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IRON:

THE

IMPURITIES WHICH COMMONLY OCCUR WITH IT, AND THEIR EFFECTS.

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IRON—THE IMPURITIES WHICH COMMONLY OCCUR WITH IT, AND THEIR EFFECTS.

Careful study of the physical character of the metals, and of their chemical composition, has brought out so many points hitherto considered mysterious, that we now have a term, "chemico-physical," to designate this important combination, and investigations are now universally conducted on this basis.

The limits of this work are necessarily narrow; but the object is to collect a few facts in regard to the iron industry, which may be of use to those producing or working iron.

This can be more easily done, since it is now common in iron districts and among iron workers to hear terms constantly used which were, a short time since, familiar only to chemists; for the reader will more readily follow the discussion if accustomed to the terms, such as silicon, phosphorus, sulphur, manganese, etc.

Iron is no longer made or worked at hap-hazard, but is treated as it should be, I will not say scientifically, but with common sense. The manufacturer and merchant are no longer guided entirely by the appearance of the fracture in valuing iron, but frequently depend on chemical analysis alone.

The iron industry is now in far better condition than it has been for years; and yet we have not, and probably never will reach, the high prices of 1872; but with that economy and perfection of method of manufacture necessary in every business, success is not now, as it was two years ago, uncertain and improbable.

Aside from the close and minute economy necessary everywhere, a comprehensive and accurate knowledge of ores, fuels, fluxes, etc., is required, and also the manner of using this knowledge to produce the best results; for of what use is information concerning the chemical composition of the materials, without the ability to make practical use of the analysis?

Chemists are now indispensable at all enterprising works, and becoming more necessary and useful as others learn to apply the results of their investigations.

Before entering fully upon the subject, a short discussion of iron will not be out of place.

When pure, iron is exceedingly soft; has a bright, somewhat silvery color, and melts only at very high temperatures; but the difficulty of preparing it absolutely pure is so great, that specimens are very rare. Iron does not normally occur in the metallic state on the earth; but meteoric masses of iron are often found, and also specks of metallic iron in lavas; the latter, however, may, in some cases, be proven to be terrestrial.

The usual mode of occurrence of iron is in combination with oxygen, and in this form, united with other substances, it is found almost universally distributed throughout the mineral kingdom.

When the amount of iron in any substance is sufficiently large for the economical production of the metal on a commercial scale, and the metal so produced is free from an excess of impurities, such a substance is called an "Iron Ore." There is, however, a point which cannot be too distinctly and emphatically stated, which is, that iron is an elementary substance, and as such is always the same, whether free or combined, whether produced from an ore or some combination unworkable on account of impurities; that is, the metal iron, when freed from its combination with other substances, is invariably the same, no matter what combination it was taken from. This is of course self-evident to the chemist; but many practical men of great experience still imagine that the ore has an influence beyond the mere question of the impurities which it gives to the metal. Such impurities are dependent not only on what the ore contains, but also on the physical structure of the ore; for two ores of the same percentage of impurities, but of different density and infusibility, treated in the same way, will give very different results.

In combination with other substances, of course the metallic properties of iron are lost, when the greater part of the mass is not iron; but by the operation of the blast furnace the foreign substances are removed, and pass off as slag, leaving the metal, which is then called cast iron or pig iron. The metal thus freed from the slag is not pure; for in order to melt and run out of the furnace it must contain carbon, and it also takes up silicon, etc.

Metallurgists are striving to establish a new classification of iron and steel; but, according to the commercial classification, which is still used, we have: cast iron, wrought iron, and steel, differing in consequence of, and in proportion to, the amount of carbon present; and these three classes, subdivided again, according to appearance of fracture, giving—

UNDER CAST IRON—Gray, mottled, and white.

UNDER WROUGHT—Fibrous and granular.

UNDER STEEL—"Soft" and "hard;" but the varieties under this head are very numerous.

Here, however, it is necessary to say again that the iron, which forms the basis of all these varieties, is always the same, and that these differences are owing to a difference in chemical composition alone, or to a combination of chemical composition and molecular structure.

As a general rule, it may be said that the varying element in these classes, and the one causing, to a great extent, so much difference in them, is carbon, of which cast iron contains most, steel less, wrought iron least; but, merging, as they must, into each other, the boundary lines are very indistinct, more especially as other substances, as silicon, phosphorus, sulphur, etc., modify the influence of carbon. It is this influence of numerous substances which renders it impossible to say what the effect of any one would be without knowing the composition of the metal.

It will be well to discuss briefly silicon, sulphur, phosphorus, etc., and the effect of each separately, then the combined effect of some important and common impurities.

SILICON.

This is one of the most important of all the substances, elementary or compound, which comes under the notice of the iron-master, as it is always present in iron and steel in varying amounts, and exercises great influence on the character of the metal. Not only is it important as silicon, but also as silicic acid—silica or quartz—in which last named form it unites with oxides, and produces slag or cinder, without which the metal could not be produced or worked. The slag covers the metal and protects it from oxidation in the furnace; also carrying off the impurities which would be injurious to the iron; and then the principal process of metallurgy—the carrying of oxygen from the air to the impurities in the metal—is effected by the slag. We speak of burning out silicon, carbon, etc.; but it is done by means of the slag, which takes up the oxygen and gives it up to the impurities.

Too much stress can scarcely be laid on the character of slags in metallurgical processes.

In the reduction of iron ore, not only is oxygen taken from the iron oxide, leaving metallic iron, but also from silicic acid, leaving silicon; and this silicon has a great affinity for iron, with which it unites. It would seem, however, from the observations of Dr. J. Lawrence Smith and others, that silicon exists also in iron in the free state, probably graphitic. Although silicon has a great affinity for iron, it would appear that the presence of carbon is necessary for the production of iron silicide, as all attempts to produce it without carbon have failed.

The blast furnace is favorable to the production of highly carbonized and also very silicious metal, as there is a highly carbonized reducing atmosphere at a very high temperature, acting on iron ore, silicic acid, lime, etc. The iron oxide in the ore loses oxygen, and metallic iron being set free, takes up carbon and silicon, the percentage taken being dependent largely on the working of the furnace, as temperature, force of blast, amount of flux, fuel, etc.

In general it may be stated, that a high temperature produces silicious iron, and merely heating the air blown into a furnace will raise the amount of silicon from one per cent. often to from two to three per cent.

The action of silicon, and the form in which it exists in iron, are but little understood, and yet we may undoubtedly say that silicon renders iron harder and more brittle; but it is still doubtful whether it may not be an advantage to steel when present in very small quantities.

In cast iron, the amount of silicon is usually from one to three per cent., but often as high as six, in which case the metal is hard, and is called silver gray. Silicon in very small quantity is believed by many to ruin steel and wrought iron; but up to three per cent. does not injure cast iron, for the soft, easily worked, No. 1 Foundry iron usually contains about this percentage. For purposes where a hardened or chilled surface is required, however, silicon is very prejudicial when the percentage exceeds about one per cent. (See page 16, chilled castings.)

PHOSPHORUS.

For many years this substance has been the great trouble of iron workers, and the attempts to eliminate it economically have been as persistent and fruitless as the search for the philosopher's stone. To-day the iron industry is at a point where great and important changes will necessarily soon be brought about. Districts which abound in iron, heretofore branded with the stigma "high phosphorus," will now come to the front with their cheap iron, and produce steels of the finest quality, free from phosphorus. The whole world is working at it, and, thanks to the freedom with which men of science give their experiments to the public, the workers are all informed as to what has been done, and all are working in the same direction, viz: towards the removal of phosphorus, in the form of phosphoric acid, by means of highly basic slags. Success in this effort is almost a certainty; and it will give an impetus to the iron industry which will be of the utmost importance, especially to the Southern States, since it will settle at once the question of their power to make steel.

The effect of phosphorus on iron is very marked, and even small fractions of one per cent. are taken into consideration. It causes cast iron to melt very thin, and hence very fine, small castings are usually made of iron carrying several per cent. of this substance. In wrought iron, 0.30 per cent. produces some cold-shortness unless the iron has been well puddled, and the carbon brought down low. In steel, a difference of but few hundredths of one per cent., the carbon remaining constant, will make a marked difference in the toughness.

Phosphorus exists in iron in the form of phosphide; but it is impossible to say whether it is always the same one of the many phosphides of iron. At any rate, one tenth of one per cent. will ruin hard steel for many purposes, and this small percentage will be found equally distributed through the mass. Phosphorus seems to cause carbon to tend to separate out as graphite.

The refining process removes phosphorus, as the following experiments,* made on 1,000 pound charges, will show—

Pig iron containing 0.23 per cent. gave refined metal with . . . . 0.03 per cent.
Pig iron containing 0.90 per cent. gave refined metal with . . . . 0.20 per cent.
Pig iron containing 0.90 per cent. gave wrought iron with . . . . 0.027 per cent.
Pig iron containing 0.88 per cent. gave refined metal with . . . . 0.18 per cent.

SULPHUR.

This is also a very common impurity in iron, but is more easily kept out than phosphorus. The blast furnace is really the place to remove sulphur, which, when lime is plentifully used as flux, goes off in the slag as calcium sulphide. Sulphur tends to cause the production of white iron; acts against

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*These experiments were made with the assistance of Mr. J. M. Duncan, Superintendent Roane Iron Works, Chattanooga; and, after many trials, we felt sure of the success of the operation of removing phosphorus from pig iron.

high carbon in cast iron; causes the metal to flow thick, and the castings to be rotten, the latter effect being produced by 0.5 per cent. and even less. In steel and wrought iron sulphur is very injurious, if present to the extent of one tenth of one per cent., producing in steel brittleness when hot, and cracking while being worked.

MANGANESE.

This metal is soft and ductile; but united with iron, tends to produce hardness, and also to raise the melting point. It is known in commerce in the form of "spiegel-eisen," which contains twenty per cent. of the metal, and as ferro-manganese, which may contain as much as seventy-five per cent. thereof. The manganese present in cast iron, when as much as ten per cent., has the peculiar property of causing carbon to be all combined, and also of raising the percentage of carbon up to five per cent. Manganese is now added to steel to counteract the effect of phosphorus, which it does, however, only to a certain extent; for both harden steel, and much manganese is injurious.

COPPER.

This is an impurity but rarely found in iron and steel; but it is stated to produce rottenness or red-shortness; to diminish carbon, and injure iron very much as sulphur does, but may be present, without injury to the metal, in larger quantity than sulphur. I have seen very fair iron with 0.3 per cent., and at Harrisburg steel of very good quality has been made (I have been told) with as much as 0.5 per cent. copper.

ARSENIC.

We need scarcely expect to find arsenic in iron and steel as a rule; but it occurs sometimes, and produces hardness and brittleness. If present in any quantity, it is likely to be detected when the metal is tested for phosphorus, as it also produces, with molybdic acid solution, a yellow salt.

CARBON.

All of the inorganic modifications of carbon, excepting the diamond, are important in the metallurgy of iron. The forms of carbon most common and important are: coal, and the product, coke; wood, and its product, charcoal; peat, graphite, amorphous carbon; many of the chemical compounds, as carbonic acid and carbonic oxide, carburetted hydrogens, etc.

Not only is carbon important on account of its use as fuel for reducing and working the metal, but also because of the great value which its presence gives to iron. As has been stated before, iron would be too soft, without carbon, for the innumerable uses to which we now adapt it by slightly changing the percentage of this element; and again, carbon used as fuel is the only means of producing the metal economically. The three great divisions of iron, mentioned before, viz: cast iron, wrought iron, and steel, vary distinctly in the amount of carbon, excepting that the line dividing them is not and cannot be sharply drawn.

Cast iron contains from 1.5 to 5 per cent. carbon. Steel contains from 0.25 to 1.5 per cent. carbon. Wrought iron contains up to about 0.25 per cent.

It will easily be understood that a statement of percentage of carbon cannot always decide at once to which of the classes a piece of metal would belong; for other substances affect greatly the influence of carbon, as, for instance, phosphorus, which renders steel very brittle, if the amount of carbon is great; and yet such a statement of amount of carbon does indicate at once what the metal is called, excepting at the boundary line between the classes.

It may very soon be decided by the metallurgists of the world whether the old classification shall hold, or a new manner of designating the varieties be chosen. Certainly it is now difficult to decide which is steel and which iron, according to the old manner of calling things, when it is a question as to "plate steel," containing 0.10 to 0.12 carbon, and iron plate with the same percentage.

Carbon hardens iron in proportion to the amount present in the combined state, and renders it more fusible, so that wrought iron is soft and very difficultly fusible, while white cast iron is hard, and melts more easily than steel, which also melts more easily than wrought iron.

The property of welding is also strongly affected by carbon, decreasing with the increase of carbon, as does also malleability. Wrought iron and steel are both distinctly malleable and ductile, while cast iron shows but faint traces even of malleability; and again, wrought iron welds perfectly, steel less perfectly, cast iron not at all.

There are two forms of carbon in iron, viz: "chemically combined" with the iron, and "mechanically mixed," as graphite, the graphite never occurring without the combined form, which, however, often occurs alone, as in white cast iron, steel, and wrought iron. This peculiarity of occurrence, in two forms, varies very materially the character of that class of iron in which it exists, viz: cast iron, producing what are called the different "grades." It is true that graphite is sometimes found in high steel when cast in large masses, or when even small masses are cooled very slowly; but, as a rule, the carbon in steel is all chemically combined, as it is also in wrought iron. (See page 13.) It will be as well now to discuss under "*Cast Iron*" the manner of occurrence and behavior of carbon in its two forms. The common name for this kind of iron is "pig" iron, which is the first product from the ores, the most impure of the three classes of iron, and the one from which the others are made. It contains, roughly stated—

93 to 95 per cent. metallic iron;
2 to 3 per cent. carbon;
1 to 3 per cent. silicon;

more or less slag, sulphur, phosphorus, etc. Carbon and silicon vary between greater limits, it is true, as in silver gray, silicon often going as high as seven per cent., and in white iron carbon reaching five per cent., the amounts depending largely on the character of ore and manner of working the furnace, but more especially the latter, which causes the production of the "grades" of iron called gray, mottled, and white.

GRAY IRON,

also called "Foundry Iron," is the typical "Cast Iron." It is a combination of iron with silicon, carbon, etc., in about the following proportions, taking No. 1 Foundry iron (coke) of good quality:

Carbon	3.00 per cent.
Silicon	2.75 to 3.00 per cent.
Iron	93.00 per cent.
Slag, etc.	1.00 per cent.

The carbon is partly "combined" and partly graphitic, the latter largely predominating, as a rule, in No. 1, and the two forms becoming more equally divided in the lower grades down to IV and "mottled," in which they are nearly equal; then, as the iron becomes white, the combined form predominates, graphite being absent in "white" iron, the "lowest" of the grades.

There is something peculiarly interesting in this division of the carbon, not only from a scientific stand-point, considering the chemical combination of a few hundredths or tenths of one per cent. of carbon with the iron, and the separation or crystallization out of the remainder in the form of graphite, but also in a practical view, as this behavior of the carbon very materially affects the character of the metal, as will be shown further on.

The cause of this division, or two forms of carbon, is easily understood and explained on the supposition that molten iron absorbs a large quantity of carbon, say 3.00 per cent., and, on cooling slowly, the greater part of this crystallizes out. On this assumption the carbon is all combined, or partly combined and partly amorphous, in the molten metal; most probably it is all combined; for sudden cooling will, in some cases, give a metal showing only combined carbon.

It has long been a favorite theory with many eminent metallurgists, that the condition of the carbon in iron is greatly influenced by the temperature to which it has been subjected previous to casting, they claiming that white iron will be changed to gray if melted and heated to a point considerably above melting. In this theory the mysterious influence is "superheating," and the temperature at the time of casting is not considered.

It seems to me, however, unnecessary to seek some unaccountable agency to explain the fact that the same iron may be gray or white, according to the manner of casting, when we have the plain and simple reason that sudden cooling prevents the separation of graphite. The question of heating far beyond the melting point, producing gray iron, is, to my mind, merely a question of giving such a heat that the iron is not ready to chill immediately on touching the mold, and therefore the temperature at the time of casting is important, while any previous overheating can have no effect. This same theory is even carried into the blast furnace practice, with the statement that high temperature there produces graphitic iron by some peculiar effect of heat on the carbon; a very unnecessary hypothesis, since we know that high temperature gives highly silicious metal, and that silicon causes graphite to separate. (See page 12.)

Gray iron is a mixture of steel and graphite, the steel being a sponge or network inclosing the graphite, and this explains the character of gray iron and the difference between gray, mottled, and white, for we may consider gray iron as a low steel, inclosing graphite; mottled iron a higher steel, inclosing less graphite; white iron a very high steel, with no graphite. Now, as before mentioned, in proportion to the carbon combined with iron, it is more fusible, more brittle, and harder; and we know that gray iron is less easily melted, is softer and tougher than either mottled or white. These properties render it especially suited for castings, because when cast it is soft enough to be worked easily with cutting tools, being also stronger than the other grades. Another peculiarity of gray iron is, that when it cools down to the point of hardening, it sets suddenly, and slightly expands, thus filling the mold well.

MOTTLED IRON

is so called from the appearance of its fracture, which shows gray specks in a white ground. It contains usually less silicon than gray iron, and also less carbon, the combined and graphitic being about equal in true mottled.

Owing to a larger percentage of combined carbon, mottled iron is harder, more fusible, and more brittle than gray, and shrinks instead of expanding when cast. It has a peculiar property of passing through a pasty condition when melting, which adapts it especially for puddling; otherwise very little use could be made of it.

This iron is made at lower temperatures than gray iron, and is less impregnated, therefore, with those substances which enter by reduction; but it always contains more sulphur, because the furnace, being much colder, the pyrites of the coke is not decomposed high up in the furnace, and because it is not possible to carry a heavy burden of lime on a cold furnace, for fear of scaffolding. If the lime were in excess, it would carry off sulphur in the slag as sulphide of calcium; but this is still more true of

WHITE IRON,

which is usually the result of a colder furnace, and contains less silicon and carbon than either of the others, which carbon is all "combined," and more sulphur. In fact, sulphur tends to prevent iron absorbing much carbon, and also to the formation of white iron.

White iron may, however, be owing to the presence of manganese, in which case the carbon is high, usually five per cent., when manganese is as much as twenty per cent.

The hardness, brittleness, lack of strength, and contraction on cooling, render white iron unfit for castings; but, melting easily, and passing through a pasty condition, it is well adapted for puddling.

The more important discussion of the combined action of some of the impurities already mentioned brings up intricate questions; but there are some plain facts to be noted.

CARBON AND SILICON.

In cast iron these two substances occur in large quantities, usually nearly equal in gray iron, which contains about three per cent. of each. The reduction of silicon is greatest in the blast furnace when the temperature is high, and this is also favorable to a highly carbonized metal, and, as some metallurgists say, to the production of a graphitic metal; but I think it is clear that the separation of the graphite in the cast iron is not owing directly to a high temperature in the furnace. (See page 13.) It seems that silicon and carbon replace each other to a certain extent; but a high percentage of silicon generally occurs with a high percentage of carbon, and on cooling, this carbon separates out as graphite, in proportion to silicon percentage, so that very silicious metal, as silver gray, contains almost exclusively graphitic carbon.

Why silicon causes graphite to separate, is the unsettled question. It is a question which has not received the attention which it merits; and with this fact, so evident to any one who is at all acquainted with metallurgy, that high silicon and combined carbon do not occur together, there can scarcely be a question as to the action of silicon in the case. Why silicon has this effect is not easily determined; whether the separation of graphite is owing to a mere replacement of combined carbon by silicon, or to the mere presence of silicon, which acts then in some unaccountable manner, or to silicon affecting the melting point, and by keeping the metal fluid, melted sufficiently for the purpose, at a low temperature, allowing time for separation of carbon, or lastly, and very probably, to the action of silicon, preventing a sudden contraction at the moment of solidification. This fact of sudden contraction, whether by cooling or by shock, is of great importance, and exerts a powerful influence on the form of carbon. (See page 21, on difference between hammering and rolling steel.)

However the question may be settled by future investigation in regard to the reason of this peculiar action of silicon, the fact remains, and I think it can be safely stated—

1st. That silicon, to the amount of three per cent., will cause iron to be gray and highly graphitic.

2d. That without materially lowering carbon, if silicon be lowered to one per cent. in such an iron, it will give white iron by chilling.

3d. That any iron containing less than one per cent. silicon will give white metal by sudden cooling, whether it be cold-blast charcoal iron or the commonest silver gray coke meta refined.

Pig iron (No. 1) containing silicon, 4.06; graphite, 2.98; combined carbon, 0.23; gave refined metal with silicon, 0.21, graphite trace; combined carbon, 2.45; and many experiments gave similar results.

These instances are sufficient to show that the use of cold-blast charcoal iron is not necessary to get a metal which will give a perfect chill, and surely lend additional weight to the other arguments in favor of the idea that silicon causes carbon to separate out as graphite.

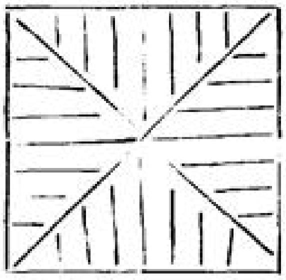
This may seem, at first sight, of but little practical moment, and yet it is of the greatest importance to one of the large industries of the country, viz: car-wheel manufacture, and the manufacture of chilled castings generally, besides the importance it has for "rolls," etc.

For car-wheels, an iron is necessary that will give a hard surface when cast against iron, and a soft, strong body where cast against sand. For this, a metal containing about one per cent. of silicon is necessary, and that is just about what we find in the high-priced cold-blast irons. Now, by refining them, the commonest, cheapest irons will answer the purpose. This is the subject of a patent taken out lately in this country, but has been in use for many years in Germany, where they refine for "rolls," and chill castings, as at Königshütte, in Silesia, where I saw, five years ago, the operation constantly conducted of refining eight tons at a heat in about eight hours.

In this connection, there has been much discussion as to the cause and peculiarity of this property, which some irons possess, of giving a hard, white surface, or "chill," when cast against iron. Among other reasons assigned, a third form of carbon has been said to be the cause; but this third form of carbon has been found in this quality of iron (as it seems to me) merely because combined carbon was high. Treatment of carbon residue, from solution of iron in hydrochloric or dilute nitric acid, and finding a substance which burns or volatilizes below redness, does not prove the existence of a third form of carbon. Carbon may be deposited in an amorphous form when iron containing only combined carbon is dissolved in acid, and the more dilute the acid, and the slower the action, the more of this amorphous carbon will be left; so that solution in dilute hydrochloric acid, with the aid of a galvanic current, is even used by no less an authority than Professor Bunsen, to obtain the carbon from iron, which carbon is then burned and CO_2 weighed. A stronger acid would evolve more hydrogen, which, in its nascent state, would tend to carry off carbon as carburetted hydrogen; but it rarely happens that simple solution in acid removes all of the combined carbon; and of course the greater the quantity of combined carbon in the iron, the greater the amount of amorphous carbon left. Again, even in the mild steels, with only 0.12 carbon, it is well known that, in making color tests, the nitric acid used (1.22 sp. gr.) rapidly dissolves the steel, but leaves a floculent carbon residue, which must be dissolved by longer standing at 80° C. This residue is combined carbon, left when the acid dissolved the metal; and if the steel is very high, say 1.5 per cent. carbon, this residue, on one decigramme, will be very considerable; but it will be entirely dissolved by two to three hours standing at 80° C.

Now, chilled iron is really a very high steel; and, it seems to me, that in order to establish the theory that "chilling" is due to this third form of carbon, it must be present in any combination of iron and carbon which will perceptibly harden by sudden cooling; for steels as well as cast irons contain graphite and combined carbon, provided the cooling be very slow.

Chilling is not at all strange in itself; but it is as yet a mystery why silicon prevents it. The hardening or crystallization takes place in the most natural manner; in a plane perpendicular to the plane of the surface which chills or cools, just as any crystallization shoots out in a plane perpendicular to the surface from which it begins. If we cast from a chilling iron or high steel an inch square bar, in an iron mold, the planes of crystallization will run in to the centre, forming distinct diagonal lines. The bar will be smaller than the mold, showing that there has been considerable contraction; the metal will be intensely hard, and the carbon all combined.



WROUGHT IRON.

The impurities are much less in this form of iron than in cast iron. It is made from cast iron, and the process, called puddling, removes silicon, and reduces carbon down to about 0.2 per cent., lowering also the percentage of phosphorus and sulphur.

Being made by squeezing together small particles of iron, of course the mass is never homogeneous, and when rolled out, consists of bundles of fibres, separated by films of slag. But there are two kinds of wrought iron known in commerce, "fibrous" and "granular," the former being the truer "wrought iron," and the latter approaching steel, the difference in carbon being that the fibrous contains less than the granular. The fracture may, however, give false indication of the nature of the metal, for a good smith can bend a granular iron so as to show some fibre, or break a fibrous iron so as to appear granular. In fact, the quality of the blacksmith often has as much to do with the working of an iron as its quality; but he cannot make the iron strong after it is worked.

Bad iron is the result of one or several of many possible causes. The purest iron may be spoiled by burning or overheating, although such pure iron will stand more heat than impure irons. This "burning" is, in my opinion, not only removal of carbon, but oxidation of the metal; for if it were merely removal of carbon, the iron would be softer instead of more brittle. There is also a change of molecular structure, of course.

The iron "pile" or "packet" is put into a heating furnace and soon oxidizes sufficiently to be covered with a scale. This scale, or oxide of iron, gives up part of its oxygen to carbon, taking up oxygen again from the air, and the carbon thus oxidized passes off as gas; but at the same time it is undoubtedly true that, at this intense heat, oxygen also goes to the metal, and, gradually passing in, soon renders the most porous parts of the mass brittle by forming oxide of iron, which is disseminated through the mass. Therefore, the less dense the metal the more readily "burned."

There are two kinds of brittleness in iron, the one called "cold-shortness," or brittleness when cold, and the other "red-shortness," or brittleness when hot. As a rule the two do not occur in the same metal, but if the red-shortness be caused by burning, or by bad puddling, leaving the iron green or badly balled, the result will be an iron both red and cold-short. Red-shortness is generally caused by sulphur, of which but a few hundredths of one per cent. will cause cracking in the rolls; but, on cooling, this brittleness will not exist.

Cold-shortness is generally owing to phosphorus, which may be as much as half of one per cent. without greatly injuring the iron, provided it has been well puddled, so as to make the carbon low. Such an iron will work smooth and well in the rolls, but will be somewhat brittle when cold, and this brittleness will be greater the higher the carbon. A theory generally held by iron-masters has been, that a mixture of red and cold-short iron would give a strong neutral metal; but only in so far as dilution affects it is the theory true. Five hundred pounds each of two irons, the one containing one half per cent. phosphorus, and the other three tenths per cent. sulphur, will give a metal with a quarter per cent. phosphorus and fifteen hundredths per cent. sulphur. Puddling will still further purify it, and the result will be a good iron. But phosphorus and sulphur do not neutralize each other.

The purification of iron by puddling should be more closely considered than it is at present; for, by properly conducted and careful work, it is possible to remove sixty per cent. at least of the phosphorus and sulphur. For this result the iron should be "bled"—that is, the slag run off before "balling." That iron may be still further purified by puddling is undoubtedly true; for, in some experiments made with Mr. J. M. Duncan, of the Roane Iron Company, Chattanooga, we puddled a heat of 1,000 pounds of an iron with 0.90 per cent. phosphorus, and produced muck bar with 0.03 per cent. This would, however, scarcely be economical puddling for ordinary work, and yet, for boiler plate, it would be far cheaper than "sinking" with charcoal.

STEEL.

Under this heading it will be necessary to be brief, although the subject would admit of extensive treatment in detail; but our State is as yet without steel industries.

As has been said before, it is difficult to say what steel is, for it is now made lower in carbon than even good wrought iron, or containing almost as much carbon as cast iron. Owing to its crystalline structure, steel bears less percentage of impurities than iron can safely carry, *i. e.*, leaving carbon out of the question. By impurities, then, we mean phosphorus and sulphur, and the amounts of these which may be present depend largely on percentage of carbon, and also on the use to which steel is to be put. Phosphorus in small quantity, say one quarter of one per cent., does not prevent steel working well, provided the carbon be low; but when cold, such steel is decidedly brittle, unless carbon be at least as low as 0.25 per cent., and manganese should be up to 0.60 per cent. Manganese acts in more than one way advantageously to steel. It prevents, to a great extent, boiling and blowholes, by its tendency to check the oxidation of carbon during casting and while the metal is setting in the molds; it also renders less active the oxidizing tendency of the heating furnace, which would cause red-shortness; and although manganese itself renders steel harder and more brittle, it neutralizes, to a certain extent, the cold-short action of phosphorus.

In working steel with 0.30 per cent. phosphorus, 0.25 per cent. carbon, 0.80 per cent. manganese, 0.03 to 0.05 per cent. sulphur, I have found that it was soft, and gave excellent results under a steam hammer or on the anvil, cold bars one inch square bending completely over on themselves and sustaining repeated blows from a sledge; but the same worked hard in the blooming rolls and one ton ingots, cracked badly. Those ingots which rolled well gave bars which were broken by a six hundred-pound drop falling six feet on four-foot bearing. Lowering phosphorus to 0.20 and manganese to 0.50 gave steel which worked soft, and stood repeated blows from a fifteen hundred-pound drop falling nine feet. In the former steel graphite was always perceptibly present, while in the latter it was rare, and then only in minute quantity. There is a remarkable difference beween the action of the hammer and the rolls on steel, more especially when carbon is high. The hammer exerts an influence similar to the cooling action of a chilling surface, producing sudden contraction, and this causes carbon to remain in the combined form, while the rolls are slower in their action, and graphite tends to separate out.