April 12, 1960 N. R. EVANS 2,932,567

CAST IRON AND PROCESS FOR MAKING SAME

Filed June 6, 1957

Fig. 1

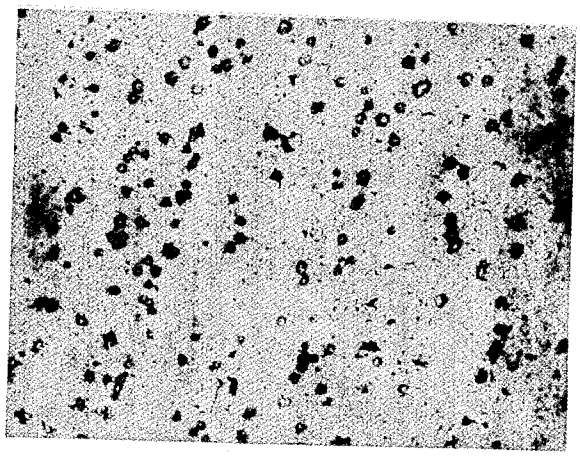
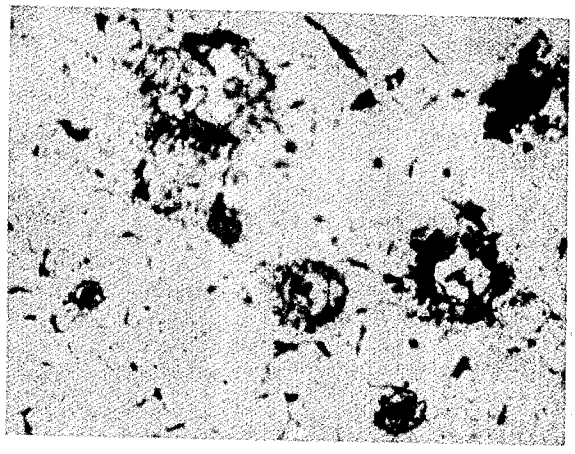


Fig. 2



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2,932,567

CAST IRON AND PROCESS FOR MAKING SAME

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8 Claims. (Cl. 75—123)

The present invention relates to a method for producing a unique ferrous alloy possessing advantageous features of gray cast iron and malleable iron, but devoid of defects and shortcomings thereof, and, more particularly, to a method for producing a successfully reproducible ferrous product having improved and unusual combinations of properties, especially an improved and unusual combination of founding properties and mechanical and physical properties.

Cast iron is a eutectiferous alloy comprised mainly of iron and containing carbon, and usually a substantial amount of silicon, the carbon being present in excess of the amount which can go into solid solution in austenite at the eutectic temperature of the alloy, whereas steel is an alloy which contains less than this amount of carbon and which does not exhibit a eutectic of iron and carbon. Cast irons are usually considered as being either white cast iron or gray cast iron. Sometimes a cast iron which possesses some of the characteristics or structural features of a white cast iron and some of the characteristics or structural features of a gray cast iron is termed a "mottled cast iron," but for general purposes and for purposes of the present description, such a product is classified as either a white cast iron or a gray cast iron, depending upon which characteristics or structural features predominate. The kind of cast iron which has generally been most commonly used for centuries is gray cast iron, i.e., the soft and machinable kind in which the major part of the carbon not required to form the matrix structure is present as graphite in the "as-cast" condition. It has been recognized that the graphitic carbon occurs as elongated particles, commonly called "flake graphite," disseminated throughout the matrix. In polished gray cast iron sections, the flake graphite appears under the microscope as a grayish, soft constituent. The weakening discontinuities produced by flake graphite are reflected in the greatly reduced tensile strength, fatigue resistance, toughness and ductility of gray cast iron compared to a product made up entirely of the matrix component, e.g., a comparable steel. White cast iron is a harder, brittle cast iron in which the major part of the excess carbon not required to form the matrix is present as combined carbon, i.e., as carbide, in the "as-cast" condition. While some advances, considered notable at the time, have been made in ordinary foundry gray cast iron, no one has proposed prior to the present invention a satisfactory, generally applicable method for eliminating from ordinary foundry gray cast iron the detrimental effect of graphite due to its flake form in the "as-cast" condition. As a result, it has been necessary to resort to the use of ferritic or pearlitic malleable iron or even cast steel when higher properties or combinations of properties were required, although these engineering materials are considerably more expensive than gray cast iron and possess other disadvantages.

The present invention is based on the discovery of a method whereby carbon is a high-carbon "as-cast"

ferrous alloy, i.e., in an "as-cast" ferrous alloy containing carbon within the cast iron range, can be made to appear consistently and reproducibly in the form of dispersed gray-colored, soft particles substantially nodular in shape, thereby eliminating the deleterious effects of flake graphite. In the ferrous alloy produced by the method embodying the present invention, this form of carbon can be obtained in the "as-cast" condition, i.e., without heat treatment, together with a combination of properties of an order entirely different from and higher than that obtained in gray cast iron.

The nodular graphite particles (1) may comprise graphite particles having a radial structure as shown in Figure 5 of Patent No. 2,485,760; (2) or they may comprise graphite nodules without a radial structure; (3) or they may comprise graphite nodules having a metal core or center surrounded by graphite, giving the appearance of "doughnut" nodules. The term "nodular graphite particles," as used herein, includes any one of the three kinds.

It is among the objects of the present invention to provide methods or processes for consistently and reproducibly eliminating flake graphite substantially or entirely from high-carbon ferrous alloys, and to provide high-carbon "as-cast" ferrous alloys in which carbon occurs as substantially nodular, soft, gray-colored particles.

Another object of the invention is the introduction of mica into molten metal to give improved physical properties of the cast metal.

Another object of the invention is the treatment of molten metal with elements or materials which separately have a lower boiling or melting point than that of the metal, but which when combined into the form of mica has a boiling or melting point comparable to that of the molten metal.

Another object of the invention is the introduction of a material having a low boiling point into a bath of molten metal whereby danger of explosion and loss of low boiling point material are eliminated.

Another object of the invention is the introduction of a volatile material into a bath of molten metal whereby danger of explosion and loss of volatile material are eliminated.

Other objects and advantages of the present invention will be apparent to those skilled in the art from the following description taken in conjunction with the drawings in which:

Figure 1 is a reproduction of a photomicrograph taken at a magnification of 100 diameters and showing, in polished sections of representative alloys produced by the process contemplated by the present invention, the nodular form of carbon obtained in the as-cast condition by the presence of a special element employed in the process contemplated by the present invention; and

Figure 2 is a reproduction of a photomicrograph taken at a magnification of 1000 diameters and showing the structure in the as-cast condition of an alloy produced in accordance with the present invention and containing the nodular form of carbon in a pearlitic matrix.

The present invention provides a novel method for producing a novel ferrous product containing at least about 50% iron and particularly at least about 87% iron, carbon and silicon within the cast iron range, the carbon in excess of that required to form the matrix being predominantly in the uncombined form, and containing a small but effective amount of mica to control the form of uncombined carbon, the quantity of mica depending upon the miscible power or the miscibility existing between the mica and the molten metal being treated. The invention provides a cast iron product characterized by a microstructure containing carbon in the form of randomly dispersed, soft, gray-colored, substantially nodu-

lar particles or agglomerates of such particles. In accordance with the present invention, the aforementioned microstructure of the product is obtained in the as-cast condition to provide a novel product characterized by an improved combination of properties and by a structure not reproducible on a successful foundry lever prior to the present invention in cast irons in the as-cast condition. The product of the invention is preferably substantially devoid of flake graphite. Another distinguishing feature of the microstructure is that usually no sulfide particles are seen embedded in the matrix, whereas ordinary cast iron usually contains many easily recognized sulfide inclusions embedded in the matrix.

Generally speaking, the present invention contemplates the method for the production of a successfully reproducible cast ferrous alloy containing uncombined carbon in a nodular form in the as-cast condition which comprises establishing a molten ferrous alloy bath of such composition that if cast it would be a gray cast iron, incorporating mica into said bath to produce the nodular carbon form in the final castings and inoculating the bath at least once (preferably with a late addition of at least 0.2%, or more preferably at least 0.3%, of silicon as a silicon-containing metallic agent such as ferro-silicon), and casting the inoculated bath. It is preferred that inoculation be employed in carrying out the process embodying the present invention. However, in some cases, where the graphitizing power of the magnesium-containing bath is very high, inoculation may not be necessary to insure that a sufficient amount of the total carbon will be in the uncombined form in the solidified casting, although inoculation is always beneficial. The instances where inoculation would not be necessary are relatively exceptional. As those skilled in the foundry art know, the inoculation of ordinary cast iron has a graphitizing effect and comprises a late addition of a strong graphitizer which is usually a silicon-containing agent such as ferro-silicon, calcium silicide, nickel silicide, etc., but may be any graphitizer. As indicated hereinbefore, the molten bath which is treated in accordance with the invention is one which would be a gray cast iron if cast in a sand mold or in the type of mold to be employed to produce the final product.

Under the microscope, the difference between the as-cast product provided by the method embodying the present invention and gray cast iron is readily apparent. In polished sections of the as-cast novel product provided by the present invention, some or practically all of the nodular form of uncombined carbon appears as compact, soft, gray-colored, rounded particles, usually nearly circular, or as agglomerates or groups of such particles. The center of the nodules in Figures 1 and 2 appear to be metal surrounded by graphite giving the appearance of "doughnut" graphite particles.

A feature of the present invention in obtaining the aforementioned product having a microstructure containing the nodular form of carbon is the introduction of mica into the molten bath. It is sufficient merely to add mica to the molten bath. While the theory of the mica effect on the form of carbon and on the properties of the product provided by the present invention is not fully apparent, it has been found that the introduction of mica is required in order to obtain the compacted nodular, soft, gray-colored form of carbon and to obtain the high combination of properties in the as-cast ferrous alloy of the present invention.

A striking characteristic which is usually exhibited by the product produced by the process contemplated by the invention, particularly in its preferred embodiment, containing a major proportion of the uncombined carbon in nodular form, is the steely appearance of its fracture as compared to the gray fracture of gray cast iron.

An important consideration in carrying out the invention is the graphitizing power of the molten ferrous bath to be treated. Satisfactory baths or melts which may be

treated in accordance with the invention to produce a product having high properties and the nodular form of gray-colored carbon in the as-cast condition are those which, before the introduction of mica, have sufficient graphitizing power to be clearly classified by those skilled in the art as gray cast irons if cast in sand molds or in the particular kind of mold to be employed if it is a different mold, at least after inoculation such as is conventially employed in producing better grades of gray cast iron. The aforementioned satisfactory baths include those molten baths having such high graphitizing power that they would be gray cast irons when solidified regardless of whether or not they were inoculated. The bath should have such graphitizing power that, when cast as indicated hereinbefore after inoculation, it would be substantially entirely devoid of massive carbides such as occur in white cast irons. The graphitizing power of the bath is the summation of a number of possible variable factors. The carbon content is one factor, i.e., for a given set of conditions graphitizing power increases rapidly as the carbon content increases. The bath generally will contain over 1.7% carbon and may contain as much as 4.5% or even 5% of carbon. Preferably, the bath to be treated contains about 2% to 4.5% carbon. Baths and final compositions containing 2.5% to 4% carbon have given very satisfactory results. Silicon present in the initial melted charge and/or added prior to the mica introduction also imparts graphitizing power but not to the same extent as carbon or as a late inoculating addition after the mica introduction and just prior to casting. As a very rough rule for predicting the effect of carbon and silicon on graphitizing power, it can be said that silicon is about three-tenths or one-third as effective in increasing the graphitizing power as carbon, i.e., that an increase of 3% of silicon is equal to an increase of 1% of carbon. It must be understood that this is only an empirical approximation and is affected by a number of other factors including the entire composition of the bath, the type of charge employed and numerous other conditions well known by those skilled in the art to influence graphitization during the cooling from casting temperatures. The aforementioned molten bath, before treatment in accordance with the invention to produce an improved as-cast product, will generally contain at least about 0.5% silicon, preferably at least about 0.8% silicon, and may contain as much as 5% or even 5.5% or 6% of silicon, although the occasions when such large amounts of silicon would be employed are rare in view of the fact that carbon is more effective in imparting graphitizing power and that silicon in large amounts at a given carbon level has a tendency to reduce the properties, especially the toughness, ductility and/or tensile strength. Silicon is a strong ferrite former, and for this reason, it might be desirable to employ large silicon contents where a matrix containing a large proportion of ferrite is desired in the as-cast condition. After the mica treatment and any required inoculation, the bath will generally contain at least about 1% silicon, preferably at least 1.3% silicon, and may contain as much as 5% or 5.5% or even 6% silicon. Satisfactory results have been obtained in as-cast products made from preferred baths which contained about 0.5% or 0.8% to 3% or 3.5% silicon before mica treatment and inoculation, and particularly with baths containing up to 2.25% silicon before treatment and inoculation, e.g., baths containing 1%, 1.25%, 1.5%, 1.75%, 2% and 2.25% silicon. After mica treatment and inoculation, which introduced additional silicon, these baths had final silicon contents when cast between about 1.0% and 4.5%, preferably at least 1.5% silicon. More preferably, the bath should have such a silicon content that, after any additional silicon incorporated during the treatment with mica or the inoculation, it will contain between about 1.5% and 2.5% or 3% silicon. Other elements which impart graphitizing power to the bath are well known to those skilled in the

art and include such elements as nickel, aluminum, etc.

In addition to the composition, many other factors also affect the graphitizing behavior of the bath as is well known to those skilled in the art of cast iron. Thus, the nature of the mold in which the iron is to be cast is a factor, as the rate at which it is able to extract heat affects the cooling rate which in turn influences the graphitization. Likewise, the graphitizing power or potential of a particular bath will operate less effectively when cast in small section sizes, e.g., one-half inch, than when cast in large section sizes, e.g., four inches or eight inches, even though the same kind of mold is employed. The temperature of the mold in which the bath is cast, the degree of superheat of the molten bath, the pouring temperature, the nature of the metallic raw materials employed in the charge used to produce the bath and numerous other factors will influence graphitization. The composition of the bath to be treated in accordance with the invention should be controlled in the light of the various factors well known by those skilled in the art to influence the amount of graphitization. A particularly responsive range of final bath compositions having sufficient graphitizing power to avoid, under most practical foundry conditions, the occurrence of massive carbides or incidental chills in sections of 3/8-inch in thickness or greater, is defined by the carbon limits 2.5% to 4.5%, the silicon limits 1.0% to 4.0%, and the silicon content being so related to the carbon content that the sum of

$$\frac{\text{Percent Si}}{3.1} \text{ plus } \frac{\text{Percent C}}{4.5}$$

is greater than 1.00. It is desirable that within this range and especially toward the lower limits of carbon and silicon, the product be substantially free from tendencies toward chilling.

The inoculation which accompanies or follows the introduction of mica into the bath is another aspect of the invention, except in certain rare cases when the bath has a very high graphitizing power, for example, such an excessive amount of graphitizing power that after the mica treatment it will produce the gray-colored nodular form of carbon in the casting regardless of whether or not inoculation is used along with or after the mica introduction. If the inoculation precedes the introduction of the mica, it may not produce the desired results in the as-cast product. This can be remedied by another inoculation along with but preferably after the mica introduction. Inoculation may be accomplished by a late addition of an inoculant such as silicon. It is preferred to employ silicon in amounts between about 0.3% and 2% or 2.5%, more preferably between about 0.4% and 1.2%, as the late addition to effect inoculation.

It is preferred, in carrying out the present invention to produce a product having the higher order of properties and the nodular form of carbon in the as-cast condition, to introduce the mica into the bath and thereafter separately introduce the graphitizing inoculant which is preferably a silicon-containing inoculant, such as ferro-silicon. While ferro-silicon, e.g., an iron alloy containing a major proportion up to about 85% or 95% silicon, gives satisfactory results as an inoculant, other metallic silicon-containing agents or alloys such as nickel-silicon alloys or nickel silicide, calcium-silicon alloys or calcium silicide, silicon metal, and various proprietary inoculating alloys commonly used for reducing dendriticism and reducing chill in foundry gray cast irons may be employed. The treated inoculated metal can be cast in accordance with accepted foundry technique, bearing in mind that the shrinkage characteristics of the molten alloy are such that castings made from the alloy should be gated and risered more in conformity with the practice employed for steel than that employed for unalloyed or low-alloyed gray cast iron.

The mica may comprise natural mica or synthetic mica.

Natural mica is a silicate of aluminum and potassium with hydroxyl and sometimes fluorine ions in the complex molecule. Natural mica also contains varying amounts of magnesium, iron or lithium which affects its properties. According to investigations, the mica molecules are flat hexagons which join at their edges to form flat crystals which are most familiar as isinglass. These crystals theoretically can be split into sheets one molecule thick or naturally any multiple thereof. The natural mica may comprise the following types:

(*a*) Biotite—$H_2K(Mg, Fe)_3(Al, Fe)(SiO_4)_3$
(*b*) Lepidolite—$(HO, F)_2KLiAl_2Si_2O_{10}$
(*c*) Lepidomelane—Near biotite plus large amount of ferric iron
(*d*) Muscovite—$H_2KAl_3(SiO_4)_3$
(*e*) Paragonite—$H_2NaAl_3(SiO_4)_3$
(*f*) Phlogopite—$H_2KMg_3Al(SiO_4)_3$
(*g*) Zinnwaldite—Lithium-iron mica

Synthetic micas are true crystallographic analogs of the natural micas in which the hydroxyl ions found in the natural mica are replaced with the fluorine ions. In synthesizing mica, it is possible to replace any of the cations in the mica molecule in whole or in part with many other cations. Mica may be synthesized in several hundred forms; however, commercial production at present is focused mainly on fluor-phlogopite, which crystallizes at atmospheric pressure and exhibits most of the superior qualities of synthetic micas. The melting point of this fluor-phlogopite mica, as well as other synthetic mica, is approximately 2500 degrees F. and the manufacture of this material may, on a commercial scale, be produced by means of a process invented by Richard A. Humphrey and more completely disclosed and illustrated in United States Patent No. 2,711,435, issued June 21, 1955. Briefly stated, this method involves the dumping of the raw materials into a large metal shell which contains a simple graphite electrode network. Ordinarily, sixty cycle electric power is applied to the electrodes and after a pool of melt has formed, the passage of current through the molten mass provides the necessary heat for continued melting. The batch thus acts as a container for the melt and also as a sufficient insulator. The synthetic micas suitable for use in the present invention have generally the following compositions which are listed hereinbelow:

	Formula
(1)	$KMg_3AlSi_3O_{10}F_2$
(2)	$KMg_3BSi_3O_{10}F_2$
(3)	$KMg_{3\frac{1}{2}}Si_4O_{10}F_2$
(4)	$KMg_2LiSi_4O_{10}F_2$
(5)	$BaMg_3Al_2Si_2O_{10}F_2$
(6)	$BaMg_2LiAlSi_3O_{10}F_2$
(7)	$CdMg_2LiAlSi_3O_{10}F_2$
(8)	$Sr_{\frac{1}{2}}Mg_3AlSi_3O_{10}F_2$
(9)	$KMgNi_2AlSi_3O_{10}F_2$
(10)	$KNi_3AlSi_3O_{10}F_2$
(11)	$KCo_3AlSi_3O_{10}F_2$
(12)	$KMg_2MnAlSi_3O_{10}F_2$
(13)	$NaMg_2LiSi_4O_{10}F_2$
(14)	$NaMg_2KSi_4O_{10}F_2$
(15)	$NaMg_2RuSi_4O_{10}F_2$
(16)	$NaMg_2CsSi_4O_{10}F_2$
(17)	$CaMg_2NaAlSi_3O_{10}F_2$
(18)	$SrMg_2NaAlSi_3O_{10}F_2$

	Formula
(19)	$BaMg_2NaAlSi_3O_{10}F_2$
(20)	$KMg_2RuSi_4O_{10}F_2$
(21)	$KMg_2CsSi_4O_{10}F_2$
(22)	$CaMg_2KAlS_3O_{10}F_2$
(23)	$SrMg_2KAlSi_3O_{10}F_2$
(24)	$BaMg_2KAlSi_3O_{10}F_2$
(25)	$LiMg_2RuSi_4O_{10}F_2$
(26)	$LiMg_2CsSi_4O_{10}F_2$
(27)	$CaMg_2LiAlSi_3O_{10}F_2$
(28)	$SrMg_2LiAlSi_3O_{10}F_2$
(29)	$CaMg_2RuAlSi_3O_{10}F_2$
(30)	$CaMg_2CsAlSi_3O_{10}F_2$
(31)	$KCaSr_2AlSi_3O_{10}F_2$
(32)	$KCaBa_2AlSi_3O_{10}F_2$
(33)	$BaMg_2RuAlSi_3O_{10}F_2$
(34)	$BaMg_2CsAlSi_3O_{10}F_2$
(35)	$KBaSr_2AlSi_3O_{10}F_2$
(36)	$SrMg_2RuAlSi_3O_{10}F_2$
(37)	$SrMg_2CsAlSi_3O_{10}F_2$
(38)	$ZrMg_2KAlSi_3O_{10}F_2$
(39)	$ZrMg_2NaAlSi_3O_{10}F_2$
(40)	$ZrMg_2LiAlSi_3O_{10}F_2$
(41)	$ZrMg_2RuAlSi_3O_{10}F_2$
(42)	$ZrMg_2CsAlSi_3O_{10}F_2$
(43)	$ZrCa_2AlSi_3O_{10}F_2$
(44)	$KZrSr_2AlSi_3O_{10}F_2$
(45)	$KMg_2ZrAlSi_3O_{10}F_2$
(46)	$KZrBa_2AlSi_3O_{10}F_2$
(47)	$KFe_3{}^{++}AlSi_3O_{10}F_2$
(48)	$KAl_2AlSi_3O_{10}F_2$
(49)	$NaAl_2AlSi_3O_{10}F_2$
(50)	$KLi_1{}^1/_2Al_1{}^1/_2AlSi_3O_{10}F_2$
(51)	$KLi_2AlSi_4O_{10}F_2$

The elements included within the rare earth classification may be utilized to replace any of the volatile cations in the synthetic mica compounds listed above and numbered (1) through (17).

The volatile cations or the purifying or nodular-inducing agents of the synthetic mica in Formula 1 would include the potassium and magnesium as distinguished from the silicon.

The fluorine in the above mica appears to function as a wetting agent to make the mica miscible with the molten iron.

The synthetic micas of the present invention are silicates of the constituents selected from the class comprising the rare earths, the alkali metals, the alkaline earth metals, zirconium and cadmium. These micas also contain fluorine.

The specific gravity of the synthetic flour-phlogopite mica, such as identified by Formula 1, is normally in the neighborhood of 3.0 as compared to water and the melting point is usually in the neighborhood of 2500° F. The volatile constitutents or purifying and nodular-inducing agents from which synthetic mica is made have a very low melting and boiling point. It is known that the temperature of the molten iron baths usually exceed the boiling temperature of the volatile constituents from which mica is made. Thus, for example, the introduction

into a molten iron bath of solid elemental magnesium, which is a purifying and nodular-inducing agent, produces a reaction of explosive violence. The introduction of magnesium into molten iron has been generally regarded as being impossible on a practical scale. Proposals have been made by the prior art to solve an analogous problem encountered in the introduction of various highly volatilizable elements into molten baths, for example, U.S. Patent No. 1,931,144 relating to the introduction of sodium as sodium vapors into a molten bath to purify the bath. However, with the present invention, the volatile constituents, including sodium as well as the others appearing in the listed formulas, from which mica is made may be introduced into the molten iron bath without any explosive violence or without any loss of the volatile constituents.

In the present invention, the mica may be introduced or intermixed with the charge in the cupola and as the charge travels downwardly or burns in the cupola the mica, along with the metal in the charge, falls into the bottom or well of the cupola where they collect in the molten state. The molten metal with the mica therein is then transferred from the well of the cupola to a ladle where it may then be poured into castings. The mica may also be introduced into the metal by putting mica into the ladle before pouring the molten metal into the ladle, or the mica may be added directly into the molten metal in the ladle.

The mica tends to float on top of the molten metal because it has a lower specific gravity than the molten iron. The molten iron in the bottom of the cupola or the molten iron in the ladle must be of sufficient temperature to melt the mica. It appears that when the mica becomes in a complete liquid state, that is, after a certain temperature has been reached, it then becomes "miscible" with the molten iron. In other words, the amount of mica which tends to go into the molten iron is automatic depending upon the impurities in the molten iron which are to be removed or to be compounded with the constituents of the mica. Thus, the more impurities in the iron, the more mica is absorbed or taken into the iron to react with the impurities and to control the occurrence of uncombined carbon as substantially modular particles. The term "miscible" amount of mica which goes into the molten iron is that amount required (1) to remove the impurities or to combine them with the constituents of the mica to thereby eliminate their effect and (2) to control the occurrence of uncombined carbon as substantially nodular particles. The introduction of the mica into the molten metal is automatic in the sense that mica which is added to the metal is dissolved into the metal until a saturation point is reached, whereat the molten metal refuses to take any more mica. This is sufficient to produce nodular carbon particles in the casting. Mica added in excess of this "miscible" amount floats on top of the metal as a slag where it may be conveniently removed by any conventional method. The "miscible" mica may not occur as mica in the molten metal, but may dissociate into the individual constituents of the mica. The "miscible" mica in the iron includes the mica as such, as well as the dissociated individual constituents of the mica. A specific example of the addition of mica to cast iron to produce a nodular iron is as follows: A charge of 2270 grams of cast iron piglets were placed into an induction furnace along with 68 grams (substantially 3.0%) of synthetic fluor-phlogopite mica, Formula 1, and were melted therein at a temperature in the neighborhood of 2500° F. The piglets which were added in the charge consisted of cast iron having the graphite particles therein in flake form. A portion of the molten iron with the miscible mica therein, namely, 425 grams, was poured from the induction furnace into a test sample and after the sample was cooled, it was then fractured. The sample fractured as a white cast iron, showing that mica is a whitener. The

remaining charge in the furnace of molten iron with the "miscible" mica therein was then inoculated with 20 grams (substantially 1.0%) of calcium silicide with the temperature maintained in the neighborhood of 2500° F. The inoculated iron was then poured into a small casting and allowed to cool, after which photomicrographs of Figures 1 and 2 were taken, showing the carbon particles to be in nodular form of the "doughnut" type. The amount of magnesium retained in the cast iron was but a small trace, less than 0.01%.

All of the micas exert a double action on the metal. One of the actions is that of a purifying and nodular-inducing agent. The other action is that of a wetting agent.

The purifying and nodular-inducing agents are potassium, sodium, magnesium, calcium, lithium, strontium, zirconium, barium, cadmium, and rare earths. The wetting agent is the fluorine in compound form with materials selected from the group comprising rare earth metals, alkali metals, and alkaline earth metals.

Some of the micas have a third action of a graphitizer. These micas are the ones which include in their structure aluminum, iron, nickel and calcium.

Cast iron treated with mica makes a "clean pour," in that the molten metal flows freely. It has a high fluidity. The grain structure of the finished castings is small, producing sound castings free from porosity. The castings may be used for high pressure castings for hydraulic equipment. The castings are ductile. The castings are reproducible on a foundry level because there is no waste of the volatile constituents as they are introduced into the molten metal. The amount of mica which needs to be introduced can be determined ahead of time. When a procedure is established on a foundry level for a particular cupola charge and for a particular size and shape of the casting, the operation may be successfully repeated with the use of mica to produce good sound castings. This accurate reproducibility of castings has been lacking in the teachings of the prior art.

Depending upon the impurities in the molten iron, the mica which is introduced in the molten iron may range from 0.05% by weight to about 15%. Preferably, the amount introduced may be 1.0% to 5.0%. It is only necessary to introduce an amount of mica in excess of the "miscible" amount, and the extra amount may be removed as a slag.

The mica used as a treating material may have related forms other than that suitable for electrical insulation. The treatment material in this invention comprises silicates selected from the class comprising the rare earths, the alkali metals, the alkaline earth metals, cadmium and zirconium. The treatment material may also include fluorine. The treating material may have a melting temperature above 1200° F. and below 2700° F.

When the treating mica of the present invention is added to molten metal which has a molten temperature less than the temperature at which mica melts in natural flake or chunk form, the mica may be ground or made in powder form, in which case the ground or powdered mica is taken into the metal by what might be referred to as a dissolving action. The finer the powder is the quicker the dissolving action. The ground or powdered mica may preferably be 100-mesh or finer. In other words, it is desirable to reach the melting point of the mica since at this temperature it is more easily taken into the metal, but it is not necessary that the temperature of the molten metal be above that of the melting point of the mica in its natural flake or chunk state because the ground or powdered mica will be dissolved by the molten metal, the action being slightly more time-consuming when the temperature of the molten metal is low.

The retained amount of volatile agents or purifying and nodular-inducing agents in the iron is substantially proportional to the percentagewise amount of the said agents in the mica, if all the mica becomes miscible or goes into the molten metal. On the other hand, if some of the mica remains as slag, then said proportion of retained amount of agents may vary, depending upon the relative activity of the agents themselves in the molten metal and the receptivity of the molten metal to receive the respective agents. The retained amount of volatile or purifying and nodular-inducing agents may range from a small trace, as low as 0.01%, to 0.5%.

The present disclosure includes that contained in the appended claims, as well as that of the foregoing description.

Although this invention has been described in its preferred form and preferred practice with a certain degree of particularity, it is understood that the present disclosure of the preferred form and preferred practice has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts and steps may be resorted to without departing from the spirit and scope of the invention as hereinafter claimed.

What is claimed is:

1. The method for producing a ductile cast iron having a microstructure containing in the as-cast condition uncombined carbon in a nodular form and characterized by a high combination of properties which comprises establishing a molten ferrous bath containing about 2% to about 4.5% carbon, about 0.5% to about 3.5% silicon, with the sum of the percentage of carbon plus one-third the percentage of silicon being not more than about 5, introducing into said ferrous bath mica in an amount ranging from 0.05% by weight to 15.0%, thereafter inoculating the mica-containing bath with a silicon-containing agent and pouring the metal from said inoculated bath in an inoculated condition into a mold to produce a ferrous alloy casting containing uncombined carbon in a nodular form in the as-cast condition.

2. The method for producing a ductile cast iron having a microstructure containing in the as-cast condition uncombined carbon in a nodular form and characterized by a high combination of properties which comprises establishing a molten ferrous bath which if cast would have graphite in flake form, introducing into said ferrous bath mica in an amount ranging from 0.05% by weight to 15.0%, thereafter inoculating the mica-containing bath with a silicon-containing agent and pouring the metal from said inoculated bath in an inoculated condition into a mold to produce a ferrous alloy casting containing uncombined carbon in a nodular form in the as-cast condition.

3. The method of producing cast iron which comprises the steps of establishing an initial molten ferrous bath containing about 2% to about 4.5% carbon, about 0.5% to about 4.0% silicon, the silicon content being related to the carbon content such that the sum of the percentage of silicon divided by 3.1 plus the percentage of carbon divided by 4.5 exceeds 1.00, introducing mica into said initial molten ferrous bath to produce a mica treated bath having a larger quantity of carbides than said initial molten ferrous bath, and adding a graphitizing agent to the mica treated bath to produce a final bath having a smaller quantity of carbides than said mica treated bath, and finally pouring the casting from said final bath.

4. The method of producing cast iron which comprises the steps of establishing an initial molten ferrous bath containing about 2% to about 4.5% carbon, about 0.5% to about 4.0% silicon, the silicon content being related to the carbon content such that the sum of the percentage of silicon divided by 3.1 plus the percentage of carbon divided by 4.5 exceeds 1.00, introducing mica into said initial molten ferrous bath to produce a mica treated bath, and finally pouring the casting from said mica treated bath.

5. The method of producing cast iron which comprises the steps of establishing an initial molten ferrous bath

containing about 2% to about 4.5% carbon, about 0.5% to about 4.0% silicon, the silicon content being related to the carbon content such that the sum of the percentage of silicon divided by 3.1 plus the percentage of carbon divided by 4.5 exceeds 1.00, introducing mica into said initial molten ferrous bath to produce a mica treated bath, and finally pouring the casting from said mica treated bath, said mica made of materials having silicate and fluoride compounds of at least one of the elements selected from the group consisting of the rare earths, the alkali metals, the alkaline earth metals, and non-ferrous metals consisting of aluminum, boron, nickel, cobalt, manganese, ruthenium, cadmium and zirconium.

6. A gray cast iron containing about 2% to 4.5% carbon, about 1.3% to 5% silicon, at least about 0.05% by weight to 15.0% mica, and the balance essentially all iron and alloying elements.

7. A cast iron containing uncombined carbon and mica, said mica being made of materials having silicate and fluoride compounds of at least one of the elements selected from the group consisting of the rare earths, the alkali metals, the alkaline earth metals, and non-ferrous metals consisting of aluminum, boron, nickel, cobalt, manganese, ruthenium, cadmium and zirconium.

8. A cast iron containing uncombined carbon and mica, said mica being made of materials having silicate and fluoride compounds of at least one of the elements selected from the group consisting of the rare earths, the alkali metals, the alkaline earth metals, and non-ferrous metals consisting of aluminum, boron, nickel, cobalt, manganese, ruthenium, cadmium and zirconium, the mica being in an amount ranging from 0.05% by weight to 15.0%.

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