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HEAT TREATMENT OF WHITE CAST IRON

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Fig. 1.

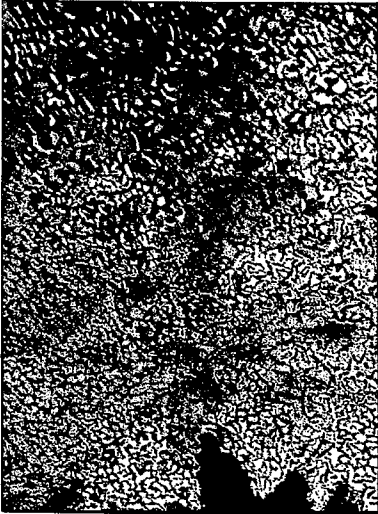


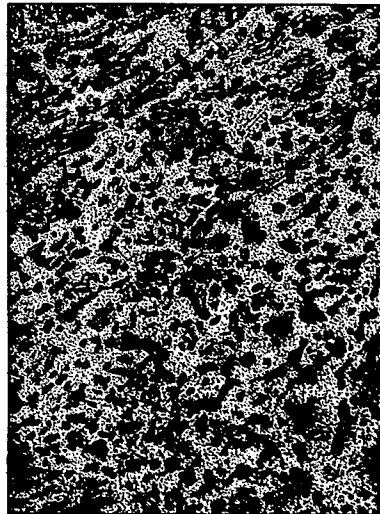
Fig. 2.



Fig. 3.



Fig. 4.



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HEAT TREATMENT OF WHITE CAST IRON

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This invention relates to the heat treatment of white cast iron, and it has particular reference to the heat treatment of white iron castings of modified chemical composition by methods producing articles of enhanced physical properties, and to the articles so produced.

The term "white cast iron" connotes cast ferrous metal containing appreciable amounts of carbon and silicon, which elements occur in such proportions as to impart to the cast metal a white appearance, and which also contains some sulphur, phosphorus, and manganese. The amounts of these customary ingredients, and their condition in the casting, are such as to prevent the classification of the iron as a steel, and the carbon content, or carbon and silicon proportion, is such as to prevent the separation of the carbon during the cooling of the cast, thereby distinguishing the material from grey cast iron. While such material is not ductile or malleable, as initially made, it may be subjected to a heat treatment to impart some ductility and strength.

Heretofore, the practical art has conducted such heat treatment by subjecting the castings to a comparatively high temperature, with slow cooling, over a period of from say six to fourteen days, to produce what has been known as malleable cast iron. This material has been known to engineers and users by virtue of its black appearance in fractured section, and the presence on the outer surface layers of a skin of white metal, and so has been known as "black heart" malleable iron. Metallurgically, such material has been understood to consist of a composition of pure iron or ferrite containing free carbon—"temper carbon"—with an outer rim or skin from which some or all of the carbon has been burned out, or decarburized.

Another species of malleable cast iron, known as white heart iron, is also known, and is formed by so treating the casting, (usually one of thin section), in such manner as to decarburize the metal throughout. Such castings, however, are apt to be porous or spongy and of limited strength, and hence have not met with great favor.

In the development of foundry practice for making white iron castings which may be heat treated by these prior art methods, the effort has been to obtain castings containing from 1.90 to about 3.00 per cent carbon, 1.3 to 0.60 per cent silicon, about 0.16 per cent phosphorus, less than 0.10 per cent sulphur, (if the iron is prepared in an air furnace, or somewhat more sulphur if the iron is made in a cupola), and a manganese content of slightly more than twice the sulphur content,

($Mn-2S=0.15+$) although it has also been the practice to keep the manganese at a fairly low figure, say less than 0.3 to 0.4 per cent. High carbon contents make for fluidity of the molten iron, thus permitting lower pouring temperatures, but also decrease the strength. Silicon has the effect of accelerating the heat treatment, by rendering more facile the separation of the carbon, from its white form of iron carbide, to its elemental or black form, but too much silicon causes the carbon to separate in the casting mold, thus producing grey or mottled iron instead of white iron. These considerations indicate the reasons for the compositions sought for in making the white iron preparatory to heat treatment.

With regard to sulphur and manganese, it has heretofore been known that sulphur acts as a retardant for the graphitization or annealing treatment, and also tends to form ferrous sulphide, which decreases the strength. It has also been known that manganese reacts with sulphur preferentially to the iron, so that the art has sought a manganese value of about twice the sulphur, to act as a neutralizer, plus some excess of manganese. It has also been thought that more than 0.6 per cent manganese makes the iron hard and difficult to anneal. (Metallurgy of Iron and Steel, Stoughton, 3rd ed., 1923).

In the foregoing discussion, reference has been made to the criteria and practices prevalent in the art of making black heart castings, which, in best commercial form, have had ultimate tensile strengths of about 55,000 pounds per square inch, with an elongation of possibly twenty per cent in two inches. This, in substance, has been the desired commercial product of the general art, and is identified metallurgically as the transformation product obtained by prolonged heat treatment of white cast iron. As noted above, white cast iron is hard, brittle, and practically devoid of malleability or ductility. It is composed essentially of iron carbide or cementite interspersed with pearlite, or a lamellar structure of iron carbide and iron, or ferrite. The heat treatment decomposes the cementite, both that which is free and that in the pearlite, to produce the black heart casting, which is composed of ferrite containing splotches of free or temper carbon.

Recently, however, it has been found that by subjecting white cast iron to other heat treating operations, under suitably controlled conditions, commercial products of enhanced physical properties may be obtained. In the conduct of these processes, it has also been observed that the con-

trol is of utmost importance. My invention deals with the manufacture of improved products, which, while made by subjecting white cast iron to a heat treatment, should not be confused with what has heretofore been recognized as "malleable iron". The method of treating, the composition of the iron, and the ultimate product may all be distinguished from the concept of "malleable iron", and, in lieu of a common trade name for such materials, they will be designated here simply as heat treated white iron castings.

Contrary to the general understanding in the art with respect to manganese, the manganese-sulphur ratio, and the time of treatment required to produce a commercial article or casting, I have discovered that desirable castings may be made from white iron compositions containing more than 0.6 per cent manganese, and I have also discovered that such articles of commerce may be made in periods of time less than those heretofore allotted to the making of black heart malleable iron. The heat treated white iron or high carbon alloys made according to my invention may possess tensile strengths in excess of 100,000 pounds, with appreciable elongations, or may be made with tensile strengths somewhat higher than high grade black heart malleable iron, with comparable elongations, in relatively short periods of time. These physical properties may be selectively imparted to the final product, by varying the nature of the heat treatment, or the manganese content, and, in this connection, it may be noted that another measure is the value of the manganese content minus twice the sulphur content, $(Mn-2S)$, which may lie within the range of 0.40 to 1.00, for ordinary commercial work. The articles so made are susceptible of machining. In these alloys, there may also be generally observed a spheroidized structure.

In general, I make these various alloys by preparing a melt of iron, carbon, silicon, sulphur and phosphorus, in the proportions heretofore generally used in foundry work, but preferentially add enough manganese, as in the form of ferromanganese or high manganese pig iron, to insure the desired high manganese content in the cast metal. From 0.60 to 1.50 per cent manganese in the casting will serve, although somewhat greater amounts may be utilized if desired, and the exact amount will depend to some extent upon the percentages of other ingredients, the time and temperature of heat treating, etc. That is to say, I may determine to use a given percentage of manganese, and vary the time or temperature of the heat treatment to obtain the product desired, or I may standardize the heat treating operations, and vary the amount of added ingredient. For I find that the excess manganese acts not only to impart enhanced physical properties to the heat treated casting, but that it also serves to change the position of the critical temperature and as a retardant for the reactions occurring during the heat treating process, and to such an extent that I may make use of these properties as a means of control of the reactions. In some methods of operation, it may be desired to utilize only the effect of reaction control, without particular regard to the properties of the end product, while in other instances, it may be desired to strive for a material of given properties without extended consideration of the effect of the added material during the heat treatment, while in other cases both effects may be correlated.

The heat treatment itself consists essentially in subjecting the castings to a temperature above the critical range, and for a length of time sufficient to effect a primary reaction of decomposition of free or massive cementite in the white iron. This reaction tends to reach an equilibrium, and the castings, in this form, may be cooled and used for certain purposes. It is advantageous, however, to subject the castings to a further heat treatment, and at a temperature or temperatures near or below the critical. In the presence of the retardant, there will now occur a new set of reactions, some chemical and others physical. The physical reactions proceed much more rapidly in these alloys, than do the chemical reactions, and hence the castings may be subjected for a definite length of time to temperatures effecting such physical and chemical reactions, and the castings may then be cooled and used. In the absence of some retardant for the chemical reactions, such as manganese, it is very difficult in some instances to effect a predeterminable physical change below the critical temperature, without concurrent chemical change. With added manganese as a retardant of chemical action, the physical change may be effected without material chemical change, and at lower temperatures, and within reasonable lengths of time, making for economy of operation. If desired, the heat treatment in the second range or lower temperatures may be prolonged, so that appreciable chemical, as well as physical changes, may occur. I find that such chemical change may be brought about in overall periods of time of less than five days, and that the reactions proceed at such rate as to permit of control, so that a partial physical, or chemical, or total physical and partial chemical reaction may be effected, and the reaction terminated when the casting has undergone such change as to impart the properties desired.

Prefatory to a detailed consideration of certain methods of obtaining these various products, reference may be made to the accompanying drawing, the several figures of which represent photomicrographs of castings subjected to various treatments and having various strengths and physical properties.

Figure 1 shows the appearance of a section of casting, etched with nitric acid and magnified to 1200 diameters, the physical properties of which are substantially as follows; ultimate strength, 100,000-110,000 pounds per square inch or more, yield point, 75,000-85,000 pounds, elongation in two inches, 4 to 7 per cent; Brinell hardness, 240-260.

In Fig. 2, a similar casting is depicted, but the tensile strength is lower, about 90,000 to 105,000 pounds, the yield point between 65,000 and 80,000 pounds, and the elongation between seven and ten per cent. The Brinell hardness is between 220 and 240.

Fig. 3 shows a section in which the ultimate strength is in the range, 75,000-90,000 pounds, with correspondingly lower yield point and hardness, and ductility up to 15 per cent.

In Fig. 4, the ultimate strength is from about 70,000-85,000 pounds, elongation from 15 to 20 per cent, and hardness from 180 to 200.

In each of these sections, there appear black areas of temper carbon in a background or matrix of ferrite, these carbon particles being not as prominent here as usually observed in white iron micrographs, due to the high magnification employed. It will also be observed that, even at the high magnification, there is no ready observance of pearlitic areas, customary in white irons of

ordinary composition which are not fully annealed, or of special composition white irons containing excess retardant, in which the anneal is conducted according to the practices of the industry heretofore employed. On the contrary, there will be observed in each section, to an extent depending upon the properties, (and hence the composition and heat treatment) a gnarled or pebbled effect, which is deemed to be due to the presence of spheroidized cementite. I believe I am the first to devise a means for the production in a useful manner of heat treated white iron castings having enhanced physical properties in which this effect obtains, and this I accomplish by preferential promulgation of physical changes over chemical changes in a white iron of modified composition, subjected to a controlled annealing operation.

For the production of these and like materials on a commercial scale, I have found it advantageous to employ a type of furnace which may be readily opened or closed to facilitate the handling of the charge, and wherein a balanced non-decarburizing or non-reactive atmosphere may be maintained, although, in certain applications of the principles of the invention, it may be found desirable to effect a controlled and partial decarburization. Such procedure, however, is not a part of this invention, although it may be used in conjunction therewith, and hence further description along this line will not be made. A furnace of the type which I have employed successfully in commercial work is shown in the patent to Breaker, No. 1,636,041, dated July 19, 1927. It will be understood, of course, that this type of furnace is referred to as providing apparatus for carrying out the invention in the manner now best known to me, and that other types of apparatus may also be employed.

It being assumed that suitable white iron castings have been prepared according to the foundry practice, the initial phase of the heat treating operation is to subject these castings to a temperature above the critical range, for the purpose of decomposing the massive or free cementite or iron carbide. In practice, this may be done by loading the castings, say a charge of from ten to twenty-five tons for the type of furnace suggested, onto a car or other suitable device, and inserting the load into the furnace. The charge is then brought to temperature by applying heat, and, for a practical case, it would require about twelve to fifteen hours to bring the load to a temperature of 1700° F., as measured by the furnace pyrometers. Too rapid application of heat is not desirable, as the carbon will tend to separate from the austenite about an excessive number of nuclei, whereas, if the heat is applied more slowly, as, for example, over a period of twelve to fifteen hours, the carbon will tend to migrate to previously established nuclei, thereby reducing the total number of carbon centers and increasing the desired properties of the final product. Temperatures between the upper boundary of the critical range and somewhat below incipient fusion may be used;—the specific temperature given being a convenient temperature producing good results. Assuming a substantially constant temperature, (although variations may be resorted to), the time of heat treatment required to break down the free iron carbide will depend upon the chemical composition, size of the castings, etc. For castings containing the usual percentages of carbon and silicon, and the amounts of manganese hereinafter noted, the

heat at 1700° F. should be held from about eighteen to thirty-six hours, the objective being to bring the reaction of decomposition of free cementite to equilibrium or completion.

Upon the completion of the high temperature heat treatment, the charge is removed from the furnace and its temperature reduced at such rate, for example, that the charge will reach a black or cherry red temperature in about eighty-five minutes. I have found that the rate of cooling is material to the characteristics of the final product. If, for example, an exceedingly rapid cooling be effected as, for example, by means of an oil quench, satisfactory results may be obtained. Or, if an air quench be employed, such as is indicated by the foregoing practical example, equally satisfactory results may be obtained. In the first case, the cooling is effected so quickly that no cementite or combined carbon may separate;—there is a tendency for such separation, but the cooling is so rapid as to preclude the effect. In the second example, the cementite may separate, but it separates in a form making it susceptible for secondary treatment in a satisfactory manner. Intermediate these two ranges where the cooling is not so rapid as to overcome the separating tendency, or so slow as to satisfy the second criterion, more or less combined carbon will separate as grain boundary carbide, and this effect is not consistent with the development of the best properties in the final product. It must be borne in mind, however, that the cooling should not be so slow as to permit the separated carbide to break down into ferrite and temper carbon, for if this effect obtains, then there can scarcely be that certainty of the nature of the casting as is conducive to uniform results in practical operation. It will be understood that occasions may arise where close supervision of the rate of cooling is not necessary, but in presenting the principles of my invention in terms of practical operation, I deem it expedient to call attention to different phases of the heat treatment cycle.

In this connection I may call attention to a variant of certain of the principles herein set forth.

If the cooling is effected at an extremely rapid rate, so as to prevent the separation of the combined carbon, as, for example, by the oil quench just referred to, and the subsequent heat treating operation below the critical is conducted at a temperature somewhat lower than those indicated herein, and for a somewhat less period of time, then the spheroidized condition of the end product may be obtained even though the casting is of normal chemical analysis. These materials will show enhanced physical properties over "malleable" cast iron.

Having effected the desired reaction on the free cementite, the next step in the process is to subject the castings to a further heat treatment at a temperature somewhat below the critical range, as between 1150° F. and 1375° F., in order to impart to the castings the properties desired. In this operation, there are several reactions, some physical, and others chemical. The major physical reaction appears to consist of a readjustment of the constituents of the casting, while the chemical reaction consists of a decomposition of the combined carbon or cementite, or that occurring in the pearlite, into ferrite and temper carbon. These reactions do not progress at the same rate, nor is the relative rate the same at varying temperatures. I find that high per-

centages of retardants, such as excess manganese, act primarily on the chemical reactions, and hence, by effecting a proper correlation of time, temperature, and manganese or other retardant value, I am able to obtain final products having properties depending upon the resultant effect of the controlled variables. Upon the completion of the low temperature reactions, the castings are withdrawn from the furnace and are cooled, and, to offset any tendency of a continuance of the reactions beyond the desired point, I preferentially cool rapidly.

I find that, at low temperatures, say below 1200° F., the reactions progress slowly, and, for commercial work, I find it advantageous to employ temperatures between 1200° F. and 1350° F., and usually for periods of time ranging from ten to sixty hours.

In order to show more concretely the results which may be obtained, I may refer to results obtained in practice, as determined from the testing of test bars included in commercial heats on car load lots of material. A consideration of these results will show certain generalities, which may be summarized as follows. With manganese as a retardant and present in amounts between about 0.60 and 1.4 per cent, (with normal sulphur value), the strength of the casting increases with the manganese content, while the ductility decreases, other things being equal. For the same value of manganese, prolonged heat treatment increases the ductility, with some decrease in the ultimate strength. The effects of time and temperature appear not to be linear functions of each other, but, for a given available retardant content, there is apparently some mean temperature below the critical where such relationship exists. The effect of increased manganese percentages is to lower the critical temperature, and hence the rate of reaction, at the same temperature, may be accelerated by increasing the manganese value.

While I have used manganese as a retardant in excess of 1.5 per cent, with normal sulphur values, and have obtained thereby products having enhanced physical properties, it appears from my investigations that like properties may be equally well obtained by using somewhat lower manganese values. That is to say, there appears

to be a range of manganese values between about 0.60 and 1.5 per cent, where, other factors being equal, the addition of manganese is beneficial, followed by another range of between about 1.5 and 2.5 per cent, where the effect of manganese, while beneficial as compared to very low manganese contents, gradually diminishes. Thus, in one example, using comparable high temperature treatments, carbon and silicon contents, I obtained the following results.

Mn, per cent	Time, hours	Temperature	Ultimate	Yield	Elongation
0.77	10	1300° F.	98800	81900	6
1.47	10	1300° F.	96700	82300	3.5
2.09	10	1300° F.	59400	59400	0
2.95	10	1300° F.	71600	71600	0

For determining the heat treatment of castings within the range, —Mn=0.60 to 1.5 per cent, —let it be assumed that the foundry is given an order for certain castings, in which the ultimate strength, yield point, elongation, or like physical properties are specified, or are known by virtue of the use to which the casting is to be put. The cycle of the lower temperature heat treatment, manganese content or the like is then selected, to determine the operations which should be performed to meet the established specifications. With certain castings, a high carbon content will be suggested to the foundryman, who, by virtue of local plant conditions, finds it expedient to use as high a carbon value as possible. The problem is then reduced to correlating the time, temperature, and manganese value for such white iron. Again, the foundry conditions may be such as to render expedient the use of a certain manganese content or manganese and sulphur factor, or may indicate the necessity of adhering to a certain operating cycle, in which case only one variable is left to the choice of the manufacturer. I provide for meeting these widely varying commercial matters in the present invention, since the effects of all may be correlated to give the product desired. This may be typified by the following table, in which the basis of arrangement is such as to determine first what ultimate strength is required, from which the cycle may be determined.

High manganese white iron

Series No.	Physical properties			Chemical analysis				Heat treatment	
	Ultimate strength lbs. per in. ²	Yield point lbs. per in. ²	Elongation percent in 2"	Mn	Mn-2S	C	Si	Temperature degrees F.	Time hours
	65,000-70,000								
1	70,566	54,336	7.8	0.61	45	2.31	0.94	1200	40
2	70,530	47,330	14.6	0.61	45	2.32	0.94	1250	40
3	65,230	48,900	18.2	0.61	45	2.32	0.95	1250	60
	70,000-75,000								
4	74,760	53,300	9.8	0.61	45	2.32	0.95	1250	20
5	74,500	49,350	15.7	0.61	46	2.32	0.94	1350	20
6	72,550	47,350	18.7	0.61	46	2.31	0.95	1350	40
	75,000-80,000								
7	77,900	57,760	8.0	0.61	45	2.33	0.94	1200	20
8	78,330	53,830	13.3	0.75	58	2.38	0.92	1300	40
9	77,460	52,150	18.2	0.75	58	2.37	0.92	1300	60
	80,000-85,000								
10	83,100	55,000	17	0.82	65	2.09	1.11	1300	20
11	85,120	57,240	12.0	0.75	58	2.37	0.93	1250	20
12	84,500	54,020	13.4	0.75	59	2.38	0.92	1350	40
	85,000-90,000								
13	87,060	56,500	12.3	0.75	59	2.37	0.92	1350	20
14	86,200	53,000	10.5	0.68	42	1.91	1.32	1200	20
15	90,100	59,300	11.0	0.98	82	2.45	0.82	1300	20
16	86,030	58,030	14.8	1.14	98	2.38	0.87	1300	60
17	90,300	62,700	16	0.80	61	2.08	0.92	1300	20

High manganese white iron—Continued

Series No.	Physical properties			Chemical analysis				Heat treatment	
	Ultimate strength lbs. per in. ²	Yield point lbs. per in. ²	Elongation percent in 2"	Mn	Mn-2S	C	Si	Temperature degrees F.	Time hours
	90,000-95,000								
18.....	92,900	68,360	6.8	0.75	58	2.37	0.94	1200	20
19.....	93,620	60,320	9.9	0.98	82	2.44	0.87	1250	20
20.....	95,500	66,300	7.8	1.14	98	2.30	0.89	1250	40
21.....	93,130	61,400	10.3	1.14	98	2.38	0.86	1300	20
22.....	93,175	64,857	7.5	1.39	123	2.39	0.96	1300	20
23.....	92,700	62,500	13.5	0.82	65	2.09	1.11	1300	20
24.....	92,700	57,700	15	0.79	60	2.14	0.92	1300	20
25.....	95,500	58,100	12	0.81	62	2.11	1.06	1200	20
	95,000-100,000								
26.....	98,525	65,625	4.4	0.98	82	2.45	0.84	1200	20
27.....	98,680	72,286	3.8	1.14	98	2.41	0.91	1200	20
28.....	100,700	65,800	8.2	1.14	98	2.40	0.88	1200	60
29.....	99,800	67,930	6.3	1.14	98	2.38	0.87	1350	20
30.....	100,720	75,220	5.0	1.39	123	2.39	0.95	1200	40
31.....	99,000	69,900	10	0.81	62	2.09	1.06	1200	20
	100,000-105,000								
32.....	101,075	76,050	3.5	1.39	124	2.36	0.96	1200	20
33.....	101,000	65,200	10	0.95	74	2.10	1.08	1200	20

From a consideration of this practical data, in which the results given are the mean results from a series of commercial heats, and hence are deemed to be reproducible at will, it will be observed that the foundryman may make a choice among several variables, and still obtain the same end result. Thus, considering a specification for a wrench, in which high yield strength is indicated, that is to say, ultimate, 90,000; yield point, 60,000; elongation, 12 per cent, and Brinell hardness 210 in connection with the foregoing table, it will be seen that this result may be obtained by Examples 15, 19, and 21, approximately, and that, as between 15 and 21, 15 has the less manganese. Example 19 is based on a lower temperature, but the elongation value appears too low, while Example 15 may run under specification on strength. Example 21, which appears to be the best, is somewhat less ductile than desired, so this may be corrected for by using less carbon, say about 2.30 per cent, or, the time of heat treatment may be extended about five hours, or, the operation may be conducted at say 1325° F. Or, since the amount of manganese may be made less, to about 1.06 per cent, a combination of these variables may be made.

As another example, let it be assumed the order is for pipeline couplings, for which the specifications are ultimate, 65,000, yield point 55,000, elongation, 12 per cent. This is readily met by Example 10.

It will be understood, of course, that the foregoing tabulated data is simply suggestive of the manner in which the invention may be applied by the practical foundryman, and that the corrections for size of casting, carbon content, pouring temperatures, and the like, being known in the art at this time, may be used conjointly with the proposals set forth above, to adapt the invention to a wide variety of uses.

It will further be understood that the invention may be practiced to produce articles of strengths in excess of 100,000 pounds, from white iron castings. Some of the results which may be thus obtained are indicated in the following table.

Ultimate	Yield	Elong.	Mn	C	Si	Temp.	Time
						°F.	
108,300	91,800	6	0.62	2.43	0.99	1200	10
112,900	98,400	5	0.77	2.43	0.99	1200	10
104,700	91,300	4.5	1.04	2.43	0.99	1200	10
101,500	73,400	9	0.77	2.43	0.99	1325	10

made according to the principles previously discussed are distinguishable from ordinary malleable cast iron or pearlite irons of normal compositions in several respects. Among other things, the castings made according to this invention, even though subjected to extensive treatment, have appreciably higher strengths than those heretofore known, whereas an ultimate tensile strength of 55,000 pounds per square inch has heretofore been regarded as high for malleable cast iron. The compositions of the present invention will normally show ultimate strengths of upwards of 62,500 pounds per square inch with comparable yield points and elongations. Again, these castings differ from ordinary malleable cast iron compositions in that they contain materially greater quantities of manganese or other available retardant than have heretofore been deemed permissible, as, for example, the difference between the manganese and the sulphur content is usually a factor exceeding about .4 per cent. As I shall presently explain, this modification on the chemical composition has a definite effect on the ultimate properties of material because of its action during the annealing cycle.

Metallographically, these compositions are also distinguishable from those heretofore known in that they reveal, when suitably etched and magnified, a spheroidal structure, the extent of which will vary with the physical properties and the chemical composition and the heat treatment to which the alloy has been subjected. This effect is typified in the several figures of the drawing, from which it will be seen that the high strength alloys present a pebbled effect extending substantially throughout the entire section whereas the alloys of lower strength reveal the same effect in the form of scattered nodules of cementite in a matrix of ferrite. To the best of my knowledge this spheroidized effect has not heretofore been obtained in the heat treatment of white cast iron, and particularly with alloys having the physical properties and chemical compositions herein contemplated.

The existence of this effect is, in my present understanding and contemplation, indicative of physical changes during the heat treating operation which occur in advance of or preferentially to the chemical change of decomposition of cementite or iron carbide. Without attempting to limit myself to any theory of operation, since the attainment of the results herein set forth may be had independent of such theory, I may state that I believe this preferential physical change

The heat treated white iron castings or alloys

is obtained, under the controlled heat treating conditions indicated, by starting with a white iron in which the composition is so modified that there is contained therein an available excess of a retardant for the breakdown of the pearlitic cementite. Insofar as I am aware, it is new with me to form a white iron having a chemical composition in which an available excess of retarding agent is not counterbalanced or neutralized by varying the other constituents of the casting from those usually employed in ordinary commercial practice, in order to effect my desired final results. I am aware, of course, that heretofore it has been proposed to modify the composition of ordinary white cast iron to include therein for other purposes elements which may have the effect of retarding the rate of annealing. In all of such proposals with which I am familiar, however, other changes have been made in the composition of the iron so that, during the heat treating operation proposed in connection therewith, no preferential control was obtained whereby physical changes leading to advantageous properties in the final metal could be obtained without concurrent chemical change limiting the strengths or ductilities which otherwise might be obtained.

That is to say, by using an excess of retardant in combination with a cycle such as that described herein wherein the reactions below the critical temperature may be controlled, I may obtain preferential physical change as typified by the spheroidized effect alluded to, and the uniformity of such control, necessary to a commercial product, may be determined by observing the uniformity of distribution of the nodulated cementite responsible for the spheroidized structure. In this aspect, therefore, the present invention is not restricted to the employment of percentages of manganese or a manganese-sulphur factor indicated in the foregoing practical examples, but other addition agents having a retarding effect may be utilized. For many practical purposes, however, such other agents are not indicated. For example, such metals as chromium, vanadium, molybdenum, and the like, while known in a general way as retardants of the annealing operation, (considered from the chemical viewpoint alone and in the preparation of "malleable" iron), are usually avoided by the practical foundrymen since their introduction into the melting furnace invariably contaminates successive batches of material of normal analysis and so leads to serious operating difficulties. When such difficulties are not imminent, however, these other retardants may be employed in small percentages, in lieu of the higher manganese specifically proposed herein.

From a further aspect, it will be seen that my invention contemplates the correlation of the heat treating cycle with the composition in such manner as to effect enhanced physical properties in the casting and that such correlation may be frequently identified by the spheroidal condition of the residual cementite. In connection with reference to spheroidized condition, it will also be understood that, if material made according to my invention is subsequently subjected to a heat treating operation as may be done for the purpose of hardening the metal, then the spheroidized effect may be masked or obscured. However, in such cases, the great hardness of the material taken in connection with other distinguishing characteristics may be referred to.

While I have described my invention by reference to certain practical embodiments, in order

that the same may be used by those skilled in the art, it will be understood that other embodiments may be made without departing from the principles of the invention, and it will accordingly be understood that the scope thereof should be ascertained by reference to the following claims.

What is claimed is:

1. The method of making heat treated white iron castings which comprises forming a white iron containing carbon, silicon, manganese and sulphur in the proportions normally employed to produce malleable cast iron, modifying such composition by the inclusion therein of a retardant for the decomposition of pearlitic cementite at temperatures below the critical, pouring the casting, subjecting the casting to a temperature above the critical for a length of time sufficient to effect the decomposition of substantially all the massive cementite, cooling the casting to below the critical temperature, and subjecting the casting to a temperature below but near the critical and for a length of time sufficient to effect desired changes in the properties of the casting, thereafter cooling the casting, and maintaining the amount of retardant and the time and temperature of treatment below the critical in such relationship as to impart to the final casting a strength in excess of 62,500 pounds per square inch, a ductility of more than three per cent in two inches, and a spheroidized structure.

2. A method of heat treating white iron castings containing manganese in proportions of between 0.6 and 1.5 per cent and wherein the difference between the manganese content and twice the sulphur content is between 0.40 and 1.25, which consists in subjecting such castings to a temperature above the critical temperature from between eighteen and thirty-six hours, cooling the castings, and subsequently subjecting them to a temperature effecting physical changes in said castings below but near said critical temperature for a predetermined length of time.

3. A method of heat treating white iron castings containing more than 0.6 per cent manganese, which consists in bringing such castings to a temperature in the neighborhood of 1700° F. for a period of time sufficient to effect desirable physical and chemical changes, conducting said step in the presence of a non-oxidizing atmosphere, quenching the castings, and again heating the castings at a temperature between 1150° F. and 1350° F. to effect further changes in the physical properties of the castings.

4. A method of heat treating white cast iron containing between 0.6 and 1.5 per cent manganese which comprises heating the iron at a temperature in the neighborhood of 1700° F. until the free iron carbide contained therein has been graphitized, cooling the iron to a temperature below the critical point thereof, and heating at a temperature of 1200° to 1350° F. for a period of time sufficient to effect physical change with substantially little chemical change in the iron.

5. A method of heat treating white cast iron containing between 0.6 and 1.5 per cent manganese which comprises heating the iron at a temperature in the neighborhood of 1700° F. for 18 to 36 hours, quenching the iron, heating the iron for 10 to 60 hours at 1250° to 1350° F., and conducting said first and last named step of heating of the iron in the presence of a non-oxidizing atmosphere.

6. Heat treated white cast iron having a chemical composition within the range—carbon 1.90 to 3.00 per cent, silicon 1.29 to 0.70 per cent, man-

ganese 0.60 to 1.50 per cent, sulphur in such proportions that twice the sulphur value reacts with a portion only of the manganese, and having an ultimate strength in excess of 62,500 pounds per square inch, in which the carbon as originally occurring in the iron as massive cementite has been converted into temper carbon by heat treatment to equilibrium at a temperature above the critical.

7. Heat treated white cast iron containing from 0.6 to 1.5 per cent manganese having an ultimate strength in excess of 62,500 pounds per square inch and characterized by a spheroidized cementite structure included in a background of ferrite interspersed with temper-carbon.

8. A manufacture consisting of heat treated white cast iron, the chemical composition of which is modified from the following limits:

Carbon	1.90 to 3.00 per cent,
Silicon	1.30 to 0.70 per cent,
Phosphorus	about 0.16 per cent,
Sulphur	less than 0.10 per cent,
Manganese	twice the sulphur plus about 0.15 per cent,

Iron and adventitious impurities, the remainder; to include in such composition a retarding agent available and effective to retard the decomposition of pearlitic cementite at temperatures below the critical; which iron has been subjected to heat treatment as evidenced by inclusion therein of temper carbon formed from cementite contained in the original white cast iron; and which heat treated white cast iron is further defined as having an ultimate strength in excess of 62,500 pounds per square inch and measurable elongations, and revealing, in metallographic section, a structure of spheroidized cementite and temper carbon, the extent of spheroidization being such at the lower order of ultimate strengths as to reveal a matrix of ferrite and increasing with increase of ultimate strength above 62,500 pounds per square inch.

9. Heat treated white cast iron containing iron, carbon, manganese and iron carbide, and wherein the manganese content is between 0.6 and 1.5 per cent, and in which some of the carbon is present as free carbon and some of the carbon is combined with some of the metal, wherein the compound of iron and carbon is interspersed with the uncombined iron in a spheroidized form, and wherein the tensile strength of the material lies between 65,000 and 120,000 pounds per square inch with an elongation of from twenty to three per cent in two inches.

10. Heat treated white cast iron containing carbon and manganese and wherein the manganese content is between 0.6 and 1.5 per cent in which a substantial amount of the carbon occurs in clumps in the free state and in which some of the carbon exists in the combined condition, and is dispersed in a fine nodulated condition throughout the mass of the alloy.

11. Heat treated white cast iron containing carbon, silicon, manganese, sulphur, and phosphorus as normal impurities, and further containing a retarding agent for the decomposition of pearlitic cementite effective in the proportions used and in the presence of the proportions of the remaining constituents other than iron, formed from white cast iron in which substantially all the carbon is originally present as combined carbon or cementite, but which, as heat treated, a substantial amount of the carbon occurs in the free state as temper carbon, some carbon exists in the combined state as cementite, which cementite is revealed metallographically as nodules dispersed substantially uniformly throughout the section, and which heat treated white cast iron possesses an ultimate strength in excess of 62,500 pounds per square inch.

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