causes this change, is sufficient reason for the limitations in the practice of those who use only partial analyses. In such cases it is necessary to limit the classes of stock much more than in strict chemical practice, supplement analyses and sampling by such considerations as "working condition of the furnace" which made the pig, besides generally admitting that "more attention is paid to the fracture of the pig in making charges for pulleys and small work than in making mixtures for large castings." Even where silicon was sup-

posed to be quite uniform in its oxidation and in its allowable amount, it is now evident that both of these matters depend upon the other elements, particularly the carbon; which latter may range, by experienced adjustment of remainder, from 3.5 per cent. to 4 per cent., even in the line of car wheels of good quality. A well-known argument against foundry chemistry has been that equally good castings of same kind may analyze quite differently, and, *vice versa*, that so-called "practically identical" analyses may be obtained from physically unequal castings. Thus, it is evident that to "guard against" "undue amounts" of certain elements and to attain, also, the proper adaptability at one foundry, which is shown to be possible by the various results of ordinary practice, some fairly accurate knowledge of the relative importance of variations and oxidation is essential. The "moderate amount," which is as vital as is the presence of an element in cast iron, can only be "positively beneficial" to a maximum degree when it is known exactly enough to permit of proper adjustment to other elements by calculation on complete analyses.

In working by chemistry, the total oxidation, which causes an increase in the percentage of iron in the casting over that in the charge, usually with an increase in phosphorus, is most practically important. That is, a variation in the amount of the principal constituent is, in general, more important than any one of the lesser variations causing it. Professor Howe's view of the comparative results of oxidation of cupola and air furnace practice, and, in a general way, the imputation of greater strength to air furnace iron from this cause, being in line with experience, does not tend to substantiate Mr. Outerbridge's explanation of the difference, by reference to dissolved oxides. In fact, the usually greater percentage of iron in the charge for air furnace work, its greater increase by the oxidation of other elements, the long exposure to oxidizing influences and final pouring of a generally harder metal at a lower temperature than such metal from a cupola would show, apparently tend to favor the presence of more oxide in air furnace castings. But in this work, also, experience shows

that in fairly hot fusible cast iron the effect of such oxides is unimportant until chemical method is used fully otherwise. The kinds and amounts of the changes caused by oxidation are greater and more difficult to follow than in cupola work, but the solution of these problems, rather than of very important amounts of oxides, has been already to a large extent accomplished.

In view of the foregoing there appears to be no sufficient proof that the oxides of manganese found in slag or on surface of molten cast iron result from a reduction of dissolved oxides by the original, or by specially added, manganese. Its real effects are, however, practically considered and utilized in my practice of the close application of chemistry. The original manganese in the metal or mixture, besides being oxidized more rapidly than other elements, is notably slagged off by the sulphur. By again restoring it in any way, more sulphur is removed and all ratios altered, the iron being decreased in percentage. The crude way in which it was first used without chemistry led to serious irregularities of quality; and whereas it was supposed to be wasted if put in large receiving ladle or in the cupola charges, I have found it useful according to the principles of my ordinary calculation on the chemistry, in much smaller amounts than originally recommended, either in charges, large ladle, with or without admixture of other material, and with limitations in small ladles. Various conditions determine which is the better way to use it, as also when to omit it.

Regarding quick tests to show quality of iron in a ladle before pouring castings, such are hardly practicable in hard iron. But even a modification of a small chill test might be devised in connection with chemical method, which would be satisfactory in spite of rapid cooling. Ordinarily the last "furnace test" of air furnace practice does not exactly represent the "ladle test," and both are too slow for immediate use. There is a doubtful method which consists in judging by the general shape of water-chilled shots. I believe it was Dr. Blair who mentioned a modification of this, which consists in the use of a sieve,



FIG. 1.—Very hard, but of fair strength, though coarse. A result aimed at by close calculation from complete analyses. Only .83 per cent. manganese. Solid white without chilling in much larger sections. The effect of chilling one edge (top) is shown in the greater length and definition of crystals from that edge. See p. 346, May, 1900, *J. F. I.*

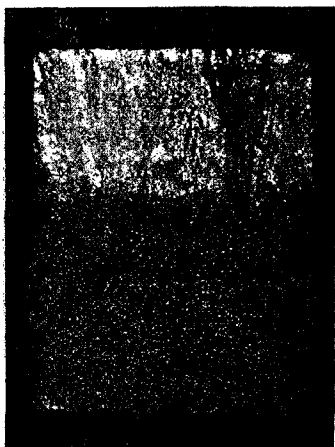


FIG. 2.—Chill test of a calculated low phosphorus mixture of which 97 per cent. was a remelt of tinned and detinned sheet iron and steel. No ferro-silicon or cast iron used. Tin, .135 per cent.

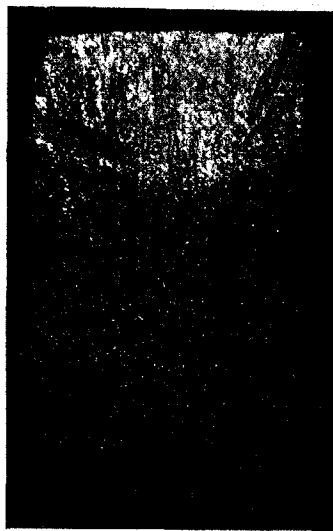


FIG. 3.—Good wheel mixture. 61 per cent. wheel scrap; 16.5 per cent. charcoal irons. No ferro-manganese in charge or ladle. Chill test of first tap.

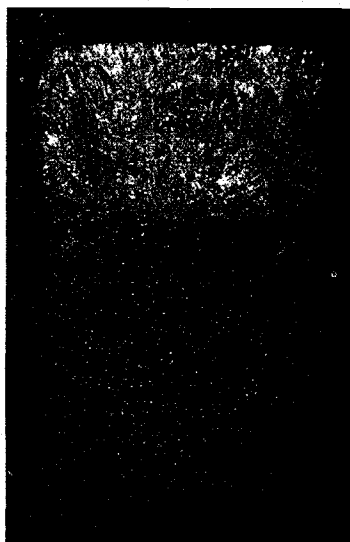


FIG. 4.—Good wheel mixture. 55 per cent. wheel scrap; 3.9 per cent. charcoal iron; .1 per cent. ferro-manganese. No ferro-manganese in ladle. Chill test of first tap.

through which the molten iron is dropped, causing it to fly mostly into shot about the size of mustard seed without melting the sieve. I have used this method in obtaining occasionally quick analyses of wheel metal during the heat. But for soft iron very small chill cup tests, cast in iron moulds similar to the "Whitney chill cup" used at some blast furnaces since 1872, would suffice. I have experimentally used, as quick chill cup tests for soft iron, the ingots 4 inches long and $\frac{1}{2}$ inch and 1 inch square, produced by the iron moulds devised by Mr. Outerbridge for investigation of chilled irons. A little modification would make them very convenient tests.

As results of mixtures made up wholly by calculation on complete analyses of component material, I show four photogravures on next page. *Fig. 1* is the very coarsely crystallized white iron sample referred to on page 346 of this discussion, March 14, 1900. It would run entirely white even if cast entirely in sand and of much greater cross-section. The effect of the more rapid cooling by the iron chiller is merely to make lines of crystals more uniform and definite in that direction. *Fig. 2* is from another crucible test for a very low phosphorus wheel mixture to show what could be done with the most unpromising material. Ninety-seven per cent. of the charge was one chunk of sash weight metal made by a change in the method of melting old and new tinned and "detinned" scrap in a cupola. The remaining 3 per cent. brought the calculated change in quality, though it was not in the form of cast iron, ferro-silicon or other magnetizable material.

Figs. 3 and 4 are from cupola melts of regular mixtures for chilled wheels; that from which *Fig. 3* was cast containing 16.5 per cent. of charcoal iron with 61.5 of wheel scrap, while *Fig. 4* was cast from mixture of which but 3.9 per cent. was charcoal iron and 55 per cent. was wheel scrap. The latter indicates much the best iron for heavy wheels, and along with experience goes to show that character of iron does not depend upon physical or chemical history before melting in a calculated mixture, but upon its composition.

As answers to Mr. Webster's questions, submitted to me also, the following condensed summary may not be sufficiently clear, save to those who may have spent many months at least, with very close attention, in the line indicated. Expertness in use, rather than in statement, of my method naturally results from the fact that my views, after three years of study connecting laboratory and foundry work, then developed into methods commercially available, through the daily necessities of the task of controlling both the quality and economies of two to six mixtures aggregating 40 to 100 tons, including chilled and gray castings. The accuracy with which these answers apply must, however, naturally exceed that expected in an examination of the old method whose data is less definite and whose results are more limited for same time and expense.

(1) My practice is to regulate the final adjustments in the composition of the charge from the reported tests of bars and castings of the previous mixture. The strength alone being an insufficient criterion, I do not associate it alone with a definite composition, because there are several which would give the same strength but give different results otherwise. However, I can of course tell the breaking load approximately for many compositions and rates of oxidation of charge.

(2) I can more or less closely. But, as above indicated, my method but rarely requires analyses of the *bar or casting*; but, under the conditions given, the calculated composition of the *charge* would usually suffice; and with some calculation, as well as estimation, the results of size and shape on other attributes as well as strength can be approximately, or, where experience comes in, very closely estimated.

(3) For calculation of the mixture I depend, of course, upon complete analyses only. In order to sample scrap and certain classes of pig, it is of course sometimes most convenient to regrade by fracture before taking the sample for analysis. Also, new lots of well-known classes of scrap are inspected to see if a certain change on the old analysis will suffice, depending upon the proportion convenient to use. Practically, the errors can be kept so small that, besides

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considering just so much of each element furnished by the stock, it is practicable to regulate by the minute alterations of ratios suggested by the variations of bars.

(4) The degree of accuracy attainable depends greatly upon the sort of chemical composition of charge, kind and rapidity of melting, and upon the *necessity* for close knowledge of the figures which analysis of water-chilled shots or casting would show. The changes that take place in melting the mixture, depending upon the above-stated conditions, are, in general, oxidation of all the elements, including the iron, which latter, however, is almost invariably decidedly increased in percentage. Though this possible increase is of course greatest where the original percentage is least, its actual increase in careful practice with full analyses and test pieces may be kept to a minimum, thus requiring the minimum amount of new iron and high-priced pig. The effect of oxidation of the other elements has been previously referred to in general, but is specifically considered in each case and kind of mixture calculated. Where necessary the composition of the metal at spout is known with the sort of accuracy which admits of the use of 95 per cent. of scrap in the charge, the unsuitable iron expected at the spout being brought to the proper quality by an already prepared heated charge of two or three kinds of alloys equal in weight to 3 per cent. of the molten iron to be held in ladle. The change in the oxidation and rate of cooling is allowed for.

(5) Very seldom exactly, because even with a proper variety of stock it is often mathematically very difficult or practically inconvenient to adjust the proportions of the various irons to give the composition necessary in the charge. But within limits it is done; the charge as first calculated usually being incorrect, the most convenient alterations are made which will give perhaps notable change in percentages of elements, but whose net result will, by reference to experience and minor principles, properly oxidize to give the required kind and approximate figures suitable for the work. The oxidations occurring in the different kinds of suitable charge compositions are neces-

sarily different and give different, but, by selection, suitable results. Such questions as 4 and 5 are confounded by many in discussing foundry chemistry.

(6) From the conditions mentioned I can, as heretofore shown, fairly estimate the strength along with other necessary considerations of bars or castings. As the latter depend upon other qualities equally with strength, the charge is not made up with that one point in view. In fact, the practical operation is quite the reverse and more direct than that inferred by the question; the observed qualities and variations of bars and castings, and occasionally their analyses, indicate the required alteration to be made on the charge or cupola practice before serious alterations of quality occur.

(7) All of the elements shown by the analyses of all stock used, the effect of all the known conditions, exclusive of fracture or physical qualities of melting stock, saving of course questions of size, dirt, oxides, etc. But since they are not used for the regulation of strength only, the aim being castings, not test bars, the general method of controlling quality of the castings has been sufficiently referred to for the purposes of this discussion, test bars being one of the principal means in following the relation of one element to another. As to "amounts per unit" of strength or other quality, this is now mainly a matter of my experience and takes months at least to learn or to teach in any one line of castings, and can hardly be so expressed. But I have had some success in close calculation of both chill and strength from analyses alone. Though insufficiently developed, one instance covering six irons is quoted by Mr. Thos. D. West,* showing my results in December, 1896, in the matter of strength by means of a valuable, though still imperfect formula, applied directly to analysis.

* "Metallurgy of Cast Iron," 1st ed., p. 525.