Fig. 4

High Tensile and Ductile Iron

750 X
This invention relates to a method of heat treating white iron castings and to articles produced by the heat treatment of white cast iron, and it has particular reference to the provision of articles of commerce consisting of iron admixed with its customary constituents, including a relatively high percentage of carbon, having high tensile strengths and appreciable ductility.

Heretofore it has been customary to subject white iron castings to a heat treatment to enhance the physical properties of the material, as exemplified by the manufacture of "black heart" malleable iron, which is made by heating the white iron casting to a temperature above the critical, and also below the critical, to provide a material, which, in good specimens, would possess a tensile strength of the order of 55,000 pounds per square inch and an elongation of say twenty to twenty-five per cent. It has also been observed that white iron castings might be so treated as to produce materials having much higher tensile strengths than that of high grade black heart malleable cast iron, but, with the advent of the increased strength, the ductility of the end product became practically negligible.

According to the present invention, we provide for the manufacture of heat treated iron castings under conditions permitting of the attainment of tensile strengths in excess of 55,000 pounds per square inch, and which are additionally characterized by the retention of an appreciable ductility, as for example, in the range of elongations between say fifteen to six per cent, for compositions of normal chemical composition. These products, as we find upon examination, are not only different in their physical properties from those known in the prior art, but they also are markedly different in ultimate chemical composition and physical structure, which factors may be appraised in identifying the new materials.

By white iron castings of normal compositions, we refer to castings of compositions such as are now employed in malleable iron practice, and which are made from suitable melts made in an air or electric furnace, or cupola furnace. These melts are poured into suitable molds, and the resulting product is termed white cast iron. The percentages of normal constituents in such compositions, other than the iron itself, usually lie between the ranges of 1.75% to 3.35% carbon; 0.65% to 1.50% silicon; less than 0.25% phosphorus; less than 0.25% sulfur, and less than 0.6% manganese; -the relation between the manganese and sulfur being such that the manganese value is greater than twice the sulfur value (Mn>2S) is greater than 0.1 and less than 0.20. These ranges illustrate the types of castings which we have employed in presenting the hereafter set forth examples of practical operation, and their significance to those skilled in the art will, of course, be readily understood.

As a general statement, it may be said that, in the treatment of such cast compositions, it has been desired to break down the carbide which is chemically combined with the iron, in the form of iron carbide, or cementite; into its respective chemical constituents. In the manufacture of the stated black heart castings, this cementite has been substantially fully decomposed,—the carbon appearing to the eye, in a broken section of finished material, as a velvety black mass, from which the name of designation has been derived. This treatment effects predominately a chemical change. It has also been found that the change goes forward in two stages. In the first stage, what is known as massive cementite is decomposed in the main, while in the second stage, what is known as pearlitic cementite or iron carbide is decomposed or broken down. The end product of these reactions, properly conducted, is the stated black heart malleable iron, characterized by a fair tensile strength and appreciable ductility.

If only the first reaction takes place, and the pearlitic iron carbide is not decomposed, the resulting material is quite hard and strong, but is substantially devoid of ductility. And we have found that two stages of reaction are requisite to the break-down of the pearlitic carbide, since the massive cementite is not entirely decomposed in the first stage, (due to the operations of the laws of mass reactions), and the second reaction does not take place until the first is practically completed. Bearing these generalities of explanation in mind,—that to obtain the non-ductile pearlitic with high tensile strength, only the first stage of reaction is effected; while to obtain the highly ductile but comparatively weak black heart metal, both reactions go to completion; it may now be stated that our present invention differs from these considerations in the manner of treating the pearlitic iron carbide. It is our desire to impart to the finished product a relatively high tensile strength, but to retain the ductility. To obtain this result, we effect a substantial break-down of the massive cementite, but instead of causing a subsequent break-down of the pearlitic structure as has heretofore been proposed, we retain this substance to the fullest possible extent...
tent. However, as stated, the pearlitic structure obtained by the initial decomposition of the massive cementite is non-ductile; but we have discovered that if the material is so treated as to cause a physical rearrangement of this pearlite, with only an adventitious chemical change, that both high strength and ductility are imparted to the end product.

In effecting the desired initial chemical change and ultimate physical change, we find it highly advantageous to effect a proper controlled control of a number of factors involved in the heat treating process. We may note among the factors of control a definite relationship between the percentage constituents of the casting and the time and temperatures of heating; the protection of the material during treatment with an envelope of non-oxidizing and non-decarburizing material, such as a gas, which may be said to the expense of the castings themselves.

The proper control of carbon from the casting and to preserve the relationships previously established; the size of the casting; the temperature of pouring the casting; and like factors. Proper control of such factors do not only permit us to effect the desired operations with predetermined results, but they also permit of the completion of the process in much shorter periods of time than those which have heretofore been deemed possible for any satisfactory mal-

leasurizing process. As typical of suitable apparatus for conducting the operations on a commercial scale, and for the satisfactory treatment of loads of upwards of ten tons, we may refer to U. S. Patent No. 1,984,864, dated December 11, 1928. Our commercial operations have been conducted in this type of device, but it will be understood that other types of furnaces may be employed.

In protecting the castings from change by reaction with the surrounding atmosphere, we have found that it is useful to provide around the castings a non-oxidizing and non-decarburizing gas, which is established and maintained but not at the expense of the castings themselves. It is well known that castings will lose carbon to the surrounding atmosphere under ordinary conditions, and we find it advantageous to avoid this loss. This, we attain by providing an atmosphere containing appreciable quantities of carbon monoxide. We may use carbon monoxide alone, but such gas when used alone is difficult to control, as it is highly poisonous and tends to leak from the furnace. Or we may use air containing appreciable quantities of nitrogen and small amounts of carbon dioxide. A suitable gas composition would be carbon dioxide less than ten per cent, carbon monoxide from ten to one hundred per cent.

Nitrogen, free oxygen should be eliminated to an extent of less than one and one-half per cent. The ratio of carbon dioxide to total oxides of carbon should be less than 0.33. Such compositions do not react with the castings, either to oxidize or to carburize, and hence a constant chemical composition of the casting may be maintained. It should be further noted, in this connection, that it is not necessary sufficiently to provide such atmosphere, allowing it to leak out, and air to leak into the furnace.

With leakage, an instantaneous gas composition might be found to comply with the stated criteria, but satisfactory results would not be obtained, as a reaction between the incoming air and the castings would be in progress. The stated atmosphere should, therefore, be main-
tained without deterioration of the castings themselves, and we may effect this result by providing a perfectly air tight furnace, and then blowing in the desired gas or by burning some carbonaceous material in the furnace at the beginning of operation.

In correlating the times and temperature of heating with the chemical composition of the iron, we make use of certain principles as set forth in a copending application of one of us, (Hayes, Serial No. 209,389, filed July 29, 1927), now U. S. Patent No. 1,901,742, patented April 21, 1931, wherein it is shown, for example, that to completely graphitize free iron carbide in castings less than one-half inch in cross section at a temperature such as 1700° F., iron containing 0.9% silicon and 2.5% carbon should be heated for 11.4 hours. In actual practice, we choose times to represent free cementite of material of greatest resistance in the load placed in the furnace, and make the load uniform insofar as plant requirements will permit. For usual operations, we find that an equilibrium of reaction is established within less than 28 hours, for castings of normal size, shape, and chemical composition.

A further understanding of the invention may be had by reference to the following examples indicative of the principles, reference being made to the accompanying drawings, wherein:

Fig. 1 is a representation of a photomicrograph of a normal composition white cast iron at 100 diameters magnification.

Fig. 2 is a representation of a photomicrograph of a white iron partially treated by our process.

Fig. 3 is a representation of a photomicrograph of the fully treated material at 100 diameters magnification.

Fig. 4 is a representation of a photomicrograph of the fully treated material at 750 diameters magnification.

The white areas in Fig. 1 may be understood to represent cementite or iron carbide, while the dark areas are non-pearlite; that is, a structural association of cementite and iron or ferrite. Our invention aims to effect a chemical change in the free cementite, and a predominating physical change in the pearlite. To effect the break-down of the free cementite, we subject the castings to a temperature above the critical, but below the point of fusion, as, for example, 1700° F., for a length of time necessary to bring the desired reaction to equilibrium. In usual furnace loads, this time will lie between seven and twenty-eight hours, depending upon section thickness, total charge, chemical composition, etc. For any stated composition, the precise time may be determined as indicated in the copending application referred to.

High temperatures, small sections, etc., favor shorter times of treatment.

This reaction reaches an equilibrium, and a small amount of free iron carbide in the first-composed, but remains in the castings. For certain purposes, this residual percentage is desired because of the desirable properties which it imparts to the casting. That these properties may be retained unimpaired, we find it advantageous to cool the casting at a fairly rapid rate from the high temperature to a temperature somewhat below the critical, thereby preventing further chemical or structural change. In practice, we find an air quench is satisfactory; ten ton charges being reduced from 1700° F. to a black or cherry red heat in from sixty to ninety minutes. Water or oil quenching causes a more rapid temperature.

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reduction, but presents some practical difficulties in use with large loads.

The material obtained by this treatment has a high tensile strength but a comparatively negligible ductility. A given test bar of the following composition: carbon, 2.52; silicon, 0.90; sulfur, 0.08; manganese, 0.32; phosphorus, 0.17; possessed an elastic limit of 92,640 pounds per square inch, ultimate strength, 58,230 pounds per square inch, and an elongation of 3½% in two inches.

As illustrated in Fig. 2, under a magnification of 100 diameters, the structure of this material comprises a matrix of pearlite character throughout which are dispersed rounded clumps, nuclei, or particles of free or temper carbon. The dark spots in Fig. 2 represent the free carbon, ferrite or iron is shown around the carbon, while the pearlitic structure is represented by the general stippling.

We propose further to alter this structure by subjecting the castings to a further heat treatment in the furnace, maintaining the protective conditions previously outlined. Because of the equilibrium attained in the first step, it is necessary to effect some intermediate cooling and heating at another temperature. We find that heating below the critical may be used, but it is not the best for plant practice, as the chemical changes set in quickly, and it is therefore difficult to control the operation so as to obtain a physical change without chemical change. This difficulty is increased as higher temperatures are employed to the critical range; but if the second heating operation is conducted above the critical temperature, the reaction desired is more controllable, and more satisfactory results are attained.

In practice, therefore, we recommend heating the load as quickly as possible, after the cooling step, to a temperature of 1400° F. to 1500° F., and, depending upon the composition of the metal, holding the castings at such temperature for from five to twenty hours, the shorter times being required at the higher temperatures. If the hold is made below the critical, a complete break-down of the pearlitic structure may obtain, and the desired strength would be lost. By holding above the critical, only the physical change is effected, the chemical change being practically negligible.

After such heating, the load is withdrawn from the furnace, and is re-heated quickly, as by means of a forced air quench. The material so obtained possesses physical properties greatly in excess of the ordinary black heart malleable iron, showing tensile strengths of from 70,000 to 95,000 pounds per square inch, yield points upwards of 65,000 pounds per square inch, and elongations of as much as fifteen percent in two inches. The material specified above, for example, had an ultimate strength of 88,130 pounds per square inch, elastic limit of 78,320 pounds per square inch, and elongation of nine per cent. Likewise, we have made materials having an ultimate strength of 90,000 pounds per square inch with an elongation of nine per cent; and 79,000 pounds per square inch with elongation of twelve per cent, in commercial operations.

In operations below the critical range, we have used successfully temperatures of from 1150° F. to 1275° F., in times ranging between ten and thirty hours.

The appearance of such materials at a magnification of 100 diameters is represented in Fig. 3. The matrix is of cementite and ferrite (pearlite), as in the case of Fig. 2, but the pearlitic structure itself is noticeably different in its crystalline form. It is our understanding that the pearlite has been subject to some re-adjustment or re-arrangement, so that, while the strength is retained, greater ductility has also been imparted to the casting. To prevent some confusion in designating a pearlitic material as ductile, we prefer to allude to this matrix as simply consisting of ferrite and carbide of iron. Clumps of carbon, shown in black, are also apparent in the material. Small amounts of ferrite also may be discerned in some or all of the carbon clumps. The grain structure of this material is distinctly finer than that of black heart malleable iron.

The same material is shown in Fig. 4 at a magnification of 750 diameters. The black spots are free or temper carbon, the white we take to be ferrite, while the residuum is of pearlitic nature. The chemical composition is also different from a normal or black heart casting. Our materials contain some combined carbon, whereas black heart malleable iron possesses practically all free or uncombined carbon. The amount of combined carbon in our materials ranges from 0.45% to 0.70%, the remaining carbon being in the free state.

We believe that the high tensile strength of the castings is due to the presence of a dense grain structure of pearlite and ferrite, while the structural reorganization of the original pearlitic and the temper carbon are responsible for the high ductility. The density of the material may be exemplified by indicating its resistance to fluid permeation. We have found that sections of 3/8 inch will not sweat at fluid pressures of 100 much below 6,000 pounds per square inch.

From the foregoing considerations, it will be apparent to those skilled in the art that we have provided new commercial articles from white iron castings having enhanced physical properties and characteristics comparable with certain grades of steel. Our compositions and articles are attained by subjecting the castings to a heat treatment permitting of the substantial break-down of the massive cementite and the structural change of the pearlite without appreciable or excessive chemical decomposition thereof. Such chemical change as may occur is not sufficient to bring about the formation of the black heart type of casting, nor is the pearlitic material such as to render what has been heretofore designated in the art as "steely fracture" metal, practically devoid of ductility. In satisfactory practice, we conduct our heat treatment by subjecting the casting to a temperature above the critical range to decompose the massive cementite and to a temperature above or below the critical range to effect the desired changes in structure, following, in our best practice, each of these heating steps by a quenching operation, and also preventing decarburization of the casting. Those skilled in the art will recognize that numerous variations from the precise modes of operation may be utilized within the principles of the invention, and it will also be understood that the results obtained are not dependent upon any matters of theory set forth herein for the purpose of teaching the manner of reaching the objectives in view.

We claim:

1. The process of treating white cast iron which consists in heating the casting at a temperature above its critical range for seven to twenty-eight hours, quenching the iron to a temperature below the critical range, reheating the
4. Iron to a point just above the critical range of the iron for five to twenty hours and thereafter quenching the iron, maintaining the iron in a non-decarburizing atmosphere during the heating periods.

2. The process of treating white cast iron of predetermined composition which consists in heating the iron in a non-decarburizing atmosphere to a temperature above the critical range of the iron, maintaining the iron at that temperature until the free iron carbide is graphitized, quenching the iron to a temperature below the critical range, reheating the iron to a temperature just above the critical range for five to twenty hours in a non-decarburizing atmosphere, and thereafter quenching the iron.

3. The process of treating white cast iron of predetermined composition which consists in heating the iron for eighteen to twenty-eight hours in a non-decarburizing atmosphere at a temperature in the neighborhood of 1700° F. quenching the iron to a temperature below the critical range thereof, reheating the iron at a temperature of 1400° F. to 1500° F. in a non-decarburizing atmosphere for five to twenty hours, and thereafter quenching the iron.

The process of heat treating white cast iron which consists in subjecting the iron to a temperature above the critical for a length of time sufficient to decompose substantially all of the massive cementite, quickly cooling the iron to a temperature below the critical range to prevent further decomposition of cementite, re-heating the iron to a temperature in or just above the critical range for a length of time sufficient to effect structural rearrangements and restricted chemical decomposition of the pearlitic cementite, and terminating said heat treatment while the combined carbon content of said iron is greater than 0.45 per cent.

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