

in the working chamber by the combustion of the additional hydrogen formed in the producer at the expense of the heat thus absorbed. Manifestly, a calory evolved directly in the working chamber is more efficient than had it been evolved in the producer, because if evolved in the producer it would be in considerable part dissipated in bringing it forward into the working chamber.

Of course the gasification of the fuel in the producer requires that the fuel itself be hot, otherwise it will react neither on air nor on steam; the temperature must be kept up to the range in which both the atmospheric oxygen and the steam itself will react on the fuel and gasify it. But in the producer itself any heat over and above that needed to keep up this temperature is not only less efficient than if that same heat was generated in the working chamber of the furnace, because in passing from the producer to the furnace much of it would be wasted, but positively injurious because it tends to melt the ash into unmanageable clinker. Introducing steam along with the air used in gasification then stores energy in the producer by there utilizing part of the locally inefficient and harmful excess of heat, increases the quantity of combustible gas formed, and so restores that energy in the working chamber of the furnace where that excess of gas is in turn burnt. In short, it absorbs heat in the producer where it is harmful, and reproduces that heat in the working chamber of the furnace where it is used most efficiently.

Producers are often run now in such a way that the gas contains 5 or 6 per cent of carbonic acid, and this is not considered a loss of energy provided that much steam is used. The explanation of this is as follows: All the heat required in the producer is enough to keep up the temperature to the point of ignition of the coal. The amount of steam we can use is limited by this: it must not cool the temperature below that point. Manifestly, if we burn part of the carbonic oxide to carbonic acid we get thereby more heat in the producer, and this extra heat enables us to decompose just so much more steam without dragging the temperature below the needed point. Thus, in this sense the increase of carbonic acid does not necessarily represent a loss of energy, but merely that part of the energy, instead of being delivered in the form of carbonic oxide, is delivered in that of hydrogen.

## APPENDIX I

327. FURTHER NOTE ON THE CONSTITUTION OF GRAY IRON.—As the conception of matrix and graphite is fundamental to the theory of the constitution of cast iron adopted in this work, it is important that it should be grasped firmly. To this end the following series of suppositious cases is here elaborated.

*Case 1.* Suppose that, within a strong iron mould, stands a cylinder of quartz, quite as the cylinder of white cast iron in Fig. 119*A* stands within its mould. Suppose, next, that this ingot is shattered by a powerful blow from above, but that its fragments remain in the mould, like those of the white cast iron in Fig. 119*B*. Then suppose that liquid asphalt or Portland cement is run into the crevices so as to fill them completely, as sketched in Fig. 119*C*, and that the whole is allowed to solidify.

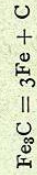
Here we have a conglomerate of which the matrix is quartz and the cementing or filling matter is asphalt or Portland cement. Let this illustrate clearly what is meant by a matrix.\*

328. *Case 2.* Next, let us suppose that the cylinder of quartz is replaced by a cylinder of white cast iron, Fig. 119*A*; that this in the same way is shattered as at *B*; that, by some means not explained, graphite is closely packed into all the crevices between the particles of iron, as at *C*, and that it cements them firmly together like the asphalt of Case 1.

\* Matrix, "that which contains or gives shape or form to anything;—(Geol.)—or the mass in which a fossil or mineral is imbedded." *A Standard Dictionary of the English Language*: Funk and Wagnalls Company, 1898, p. 1090.

I am not wholly satisfied with this word "matrix" for expressing the conception to which it is applied in this work, especially because in the not wholly dissimilar case of concrete it is the filling of cement or other material which is called the matrix. The filling of a concrete forms a much larger proportion of the whole than the filling in our present series of cases; and the use of the word matrix is, as I understand it, governed rather by homology than by analogy. Hence the apparent discrepancy. The sense in which I use "matrix" in this work is related closely to the sense in which it is used in geology and mineralogy; at the same time, a better word is needed to express this idea. I use matrix simply because I do not think of any better word.

Solid Ingot	CASE 2		CASE 3	CASE 4		
	A. White Cast Iron Ingot	B. Shattered Ingot		D. White Cast Iron Ingot	E. Shattered Ingot	G. White Cast Iron Ingot
Shattered Ingot	C. Shattered Ingot with Extraneous Graphite Filling		F. Shattered Ingot with Indigenous Graphite Segregated		H. Solid Ingot with Indigenous Graphite Segregated	
	White Cast Iron { Cementite, Fe <sub>3</sub> C, 6.0% (C. assumed to be 4%) Ferrite, Fe, 4.0%		Ferrite, Fe = Soft Steel		Ferrite, Fe = Soft Steel	
Graphite Filling or Segregate	Extraneous Graphite		Indigenous Graphite		Indigenous Graphite	
	Gray Cast Iron		Gray Cast Iron		Gray Cast Iron	
Matrix						
Filling						
Segregate						
Whole						



Here, again, we have a conglomerate, of which the matrix is white cast iron and the filling is graphite. But this conglomerate itself taken as a whole would be gray cast iron. It would, indeed, contain more carbon than any cast iron actually contains; but nevertheless because it contains more than two per cent of carbon such an imaginary substance would be cast iron; and it would be gray, because, if it was broken open, rupture would travel through the crevices filled with graphite, so that graphite alone would be seen in the fracture. The essential point to which attention is directed is that this conglomerate called gray cast iron is composed (1) of a matrix which is white cast iron and (2) a filling which is graphite.

329. Case 3. Next suppose that a like cylinder of white cast iron (D) is shattered (E), and that the crevices are filled and the fragments of iron are cemented together (F), not as in C with extraneous graphite, but with what we may call indigenous graphite; by which I mean graphite generated out of the fragments of the white cast iron matrix itself.

That such graphite should be thus generated we can readily conceive, in the following way. Let us first assume that the initial blocks of white cast iron contain 4.00 per cent of carbon and 96 per cent of iron, and that the whole of this carbon is united with  $4 \times 14 = 56$  per cent of that iron to form  $4 \times 15 = 60$  per cent of cementite. As there is nothing left for the remaining  $96 - 56 = 40$  per cent of iron to be combined with, it must be present in the free state as ferrite; so that our white cast iron is composed initially of 60 per cent of cementite and 40 per cent of ferrite.

Let us next suppose that this 60 per cent of cementite decomposes, splitting up into 56 per cent of free iron and 4.00 per cent free carbon in the form of graphite, by the reaction  

$$(34) Fe_3C = 3Fe + C.$$

The free iron generated by this reaction is clearly ferrite by definition, since free iron and ferrite are one and the same thing; let us assume that each particle of it remains exactly where it came into existence, so that this 56 per cent of ferrite thus generated remains in the lumps of metal or matrix alongside of the 40 per cent of ferrite initially present. Let us further suppose that, by some unexplained means, the 4.00 per cent of graphite thus generated migrates out of the lumps of matrix inside which it was

born, and works its way out into the crevices between these lumps, filling them completely, and cementing the lumps together into a solid coherent whole or conglomerate. Here, as shown at *F*, the matrix of our conglomerate is ferrite, while the cement or filling is indigenous graphite.

Such a mass is clearly gray cast iron, for the same reasons as in Case 2.

Now, were some one to pick out these particles of ferrite, clean them scrupulously from adhering graphite, send them to a competent metallographist, and ask him whether this substance corresponded in composition to any familiar class of steel, he would have to reply that it was identical in composition with the most extreme type of soft steel, not only low in carbon but actually without carbon: in short, with the most dead soft steel. And, since the composition is that of such dead soft steel, doubtless the properties both chemical and physical are identical with those of such steel. So that, in this sense, the matrix of this conglomerate, the matrix of this gray cast iron, may be said to be equivalent to dead soft steel. This and the parallel constitution of the matrix under other conditions is what the upper line of Fig. 120 attempts to set forth; that the matrix of different cast irons is, in its composition and doubtless in its properties both chemical and physical, identical with some one member of the pearlite series.

330. *Case 4.* Finally let us suppose a somewhat similar course of events, omitting only the shattering. Let us suppose that a like block of white cast iron (*G*, consisting initially of [1] 4.00 per cent of carbon plus 56 per cent of iron, combined as cementite, and [2] 40 of ferrite), is heated up into region VII of Fig. 68, *i.e.*, to within a few degrees of the melting-point, so that it becomes extremely soft.

Let us suppose that the same reaction occurs,  $\text{Fe}_3\text{C} = 3\text{Fe} + \text{C}$ ; that as before the resulting 56 per cent of ferrite unites with the 40 per cent of initial ferrite; and that the little particles of graphite which collectively constitute this 4.00 per cent of graphite are able to assemble themselves into little hexagonal flakes, say  $\frac{1}{16}$  of an inch across shown very much magnified at *H*. This they are able to do by pushing aside the pasty mass within which they are born. This they do exactly as when any salt, say cupric sulphate, crystallizes out of an aqueous solution. Its individual molecules in assembling out of the solution into the form of solid crys-

tals, must travel a finite and sometimes a large distance through the water to meet the particles which have already assembled in the growing crystal, and in so traveling and assembling must push aside the water through which they travel and in which they assemble. The force, or the resultant of forces, which compels this traveling and assembling we may call the crystalline force, that which forces the particles to assemble themselves in crystals.

Now, these little flakes of graphite thus formed constitute a sort of skeleton running throughout the mass.

Here exactly as in Case 3, the block as a whole is a conglomerate, of which the matrix is ferrite and the filling is indigenous graphite. This filling is parallel or comparable with the graphite filling in cases 2 and 3; the difference is that in those two cases the graphite assembled in preëxisting crevices, whereas in Case 4 these crevices do not preëxist, but the graphite in assembling under the pressure of the crystalline force, pushes aside the soft metal in which it is born. But in spite of this difference the cases are parallel as far as the structural distinction of matrix and filling is concerned.

331. ACTUAL GENESIS OF WHITE AND GRAY CAST IRON. — §§ 327 to 330 have for their object to make clear this fundamental conception of matrix and filling. They have incidentally pictured conversion of white cast iron into gray (Case 4). Now, while it is true that in the process of making "malleable cast iron" (§ 227, p. 281), just this conversion of white into gray cast iron does occur on a very large scale, constituting the very essence of this process, and while the difference between white and gray cast iron is essentially just such a difference as would exist were gray iron thus habitually made out of white, yet the actual genesis of the common gray cast iron of commerce is quite different. It is not made out of white iron, but is the direct product of the solidification and cooling of the molten cast iron itself.

Thus, when molten, and as it runs from the iron blast-furnace, the cast iron contains much carbon (to fix our ideas let us continue to assume that this is 4.00 per cent) dissolved in the iron, as sugar or salt dissolves in water. The cast iron habitually contains other elements, especially silicon, phosphorus, sulphur and manganese. Ignoring these here for simplicity, let us consider our molten cast iron as consisting of 4.00 per cent of carbon dissolved in 96 of iron.

In the solidification and further cooling of this iron, the carbon may take either of two wholly distinct paths; or, as is habitual, some of it may take one of these paths and some the other (§§ 220 to 224, pp. 276 to 279).

Of these two paths one is that the carbon isolates itself within the pasty solidifying metal in the form of sheetlets of graphite, much as sketched in Case 4. This gives us "ultra-gray" cast iron, corresponding to the left-hand end of Fig. 120, p. 438. (See § 224.) Were all the carbon to do this, then the molecules of iron themselves being wholly free from carbon, would be ferrite; and the result would be the same as in Case 4, a conglomerate of which the matrix is ferrite and therefore identical in composition and properties with ultra-low-carbon steel, and the filling is graphite.

The other path is that the carbon in freezing remains dissolved in the iron, as the solid solution austenite, which on cooling past  $Ar_1$ , line  $PSP'$  of Fig. 68, is resolved into ferrite and cementite,  $Fe_3C$  (§ 223, p. 279). Here, by the same reasoning as in the second paragraph of Case 3, proportions of cementite and ferrite would be 60 per cent of the former and 40 of the latter. The whole mass is white cast iron, and the case is represented by the right-hand end of Fig. 120.

But habitually the case is intermediate between these two. Habitually part of the carbon passes into the state of graphite and part into that of cementite. To fix our ideas let us assume that 3.50 per cent becomes graphite and the remaining 0.50 per cent becomes cementite. The case then is represented by the 0.5 per cent carbon ordinate of Fig. 120. (It is not likely that so much of the carbon would pass into the state of graphite unless, as explained in § 224, the formation of graphite was stimulated by the presence of much silicon.)

Then our conglomerate as a whole is gray cast iron consisting of a filling of graphite, representing 3.50 per cent of the whole mass, and a matrix which by difference must represent  $100 - 3.50 = 96.50$  per cent of the whole mass. This matrix contains all the 96 per cent of molecules of iron present, and also the 0.50 per cent of carbon which is in the condition of cementite which just adds up to the required 96.50 per cent.

What, now, is the constitution of this matrix?

With the 0.50 per cent of carbon existing as cementite must be combined  $0.50 \times 14 = 7$  per cent of iron (§ 153, p. 182), so

that this matrix contains  $0.50 + 7 = 7.50$  parts of cementite (7.50 per cent of the entire mass). The remaining  $96 - 7 = 89$  per cent of iron contained in this matrix has nothing to combine with, and is therefore free iron, which by definition is ferrite. Thus the matrix consists of

cementite . . . . .	$0.50 (1 + 14) =$	7.5	per cent
ferrite . . . . .	$96 - 7 =$	89.0	" "
Total matrix . . . . .	$96.5$	"	"

of the entire conglomerate.

Or looking at it in another way, the matrix contains 0.50 per cent of combined carbon. But Table 6, p. 184, shows us that this is the constitution of medium hard steel; and it is familiar to all that this is essentially the composition of rail steel, save that the latter habitually has in addition considerable manganese by intent and some phosphorus, sulphur and silicon in spite of us. We can then say that the cast iron as a whole is a conglomerate consisting of a graphite filling forming 3.50 per cent of the whole, and a matrix forming 96.50 per cent of the whole; and that this matrix is in composition and doubtless in properties the equivalent of rail steel of 0.50 per cent of carbon, a member of the pearlite series. This is indicated in the upper line above Fig. 120, above the 0.5 per cent carbon ordinate, and the fact that the cast iron as a whole is a very open gray one is indicated in the next lower line above that figure.

And so we could go on and indicate the genesis and constitution of other grades of cast iron.

332. GENERAL DIAGRAM OF THE CONSTITUTION AND PROPERTIES OF CAST IRON OF 4.00 PER CENT CARBON. — Following out the general ideas on the constitution of cast iron which have been here set forth, Fig. 120 is an attempt to represent in a condensed form the properties and constitution of a series of cast irons all containing 4.00 per cent of carbon, but with varying distribution of that carbon between the states of cementite and graphite; and also to represent the constitution and properties of the matrix of that iron, together with what we may call the trade name of the class of iron to which the matrix corresponds. First the lines which in Fig. 59, p. 162, show the physical properties of the pearlite series, and those showing the proportion of ferrite and of cementite

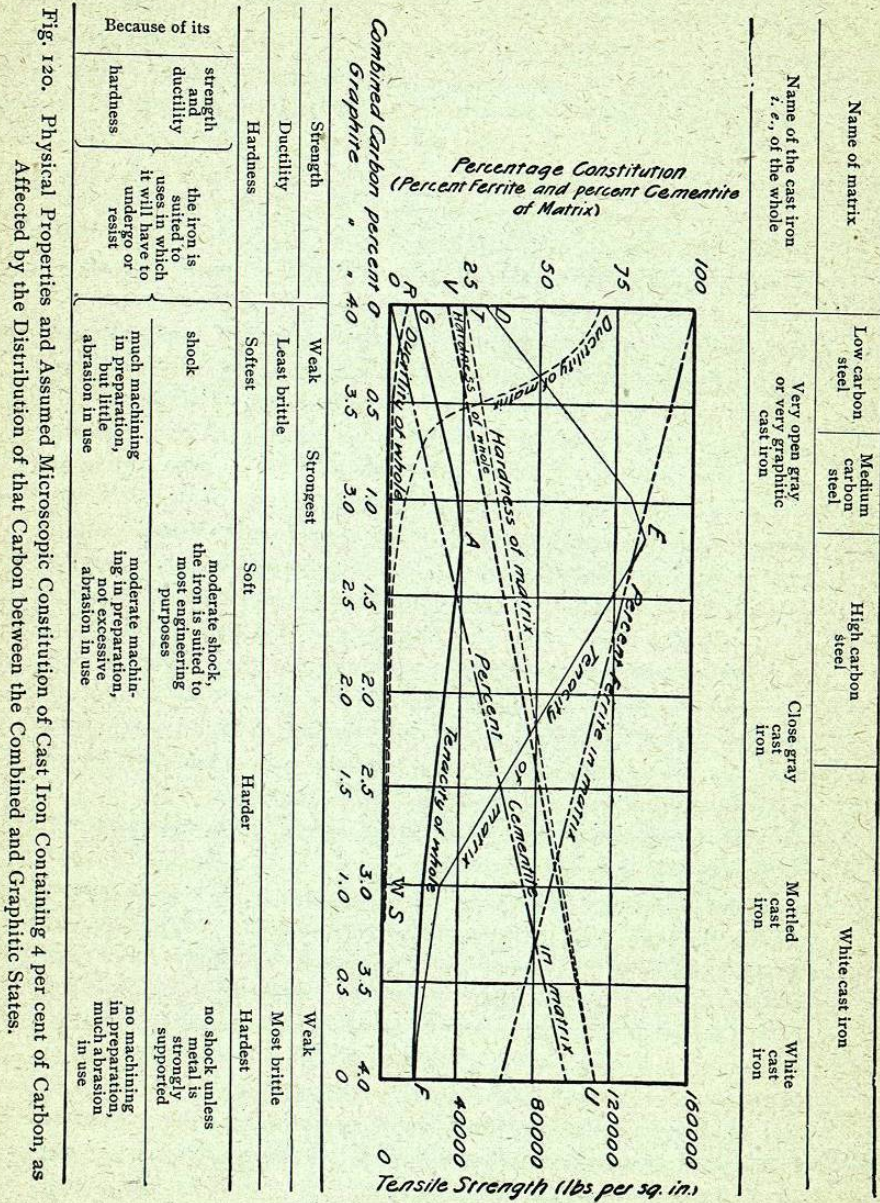


Fig. 120. Physical Properties and Assumed Microscopic Constitution of Cast Iron Containing 4 per cent of Carbon, as Affected by the Distribution of that Carbon between the Combined and Graphitic States.

in that series, are here reproduced, with the same lettering as in Fig. 59. These lines are supposed to show the constitution and properties of the matrix, for varying composition, *i.e.*, for varying carbon-content, of that matrix on the assumption that the properties of the matrix itself, its tensile strength, ductility and hardness, are the same as those of a graphiteless steel or a graphiteless white cast iron which has the same carbon-content and hence the same microscopic constitution as the matrix. For instance, a mottled cast iron containing 3 per cent of carbon combined as cementite, and 1 per cent of graphite, may be represented by ordinate *W* of Fig. 120. Table 6 shows us that the constitution of its matrix is ferrite 55 per cent, cementite 45 per cent, that of a white cast iron of the pearlite series. Accordingly, the lines in Fig. 120 which give the constitution of this matrix ("Per cent Ferrite in matrix" and "Per cent Cementite in matrix") cut this ordinate *W* at 55 per cent and 45 per cent, respectively. Next, Fig. 120 assumes that the properties of this matrix itself, as distinguished from the cast iron which contains it, are the same as the properties of such a white cast iron with 55 per cent ferrite and 45 per cent cementite; hence the line "Tenacity of matrix" cuts ordinate *W* at the same height as that at which it cuts the 3 per cent carbon ordinate in Fig. 59; and so with the lines "Hardness of matrix" and "Ductility of matrix."

These three lines, then, give us the tenacity, ductility and hardness, on the present hypothesis, of the matrix of each cast iron of this series shown in Fig. 120, as a basis for forecasting the properties of the cast irons themselves regarded as a conglomerate of (1) their matrix and (2) graphite; the properties of this conglomerate, *i.e.*, of the several cast irons each taken as a single conglomerate whole, are represented by the lines "Tenacity of whole," "Ductility of whole" and "Hardness of whole." These three lines are the result of a first attempt made by the author.\*

Above the diagram is a line showing the trade name or grade of the cast iron as a whole, and above it a second line showing the nature of the matrix by what we may call its trade name. In other words, this line gives the trade names of the different classes of steel or cast iron to which the matrix corresponds in constitution, in different regions of this series. For instance, the words

\* Proc. Am. Soc. Testing Mats., II, 1902.