MAGNESIUM-TREATED MALLEABLE IRON

Filed Sept. 2, 1949 3 Sheets-Sheet 1

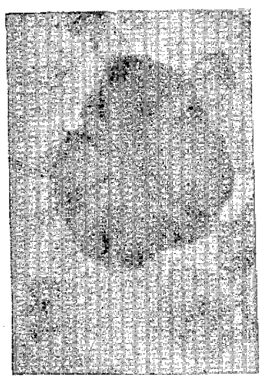

Fig. 1.

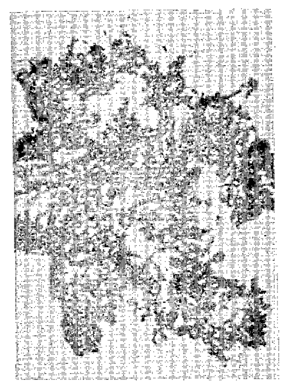

Fig. 2.

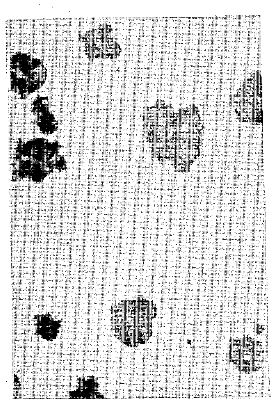

Fig. 3.

ALBERT PAUL GAGNEBIN
KEITH DWIGHT MILLIS
INVENTORS

BY A. W. Weller
ATTORNEY

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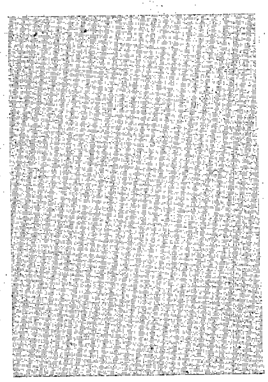

Fig. 4.

Fig. 5.

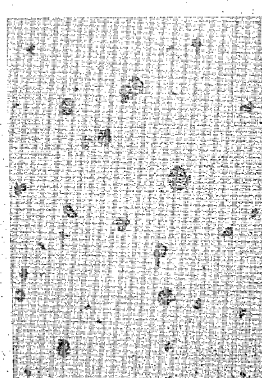

Fig. 6.

Fig. 7.

ALBERT PAUL GAGNEBIN
KEITH DWIGHT MILLIS
INVENTORS

BY A. W. Weller
ATTORNEY

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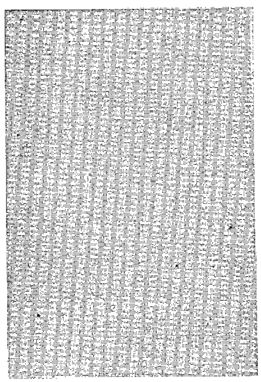

Fig. 8.

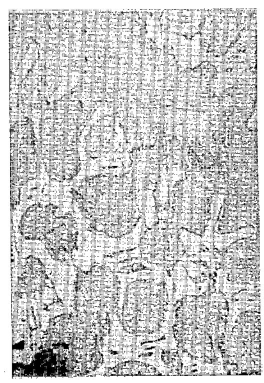

Fig. 9.

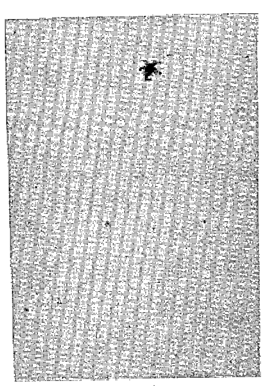

Fig. 10.

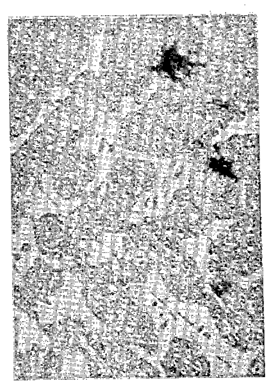

Fig. 11.

ALBERT PAUL GAGNEBIN
KEITH DWIGHT MILLIS
INVENTORS

BY A. J. Weller
ATTORNEY

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UNITED STATES PATENT OFFICE

2,578,794

MAGNESIUM-TREATED MALLEABLE IRON

Albert Paul Gagnebin, Red Bank, and Keith Dwight Millis, Rahway, N. J., assignors to The International Nickel Company, Inc., New York, N. Y., a corporation of Delaware

Application September 2, 1949, Serial No. 113,772

7 Claims. (Cl. 148—21.8)

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The present invention relates to a novel malleable cast iron product having an improved combination of properties and to a process for making the same wherein the annealing time required to produce the novel product is greatly reduced.

It is well known that malleable irons have always been subject to severe practical limitations relating to useful ranges of composition, section size, and the combinations of mechanical, physical and chemical properties which could be produced therein. For example, it has been a difficult problem to control the size, density and distribution of the graphite nodules formed in the malleable iron during the heat treatment of a white cast iron to produce the same. It has been essential that the castings employed to make high quality malleable iron be completely white in the as-cast condition as otherwise poor ductility was obtained during the subsequent heat treatment. Furthermore, the section size of castings from which high quality malleable iron could be made by the prior art was limited to a practical maximum of about two inches. In addition, the prior methods for producing American malleable iron have been time-consuming and expensive; for example, total heat treating times of about 30 to about 150 hours have been required to produce American or "black-heart" malleable iron, and it is very desirable that this heat treating time be reduced very materially.

Although many attempts have been made to overcome the foregoing and other disadvantages and shortcomings, none as far as we are aware was entirely successful when carried into practice on an industrial scale.

It has now been discovered that the uncombined carbon or graphite produced in malleable iron during the heat treatment of a white cast iron to decompose the combined carbon forms contained therein can be made to appear consistently and reproducibly in the form of dispersed, dense spheroidal particles.

It is an object of the present invention to provide a novel malleable cast iron having a new combination of properties and containing uncombined carbon or graphite in a dense spheroidal form.

It is a further object of the invention to provide a novel malleable cast iron which can be made in heavier sectioned castings than have been generally available heretofore.

Another object of the invention is to provide a novel malleable cast iron having improved corrosion resistance.

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The invention also contemplates providing an improved method for producing a new malleable cast iron wherein the annealing time required is markedly reduced as compared to the annealing time required in producing conventional malleable iron.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawings in which:

Figure 1 is a reproduction of a photomicrograph taken at a magnification of 1000 diameters and showing in a polished and etched section of a pearlitic malleable cast iron product produced in accordance with the invention the spheroidal form of uncombined carbon or graphite obtained therein;

Fig. 2 is a reproduction of a photomicrograph taken at a magnification of 500 diameters and showing, in a polished section of a representative alloy, the flake-aggregate type of graphite obtained in conventional American or "black-heart" malleable iron;

Fig. 3 is a reproduction of a photomicrograph taken at a magnification of 250 diameters and showing in a polished and etched section of a ferritic malleable cast iron product produced in accordance with the invention the spheroids of uncombined carbon or graphite obtained therein;

Figs. 4 and 5 are reproductions of photomicrographs taken at magnifications of 100 diameters and 250 diameters, respectively, and showing the unetched and etched structure, respectively, of a white cast iron composition in the as-cast condition and containing a special element in an amount contemplated by the present invention;

Figs. 6 and 7 are reproductions of photomicrographs taken at magnifications of 100 diameters and 250 diameters, respectively, and showing the unetched and etched structures, respectively, of the same white cast iron composition, containing the special element, depicted in Figs. 4 and 5, after a 10-hour treatment at a high temperature;

Figs. 8 and 9 are reproductions of photomicrographs taken at magnifications of 100 diameters and 250 diameters, respectively, and showing the unetched and etched structures, respectively, of the white cast iron composition illustrated in the two preceding photomicrographs but devoid of the special element employed in obtaining the results of the present invention; and

Figs. 10 and 11 are reproductions of photomicrographs taken at magnifications of 100 diameters and 250 diameters, respectively, and showing the unetched and etched structures, respectively, of the same white cast iron composition depicted in Figs. 8 and 9 after the same 10-hour treatment as given to the cast iron of Figs. 6 and 7.

Generally speaking, the present invention contemplates a special malleable cast iron composition characterized by dense, well-distributed spheroidal graphite particles and containing retained magnesium in critical amounts ranging from a small but effective amount, e. g., 0.03%, 0.035%, 0.04%, etc., to about 0.4% or 0.5%. Preferably, the retained magnesium does not exceed 0.3% and, more preferably, does not exceed 0.2%. The special malleable iron compositions contemplated by the invention contain, besides the aforementioned amounts of magnesium, about 1.8% to about 3.5% or 4% carbon, about 0.4% to about 4% silicon, up to about 3.5% nickel, up to about 2% copper, up to about 2% manganese, and the balance essentially iron. In general, the iron content will be at least 87% or 85% of the composition. The iron in the composition will be in the alpha form at atmospheric temperature.

The special process contemplated by the invention essentially comprises treating at elevated temperatures special white cast iron castings containing the aforesaid amounts of magnesium and alloying elements, and containing more than half of the excess carbon not required to form the matrix structure as combined carbon, to decompose the combined carbon contained therein and to obtain a product containing uncombined carbon. The uncombined carbon produced in the castings by the heat treatment contemplated by the invention appears in the form of well-distributed spheroidal particles usually having a radiating and polycrystalline appearance. Figure 1 shows the representative radiating or radial structure of the spheroidal particles produced according to the treatment contemplated by the invention. The dense spheroidal form of uncombined carbon or graphite obtained in the special product provided by the invention is distinguished from the irregular and fluffy-appearing form of uncombined carbon or graphite found in American or "blackheart" malleable iron, which form is an aggregate of fine flake graphite. The flake-aggregate form of uncombined carbon which characterizes American malleable iron is illustrated by Figure 2. Figures 6 and 3 show the well-distributed occurrence of the dense spheroidal particles of uncombined carbon or graphite produced in accordance with the invention. The dense, well-distributed, fine graphite or uncombined carbon particles which characterize the product provided by the present invention contribute importantly to the improved combination of properties, including strength and ductility, possessd by the said product as compared to the properties possessed by ordinary malleable cast irons.

The cast iron compositions employed in the present invention are not restricted to those having low graphitizing power, i. e., to white iron base compositions, as was the case in the production of prior art malleable iron. On the contrary, the magnesium-containing white cast iron compositions contemplated by the present invention beneficially contain large amounts of the powerful graphitizing elements carbon and silicon, as such compositions have improved malleabilization rates and other improved properties as compared to prior art malleable irons. Those compositions contemplated by the invention and containing large amounts of graphitizing elements are rendered white in the as-cast condition due to the powerful whitening effect exerted by magnesium retained in cast iron compositions. A feature of the present invention is that white cast irons having base compositions which would be gray cast irons in the as-cast condition when cast without retained magnesium can be treated to obtain very satisfactory malleable iron products containing spheroidal graphite. Cast iron compositions containing such large amounts of graphitizing elements that they would normally be gray cast irons in the as-cast condition in sections of three-eighths inch in thickness or greater when cast without retained magnesium have compositions within the ranges set forth hereinbefore and have the silicon content so related to the carbon content that the sum of the percentage of silicon divided by 3.1 plus the percentage of carbon divided by 4.5 exceeds 1.00. The compositions containing large amounts of graphitizing elements to which the invention is applicable include high- silicon compositions containing over 1.5% and up to 4% silicon, e. g., 1.75% to 2.6 silicon. Castings cast with high graphitizing power, e. g., castings containing the larger amounts of graphitizing elements set forth hereinbefore and/or castings cast in large section such as castings heavier than about 2 inches in section, preferably contain about 0.04% or more magnesium, more preferably at least 0.05% magnesium, to insure that such castings are white cast iron castings in the as-cast condition. A generally satisfactory retained magnesium range in such castings is about 0.06% to about 0.1% or about 0.15% magnesium.

A feature of an embodiment of the invention is that it provides malleable iron castings which contain larger amounts of graphitizing alloying elements such as nickel, copper, etc., and/or larger amounts of the graphitizing elements carbon and silicon, than it has been possible to employ in conventional malleable irons. The ability to employ the larger amounts of these elements enables the use of these elements to obtain improved malleabilization rates, improved strength, improved corrosion resistance, and other improved properties or combinations of properties. Silicon in amounts over 1.5% has a beneficial effect on the properties and for this purpose can be employed as an alloying element either alone or in combination with nickel, copper, and other appropriate graphitizing elements. For example, satisfactory results can be obtained by using silicon from about 1.5% to about 3%, nickel from about 0.1% to about 3.5% and/or copper from about 0.05% to about 2%. Other features derived from the larger amounts of carbon and silicon that can be present are that better fluidity and castability are obtained in the molten state and that the base irons can be produced from a greater variety of raw materials and with less need for close control over the carbon and silicon contents.

It has been found that compositions having low manganese contents, i. e., manganese contents less than about 0.3%, e. g., about 0.1% to less than about 0.15% or 0.2%, are characterized by a more rapid malleabilization rate as compared to similar compositions containing greater amounts of manganese than 0.3%, e. g., about 0.5% manganese or more. Preferred low-manganese compositions which are characterized by improved malleabilization rates and by particularly beneficial combinations of mechanical and physical properties, including strength and ductility, are those containing about 0.05% to about 0.20% manganese, about 2.5% to about 3.5% carbon, about 0.4% to about 2.6% silicon, about 0.04% or 0.05% to about 0.1% or 0.15% magnesium, and the balance essentially iron.

The combined carbon content in malleable iron castings produced according to the invention and having a predominantly ferritic matrix is usually low, e. g., below about 0.2% or 0.1%, although the combined carbon content in castings having a predominantly pearlitic matrix is higher, e. g., about 0.5% to about 0.8% or about 1%. In the preferred products produced in accordance with the invention, a substantial or major portion or preferably nearly all of the uncombined carbon or graphite occurs in a spheroidal form although beneficial results are still obtained when a relatively minor portion of the graphite occurs in a spheroidal form.

The heat treatment employed in producing the malleable cast iron castings contemplated by the invention and having an essentially ferritic matrix comprises treating a white cast iron casting containing the aforesaid required amounts of magnesium and combined carbon at temperatures between about 1550° F. and about 1750° F. or 1800° F., e. g., about 1650° F. to about 1700° F., for short time periods on the order of a fraction of an hour or more, e. g., 5 to about 15 or about 25 hours, followed by a treatment at a temperature within about 75° F. below the alpha-gamma transformation temperature for the composition being treated, e. g., about 1275° F. to about 1310° F. for short periods of time of the order of a fraction of an hour or more, e. g., about 2 to about 5 or about 15 hours. When a product having an essentially pearlitic matrix is desired, the treatment at the lower temperature is omitted. Of course, many combinations and variations of the foregoing heat treatment to obtain a pearlite matrix, a ferrite matrix, a ferrite-pearlite matrix or other matrix such as a matrix containing bainite, etc., are within the contemplation of the invention. For example, very satisfactory properties are obtained by the heat treatment of a white cast iron casting according to the invention at temperatures of about 1700° F. for time periods of about 5 to 10 hours followed by furnace cooling or pit cooling to temperatures below the critical range. Likewise, the castings may be held at temperature for longer periods of time but usually such longer treating times are not necessary to obtain satisfactory results.

In the manufacture of the white cast iron castings required to produce the special malleable iron products provided by the invention, it is not sufficient merely to add magnesium to the cast iron melt to obtain the new results provided by the invention. Magnesium in the critical amounts required by the invention must be incorporated and retained in the melt and in the castings made therefrom. It has been found that castings containing less than the critical amounts required by the invention yield only flake forms of graphite upon heat treatment whereas castings containing the critical amounts of retained magnesium required by the invention will yield the spheroidal form of graphite on heat treatment. A magnesium-free white iron casting containing about 2.8% carbon, about 0.8% silicon, and about 1% nickel and a similar casting containing, in addition, about 0.016% retained magnesium had, after a malleabilizing treatment at 1700° F., the graphite present in the form of aggregates of flake similar to those found in conventional "black-heart" malleable iron. In contradistinction, a similar casting containing about 0.07% retained magnesium had the graphite in the form of spheroids after receiving the same malleabilizing heat treatment. It has also been observed in certain tests that small quantities of retained magnesium, less than those required by the present invention, sometimes have a graphitizing effect on the casting in the as-cast condition as compared to the larger amounts of retained magnesium required by the present invention which always have a whitening effect on the casting.

White cast iron castings contemplated by the present invention may be produced by a process which comprises establishing a cast iron bath containing the amounts of carbon, silicon, alloying elements, etc., set forth hereinbefore, incorporating and retaining at least a small but effective amount up to about 0.3% or 0.4% or 0.5% magnesium in said bath and casting the metal from said bath to obtain white cast iron castings containing at least a small but effective amount up to about 0.3% or 0.4% or 0.5% magnesium. Metallic magnesium may be added to the cast iron bath to obtain the retained magnesium contents in the bath that are required by the present invention provided due caution is observed. However, it is preferred to add magnesium in the form of an alloy, e. g., with such metals as nickel and/or copper. Nickel-magnesium alloys containing about 4% to about 20% magnesium, balance essentially nickel, and nickel-magnesium-carbon alloys containing about 12% to about 15% magnesium, about 1.3% to about 2.5% carbon, balance essentially nickel, have given satisfactory results. Retained magnesium present in white cast irons produced in accordance with the invention, while having a carbide stabilizing effect during the cooling of a cast iron composition from temperatures above the melting point of the cast iron, itself promotes the decomposition of combined carbon contained in the cast iron casting during a subsequent heat treatment operation. In many compositions, the heat treating time required to produce a malleable iron from a white cast iron in accordance with the invention is reduced 50% to 75% or much more, while at the same time, very satisfactory properties are produced in the heat treated products. Thus, total treating times of about 10 to about 30 hours have given very satisfactory results.

The malleable iron products provided in accordance with the invention having the preferred compositions described hereinbefore will usually have properties within the following ranges when the matrix is substantially fully ferritic and the phosphorus content is low:

Yield strength, 30,000–55,000 p. s. i.
Tensile strength, 50,000–75,000 p. s. i.
Elongation, 10–20%
Hardness, 150–180 BHN

As those skilled in the art will appreciate, many other combinations of properties are produced in the products contemplated by the invention by heat treatments to obtain matrices other than ferritic matrices, e. g., pearlitic matrices, etc. A feature of the invention is that a wider variety of mechanical properties can be obtained than was obtainable in conventional malleable iron.

It has been found that magnesium has, by itself, a very powerful desulfurizing effect in cast iron, and this effect operates very strongly in cast iron melts even when such melts are under the influence of an acidic environment, such as that produced by an acid-lined ladle or other container. Accordingly, the malleable cast iron products provided by the invention are low in sulfur, e. g., the sulfur content is usually less than about 0.02%. In many compositions, the sulfur content is about 0.01% to about 0.015%. In addition to sulfur and other elements set forth hereinbefore, the malleable cast iron products provided by the invention may contain impurities and incidental elements in amounts usually found in cast iron. Thus, the novel product contains phosphorus in amounts up to about 0.2%, e. g., 0.05% to about 0.12%. Phosphorus detrimentally affects the ductility of the novel product and is preferably maintained at a low level, e. g., below about 0.12%, although phosphorus does not interfere with the formation of uncombined carbon in the spheroidal form during the heat treatment of a special white cast iron as contemplated by the invention. It has been found that certain other elements not usually found in cast iron are subversive and should be avoided. These subversive elements include tin, lead, arsenic, bismuth, antimony, tellurium, etc., and these elements should not be present in amounts exceeding a total of about 0.1%. Tin is particularly detrimental and should not be present in amounts exceeding about 0.05%. Carbide stabilizing or whitening elements such as chromium, etc., should be avoided or should be present in small amounts, e. g., the chromium content preferably should not exceed about 0.1% or about 0.15%, etc. As is well known, carbide stabilizing elements such as chromium, etc., interfere with the decomposition of carbides during heat treatment and increase the heat treating time.

For the purpose of giving those skilled in the art a better understanding of the invention, the following illustrative examples are given:

Example 1

A molten cast iron bath containing about 3% carbon, about 0.4% silicon, about 0.014% phosphorus, about 0.07% manganese and about 0.04% sulfur was established. One portion of the cast iron bath was treated with magnesium, as a nickel-magnesium alloy containing about 87% nickel and about 13% magnesium, and was cast without inoculation into a hard white cast iron bar which contained about 0.06% retained magnesium and which was substantially devoid of uncombined carbon. Another portion of the aforesaid bath was cast without a magnesium addition into a hard white cast iron bar. The representative microstructures of the magnesium-containing casting as-cast and after malleabilization are shown in Figs. 4 to 7 and the corresponding microstructures for the magnesium-free casting are shown in Figs. 8 to 11, respectively. The representative as-cast microstructure of the magnesium-containing bar is shown in the unetched and etched conditions in Figs. 4 and 5, respectively, and the corresponding unetched and etched structures of the magnesium-free bar are shown in Figs. 8 and 9, respectively. Each of the aforesaid white cast irons was subjected to a heat treatment for about 10 hours at about 1700° F. and air cooled. The representative microstructure of the magnesium-containing bar after the aforesaid heat treatment is shown in the unetched and etched conditions in Figs. 6 and 7, respectively, and the corresponding unetched and etched microstructures of the magnesium-free bar after the aforesaid heat treatment are shown in Figs. 10 and 11, respectively. The uncombined carbon in the heat treated magnesium-containing bar appeared in the form of dense spheroids dispersed in a pearlite matrix. Substantially all the massive carbides originally present in the magnesium-containing bar were decomposed by the aforesaid heat treatment to uncombined carbon which appeared in a spheroidal form after said treatment and the heat treated magnesium-containing bar was essentially pearlitic malleable iron, e. g., the hardness was about 279 Brinell. The small amount of uncombined carbon in the heat treated magnesium-free bar, on the other hand, appeared in the form of irregular, fluffy-appearing aggregates of flake graphite dispersed in a matrix of pearlite and carbides. Only a minor portion of the massive carbides originally present in the magnesium-free bar was decomposed to uncombined carbon in the fluffy-appearing flake-aggregate form during the aforesaid heat treatment, and the heat treated magnesium-free bar was essentially white cast iron, e. g., the hardness was about 393 Brinell.

Although the aforementioned heat treated magnesium-containing bar had a microstructure containing a pearlite matrix, other matrix structures, e. g., pearlite-ferrite matrices, ferrite matrices, etc., are obtained by varying the heat treatment as indicated hereinbefore. Thus, slow cooling, e. g., furnace cooling, from the high heat treating temperature provides a matrix of pearlite and ferrite, while an additional treatment (after the high temperature treatment) conducted at a temperature within about 75° F. below the gamma-alpha transformation temperature provides a ferrite matrix. An example of a ferritic malleable iron within the invention was shown in Fig. 3.

Example 2

A cast iron melt containing about 2.4% carbon, about 0.65% silicon, about 0.24% manganese, and about 0.03% sulfur was established. One portion of the melt was cast without further treatment to obtain a white cast iron which had a hardness of 387 Brinell. To a separate portion of the melt, sufficient magnesium was added to provide a retained magnesium content of about 0.05% in a casting made therefrom, and this portion was cast in a similar manner. The magnesium-treated white iron casting had a hardness of about 428 Brinell. The two castings were then subjected to a heat treatment comprising heating at about 1750° F. for 5 hours, furnace cooling to about 1275° F., and heating at about 1275° F. for about 5 hours followed by air cooling to atmospheric temperatures to obtain a ferritic product. After the aforesaid heat treatment, the magnesium-free casting had a hardness of about 207 Brinell and had the graphite in the flake-aggregate form. The magnesium-containing casting after the same heat treatment had a lower hardness of about 157 Brinell with a tensile strength of about 63,000 pounds per square inch and was a ferritic malleable iron having graphite in the spheroidal form.

Example 3

In a similar manner, a cast iron melt containing about 3.2% carbon, about 0.7% silicon, about 0.18% manganese, and about 0.03% sulfur was established and two white cast iron castings were made, one of which was devoid of magnesium and the other of which contained about 0.05% magnesium. The magnesium-free casting had a hardness of about 444 Brinell while the magnesium-containing casting had a hardness of about 467 Brinell. After a heat treatment similar to the one set forth in Example 2, the magnesium-free casting had a hardness of about 170 Brinell with graphite in the flake-aggregate form and the magnesium-containing casting had a hardness of about 149 Brinell with graphite in the spheroidal form.

Example 4

A cast iron melt containing about 3.2% carbon, about 1.4% silicon, about 0.2% manganese and about 0.03% sulfur was established and a white cast iron casting containing about 0.07% retained magnesium and about 1.4% nickel was produced therefrom. The as-cast hardness of said casting was about 450 Brinell. After a heat treatment similar to the one set forth in Example 2, the aforesaid magnesium-containing casting had a hardness of about 144 Brinell and was a ferritic malleable iron containing graphite in the spheroidal form.

The powerful whitening effect of magnesium referred to hereinbefore insures a uniform white cast iron structure throughout castings having heavy sections, e. g., sections greater than about 2 inches, and throughout castings containing larger amounts of graphitizing elements, e. g., silicon and graphitizing alloying elements, than could be employed heretofore in the production of malleable iron. It has been found that even when some graphite is present in magnesium-containing white cast irons produced in accordance with the invention, this graphite is in the spheroidal form and does not detrimentally affect the properties of the heat treated casting and, in fact, is beneficial. This feature enables the use of inoculation as well as highly graphitizing compositions in the production of the initial white casting to be malleabilized.

The magnesium-containing malleable iron product is characterized by improved combinations of strength and ductility and by improved corrosion resistance as compared to prior art malleable irons which were restricted to low alloy contents.

The improved combination of properties provided by the products embodying the present invention make the product particularly useful in applications such as castings for agricultural implements, automotive and railroad castings, hardware, etc.

It is recognized that magnesium determinations of the order involved herein are difficult to make, and the values given herein are based upon analyses by a chemical wet method and are reproducible within about 0.005%. As the skilled analytical chemist will understand, the wet method for obtaining the correct values of retained magnesium in an iron-base composition must take into account the elements associated with magnesium in the product, for example, iron, phosphorus and other elements which may affect the values obtained for magnesium.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and of the appended claims.

We claim:

1. In the process for producing malleable iron having improved properties, the improvement which comprises subjecting a white cast iron casting containing about 2.5% to about 3.5% carbon, about 0.4% to about 2.6% silicon, up to 0.3% manganese, about 0.05% to about 0.2% magnesium, less than about 0.02% sulfur, and the balance essentially iron, with the iron being in the alpha form at atmospheric temperatures, to a malleabilizing heat treatment comprising heating said casting at a temperature of about 1550° F. to about 1800° F. to decompose massive carbides to uncombined carbon whereby graphite in a spheroidal form is produced through the effect of magnesium in the thus-treated casting.

2. In the process for producing malleable iron having improved properties, the improvement which comprises subjecting a magnesium-containing white cast iron casting containing iron in the alpha form at atmospheric temperatures having such a carbon and silicon content that without magnesium it would be a gray cast iron and containing about 0.06% to about 0.2% magnesium such that the casting is a white iron casting when cast, containing not more than about 0.02% sulfur, with the balance essentially iron, to a malleabilizing heat treatment comprising heating said casting at a temperature of about 1550° to about 1800° F. and thereafter heating said casting at a temperature within about 75° F. below the alpha-gamma transformation temperature whereby carbides contained in said casting are decomposed to graphite predominantly in a spheroidal form through the effect to said magnesium contained in said casting.

3. In the process for producing malleable iron having improved properties, the improvement which comprises subjecting a white cast iron casting containing about 1.8% to about 3.5% carbon, about 0.4% to about 4% silicon, up to about 3.5% nickel, up to about 2% copper, up to about 2% manganese, about 0.03% to about 0.5% magnesium, not more than about 0.02% sulfur, the balance essentially iron to a malleabilizing heat treatment comprising heating said casting at a temperature of about 1550° to 1800° F. to decompose combined carbon contained therein, whereby graphite in a spheroidal form is produced through the effect of magnesium in the thus-treated casting.

4. In the process for producing malleable iron having improved properties, the improvement which comprises subjecting a magnesium-containing white cast iron casting having iron in the alpha form at atmospheric temperatures and having such a carbon and silicon content that without magnesium it would be a gray cast iron, containing about 0.04% to about 0.3% magnesium to obstruct the formation of substantial amounts of flake graphite during solidification of said casting, and containing less than about 0.02% sulfur, with the balance of the composition being essentially iron, to a malleabilizing heat treatment comprising heating said casting at a temperature of about 1550° to 1800° F. whereby graphite in a spheroidal form is produced through the effect of said magnesium in the cast-

ing as compared to the flake-aggregate form of graphite occurring in a comparable magnesium-free malleable iron.

5. A malleable iron containing about 1.8% to about 4% carbon, about 0.4% to about 4% silicon, a small but effective amount up to about 0.4% magnesium, less than about 0.02% sulfur, up to about 3.5% nickel, up to about 2% copper, up to about 2% manganese, with the balance essentially iron, said malleable iron having the iron present in the alpha form at atmospheric temperatures and being characterized by improved properties and by a microstructure containing uncombined carbon in a substantially spheroidal form effected by the presence of said amounts of magnesium after a malleabilizing heat treatment conducted upon a cast iron casting containing said amounts of magnesium and which initially contained more than half the excess carbon not required to form the matrix structure as combined carbon, said malleable iron in the absence of magnesium containing graphite in the flake-aggregate form.

6. A malleable iron having included sections of at least three-eighths inch in thickness and containing about 0.04% to about 0.5% magnesium, not more than about 0.02% sulfur, about 1.8% to about 4% carbon, about 0.4% to about 4% silicon, up to about 3.5% nickel, up to about 2% copper, up to about 2% manganese, with the carbon and silicon contents being so related that the sum of the percentage of silicon divided by 3.1 plus the percentage of carbon divided by 4.5 exceeds 1.00, and with the balance being essentially iron, said malleable iron being characterized by improved properties and by a microstructure con-

taining uncombined carbon in a substantially spheroidal form effected by the presence of said amounts of magnesium after a malleabilizing heat treatment conducted upon a cast iron casting containing said amounts of magnesium and which initially contained more than half the excess carbon not required to form the matrix structure as combined carbon.

7. A malleable iron containing carbon and silicon such that without magnesium the iron would be a gray cast iron in the as-cast condition, about 0.06% to about 0.15% magnesium, not more than about 0.02% sulfur, with the balance essentially iron, said malleable iron having iron present in the alpha form at atmospheric temperatures and being characterized by improved properties and by a microstructure containing uncombined carbon predominantly in a spheroidal form effected by the presence of said amounts of magnesium after a malleabilizing heat treatment conducted upon a cast iron casting containing said amounts of magnesium and which initially contained more than half the excess carbon not required to form the matrix structure as combined carbon.

ALBERT PAUL GAGNEBIN.
KEITH DWIGHT MILLIS.

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