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HIGH QUALITY CAST IRON

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Fig. 2.

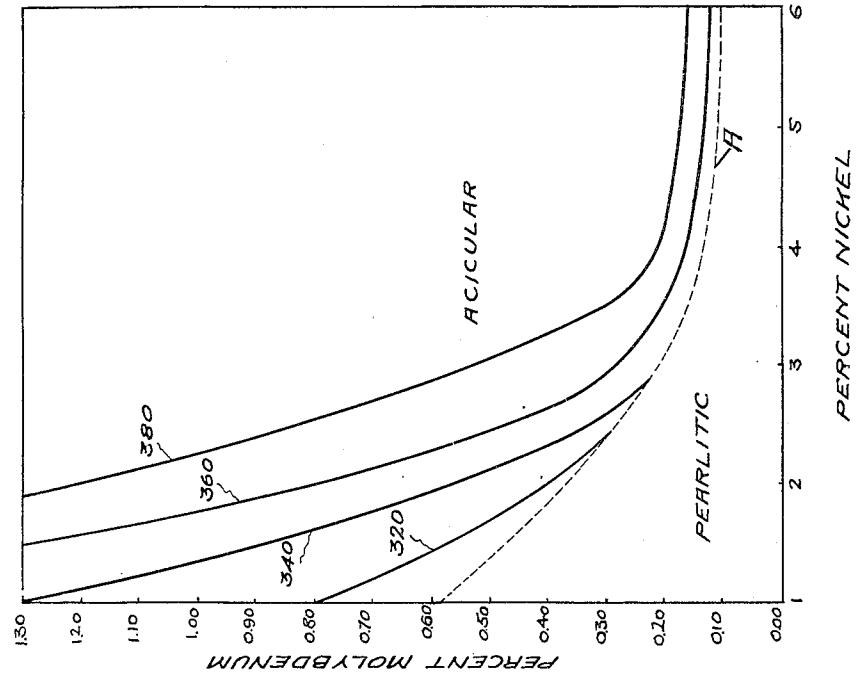
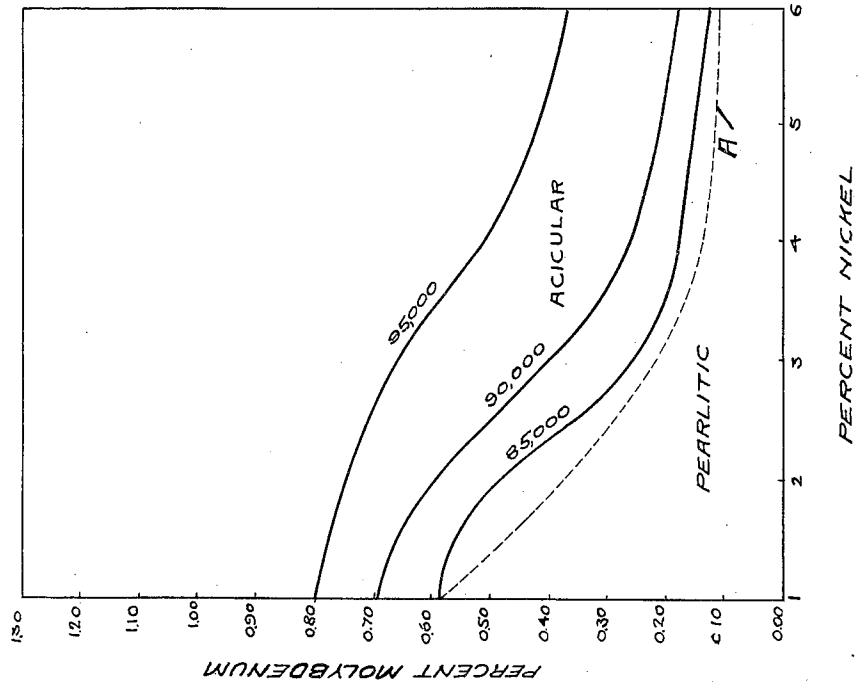


Fig. 1.



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HIGH QUALITY CAST IRON

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The present invention relates to a method of producing high quality, moderately alloyed cast iron, and more particularly, to a method of producing high quality, moderately alloyed, nickel-molybdenum cast iron possessing markedly improved strength properties and other properties in large section sizes as well as in small section sizes; and to products made therefrom.

It has been proposed to produce high strength gray cast iron from cupola charges composed of at least about 60% steel scrap and of low silicon content so as to produce an iron which would be white or mottled, if cast without further treatment. Heavy ladle additions, such as silicon, nickel, carbon, alkali silicide, alkali earth metals, and the like, have been specified to precipitate graphite in the metal and thereby render the iron gray and machinable. It has also been proposed to add alkaline earth metal silicides to molten gray iron but the purpose of this addition was also to precipitate additional carbon. In some cases it has been required to hold the metal for a specified interval before pouring to permit this graphitization to take place. Attempts to produce high strength gray cast irons based upon considerations of the matrix of the cast iron generally have been limited to the structure of the well known Maurer diagram, i. e., ferrite, carbide and pearlite. Since pearlite is the strongest machinable structure of these three, previous efforts in this direction have been directed to the production of a pearlitic matrix, or as sometimes stated, an eutectoid combined carbon content of about 0.85%. Ladle additions, preheated molds, and other means have been advocated to obtain this objective. The addition of chromium, a carbide forming element, has been proposed as a means of keeping the combined carbon in cast iron near the eutectoid content. Attempts to improve the properties of cast iron by heat treatment involving heating and quenching operations were not completely satisfactory, particularly in large sections, for example, in excess of about 3 inches, and especially in excess of about 10 inches, where difficulties were encountered in handling and treating large masses and where cracks and the like often occurred as a result of rapid cooling. Other disadvantages and defects were frequently encountered in prior methods. Thus, the surface of the castings was frequently decarburized thereby producing an undesirable soft skin. Likewise, the large ladle additions which were advocated tended to chill the molten metal to too low temperatures. The time of holding the molten metal after the additions were made was also detrimental due to loss of temperature. The formation of slag on top of the ladle increased the problem of producing castings free from slag inclusions.

Prior procedures in cast iron practice did not give assurance of high quality cast irons which consistently possessed a high combination of properties, particularly high strength, toughness and impact. Although many attempts were made to remedy the aforementioned shortcomings, none, so far as we are aware was entirely successful in consistently producing satisfactory results and could be carried into practical and economical industrial scale operation.

We have discovered that the foregoing shortcomings may be overcome in a particularly effective manner and that high quality cast irons are obtained when produced by a novel process involving a special sequence of critical operations. The high quality cast irons possess tensile strengths in excess of about 85,000 pounds per square inch in standard arbitration test bars after special heat treatment and have a special microstructure. We have found that when moderate amounts of the austenite-retaining elements nickel and molybdenum are present in gray cast iron in which the carbon and silicon are properly adjusted for section size the microstructure of the cast iron at room temperature has an acicular matrix containing austenite, in the presence of graphite, the austenite of which can be transformed to an acicular constituent at low temperatures to impart to the cast iron markedly improved properties, e. g., increased strength properties. We have also found that the higher strength properties of gray cast iron are influenced by the section size, melting operations, inoculation treatment, pouring temperature, speed of pouring and ferrostatic pressure during solidification, as well as by the composition and heat treatment at low temperatures and that the former are as important as the latter in obtaining high quality gray cast irons possessing, for example, tensile strengths of 85,000 and often above 90,000 pounds per square inch in standard arbitration test bars after heat treatment.

It is an object of the present invention to provide a method of producing high quality gray cast iron which is simple, practiral and economical and which is capable of being operated consistently and successfully on an industrial scale to produce improved commercially acceptable gray cast iron products, particularly products having the larger cross sectional thicknesses, such as rolls.

It is another object of the present invention to provide a method of manufacturing cast iron whereby gray cast iron products can be obtained which possess a combination of high mechanical properties, especially high tensile strengths combined with high toughness and impact strength.

The invention also provides a process for producing moderately alloyed gray cast iron having a partially austenitic microstructure as cast which involves a novel combination of operations including a proper selection of composition and chemistry, a special inoculation operation, special pouring temperatures and casting conditions and a low temperature heat treatment to transform the austenite contained in the "as cast" microstructure into an acicular constituent.

The invention further provides a high quality cast iron comprising controlled and balanced proportions of constituents and possessing an acicular structure, said cast iron being characterized by high mechanical properties, including high tensile strength and/or high impact values.

The invention also contemplates providing articles of manufacture of large section size, for example rolls, particularly those of large diameter, made of the special cast irons provided by the present invention.

Other objects and advantages of the invention will become apparent to those skilled in the art from the following description taken in conjunction with the accompanying drawing in which:

Fig. 1 is a graph depicting the effect of nickel and molybdenum upon the microstructure and tensile strength of heat treated standard 1.2" arbitration bars of gray cast irons made in accordance with the present invention; and

Fig. 2 is a graph depicting the approximate relation between the hardness and the nickel and molybdenum content of heat treated standard 1.2" arbitration bars of gray cast irons made in accordance with the present invention.

In general, the invention involves a novel combination of operations for producing high quality gray cast iron containing controlled proportions of both nickel and molybdenum which comprises correlating the composition and chemistry of the charge with the melting medium, the desired properties, the section size of the final product and the molding conditions to produce a cast iron which is in most cases machinable "as cast" and which possesses a transformable microstructure due to the presence of controlled amounts of austenite and contains randomly distributed small primary graphite flakes; controlling the melting temperatures and conditions to produce molten metal having the desired composition when tapped; inoculating the molten metal in the ladle; and casting the metal, preferably while controlling the casting conditions to obtain high pouring temperatures, fast pouring speeds and high ferrostatic pressures. The solidified gray cast iron having a partially austenitic matrix is markedly benefited by a low temperature heat treatment to transform most of the austenite in the "as cast" microstructure to an acicular constituent. When the term "gray" is used herein in reference to cast iron, it is meant to indicate that the cast iron contains primary graphite as distinguished from white cast iron in which the carbon is in the combined form. The term "gray" does not refer to the matrix which in the present invention is austenitic and acicular but which in the prior art has usually been pearlitic or pearlitic and ferritic. The acicular constituent, in accordance with a common theory, is a decomposition product of austenite known under various names such as bainite, a constituent explained by the well-known S-curve for steel. We have found that in order to obtain high quality cast irons proper processing is important and that simply selecting alloy contents will not necessarily give the desired high quality product. Proper graphite conditions and matrix conditions are essential and appear to be influenced by the inoculation treatment, pouring temperature, speed of pouring, ferrostatic pressure, section size, heat treatment and composition or chemistry, including the ratio of carbon to silicon and the proportions of the austenite-forming elements, nickel and molybdenum.

Chemistry and composition

The production of high quality or high strength cast iron by the present invention requires the correlation of the selected chemistry and composition with the desired properties, section size of the product to be cast, and the molding conditions to produce the desired partially austenitic "as cast" microstructure in a gray cast iron containing randomly distributed small primary graphite flakes. The composition must be so selected that the cast iron is capable of passing through the austenite transformation range, for example through the range of 1500° F. to 350° F., without complete transformation of austenite to its lower forms but with partial transformation of the austenite to produce an acicular constituent in the "as cast" microstructure. Pearlite should not be present but small amounts up to about 10% may be tolerated where maximum strength properties are not the primary consideration and it is to be understood that when we refer to "acicular" structure we do not mean to exclude such small amounts of pearlite.

A charge should be employed which will produce a partially austenitic gray cast iron having the approximate composition set forth in Table I.

Table I

Element	Percentage
Total carbon	1.5 to 3.4
Combined carbon	0.4 to 1.0
Graphitic carbon	0.5 to 3.0
Silicon	1.0 to 4.75
Nickel	1.0 to 6.0
Molybdenum	0.2 to 1.5
Iron	Balance

Preferably the silicon falls within the range of about 1.25% to abou 3.25% for section sizes up to about 60 inches. As will be pointed out hereinafter some of the silicon is added in the ladle for a special purpose. Accordingly, the total amount of silicon set forth hereinbefore will include the silicon retained from the charge and that incorporated in the ladle. The graphitic carbon is preferably between about 0.7% and about 2.5% by weight. It is very important that the volume of the graphite not exceed about 5% to 10% of the volume of the cast iron. The lower amounts of graphitic carbon contents are preferred where maximum strength is desired while the higher graphitic carbon contents produce the best founding properties and the best machinability but with some sacrifice in strength properties. Other elements, minor constituents and impurities may also be present. Thus, about 0.03% to about 0.25% sulfur, preferably not exceeding about 0.15%, is frequently present in cast

irons as a result of commercial practice. Likewise, the cast iron may contain 0.01% to about 0.45% phosphorus, preferably not exceeding about 0.15%, and about 0.3% to about 2.5% manganese, usually about 0.6% to about 1.2%. Manganese in amounts above about 1% and up to about 2.5% is considered as a minor alloying element having austenite-forming tendencies. Copper in amounts up to about 3.5%, preferably below about 0.6%, may also be present under certain circumstances. Chromium in amounts up to about 0.5% may be present as a residual element from scrap used in the charge, as in the case of scrap from the roll industry, and also may be used to gain additional hardness in high strength cast iron. Aluminum in amounts up to about 0.2% may be present, e. g., as a result of the inoculants used to process the present high strength cast irons as will be pointed out hereinafter. Hydrogen has also been found to be present in the inoculants. Although the theory of inoculation is as yet unexplained it is probable that both aluminum and hydrogen play a part in its beneficial effect. It is thought that the effect of hydrogen may be in the direction of stabilizing austenite. Cobalt is often present in commercial nickel and may be introduced into the high strength cast irons in amounts up to about 1% along with the nickel additions. Boron is finding use in commercial practice as a substitute for chromium and may be present in the high strength cast irons, for example in amounts up to about 0.05%, for the same reasons as stated hereinbefore for chromium. Small amounts of titanium, e. g., 0.3%, have been found in cast iron as a minor constituent or impurity. Calcium has been suggested as a deoxidizer and small amounts in cast iron are believed to have a beneficial effect under certain conditions. Small amounts of zirconium may also be present, for example, because of the use of zirconium-silicon alloys as inoculants instead of ferro-silicon. It is to be understood that when it is stated that the "balance is substantially all iron" the expression does not exclude minor constituents and impurities such as have been mentioned hereinbefore which may be present as a result of commercial practice or for known purposes in known amounts insufficient to deleteriously alter the desired properties of the high-quality cast irons provided by the present invention.

The present invention has been found to be particularly advantageous in the larger section sizes, for example about 5 inches and up. Where the cast irons are to be used in section sizes of about 5 inches up to about 60 inches or more, the composition should preferably be maintained within the ranges of about 2.5% to about 1.25% silicon, about 3% to about 1.5% carbon, about 2% to about 6% nickel, about 0.5% to about 1.3% molybdenum, and the balance substantially all iron, including impurities and minor constituents; said carbon content decreasing as the section size increases and said nickel and molybdenum contents increasing as the section size increases. The silicon content will usually decrease with the section size but a wide range of silicon is permissible for any given section size. For section sizes of 10 inches or more the nickel content is preferably at least 3%. The present invention accordingly provides improved cast iron articles having the composition set forth in Table I, and particularly cast iron articles having a large section size of at least about 5 inches and having the foregoing compositions.

The process provided by the present invention is applicable to cast iron made in any suitable melting medium, including the cupola, air furnace, rotary furnace, crucible furnace, electric furnace and open hearth and various combinations of two or more furnaces. The latter practice, often called duplexing, is advantageous where carbon contents below about 2.4% are desired and it is desired to use the cupola initially. Duplexing is usually carried out in an electric furnace, open hearth or converter. The cupola possesses the disadvantage, not encountered with other melting media, that the attainable carbon level and control band at any given level is difficult. Consequently the use of the cupola requires special control as will be pointed out hereinafter. The composition of the charge must be adjusted to suit the particular furnace characteristics as is well known to those skilled in the art. Thus, a cupola charge may require about 50% or 60% steel scrap whereas an equivalent charge in an air furnace might not require more than about 15% steel scrap.

We have discovered that the micro-constituents in a high-carbon low-silicon cast iron are less stable than in a lower-carbon higher-silicon cast iron of equivalent structural composition. The present invention aims at lower total carbons and higher silicon contents than usually recommended. The carbon and silicon content and ratio must be correlated with the section size of the final cast product and the desired properties. When castings of varying section sizes are to be made, the predominant section should govern the selection. In general the carbon content and the silicon content should decrease as the section size increases. Preferably, the carbon and silicon contents and ratios are maintained within the approximate ranges indicated in Table II for the particular section size. The composition of intermediate or larger section sizes should be adjusted accordingly.

Table II

Section size in inches	Percent total carbon range	Percent silicon range
0.25	3.05–3.4	2.25–3.25
0.50	2.75–3.2	2.0 –3.0
1.0	2.50–3.0	1.75–2.75
2.0	2.45–2.9	1.25–2.50
5.0	2.2 –2.7	1.25–2.25
10.0	2.0 –2.35	1.25–2.25
20.0	1.8 –2.15	1.25–2.25
24.0	1.7 –2.10	1.25–2.25
30.0	1.7 –2.05	1.25–2.25
36.0	1.6 –2.0	1.25–2.25
40.0	1.6 –1.95	1.25–2.25
50.0	1.55–1.9	1.25–2.25
60.0	1.5 –1.85	1.25–2.25

It should be noted that small variations in carbon content have much greater effect upon the properties of the final product than variations of three to five times as much in the silicon content. The present invention involves wide control ranges for silicon and narrow control ranges for carbon as compared with prior practices based on narrow control ranges for silicon and wide control ranges for carbon.

It is an essential requirement of the present invention that the composition of the cast metal have a partially austenitic but not wholly austenitic "as cast" microstructure. The austenite-retaining elements nickel and molybdenum must be co-present in special proportions in order to assure the desired "as cast" partially austenitic microstructure which can be transformed by a low temperature transformation draw. Fig. 1

shows the effect of nickel and molybdenum upon sand cast standard arbitration bars of a typical high strength base composition (2.5% total carbon and 2.5% silicon) produced in accordance with the present invention and given a low temperature transformation draw at 600° F. The effect of low alloy additions (below the broken curve A) is to produce alloyed pearlitic cast irons having fairly high tensile strengths of about 50,000 pounds per square inch and more. Nickel and molybdenum contents which are above the broken curve A produce a cast iron which in the "as cast" condition is characterized by an acicular structure containing retained austenite, i. e., a partially austenitic structure, which upon heat treatment at low temperatures is transformed to an acicular microstructure to produce a cast iron that has consistently exhibited tensile strengths of at least about 85,000 and often of about 90,000 to 105,000 pounds per square inch in the standard arbitration test bars. The transition from the pearlitic to the acicular structure indicated by curve A is gradual rather than as sharp as plotted on the graph in Fig. 1 for the sake of simplicity.

The minimum amount of the alloying elements nickel and molybdenum required to produce a partially austenitic and partially acicular structure in the "as cast" condition is an inverse function of the cooling rate through the austenite transformation range. The co-present amounts of nickel and molybdenum to be incorporated in the cast iron are dependent on the level of properties desired in the final product as indicated in Fig. 1 and on the cooling rates encountered in the particular method of founding or molding. As is well known, the section size of a casting has an important bearing on the cooling rate. In general, the greater the section size, the slower the cooling rate under similar conditions. Accordingly, as the section size increases, curve A of Fig. 1 will be displaced to higher alloy contents.

In general, the nickel content falls within the range of about 1% to about 6% and the molybdenum content falls within the range of about 0.2% to about 1.3% or 1.5%, the nickel and molybdenum contents within said ranges being larger the greater the section size of the final cast product. For any given section size, it is preferred either to use low nickel contents with high molybdenum contents or to use high nickel contents with low molybdenum contents, particularly the latter, the nickel and molybdenum contents jointly rendering the final casting partially austenitic in the "as cast" condition for the desired section size.

In actual practice it is preferred to maintain the nickel and molybdenum contents within the approximate ranges given in Table III for the desired section size. The composition for intermediate or larger section sizes should be adjusted accordingly.

Table III

Section in inches	Nickel percentage	Molybdenum percentage
0.25	1.0–1.5	0.3–0.2
0.5	1.0–1.75	0.4–0.3
1.0	1.0–2.0	0.6–0.4
2.0	1.5–2.5	0.6–0.4
5.0	2.0–3.0	0.7–0.5
10.0	2.5–3.5	0.7–0.5
20.0	3.0–4.0	0.8–0.5
30.0	3.0–5.0	0.9–0.6
40.0	3.0–5.0	1.0–0.7
50.0	3.0–5.5	1.1–0.8
60.0	3.0–6.0	1.3–0.8

In general, the nickel and molybdenum contents are larger the greater the average or predominant section size of the final cast product. When the desired level of properties is high and/or the cooling rate slow, the alloy content should be toward the maximum values given for nickel and molybdenum. When the desired level of properties is only moderately high or the cooling rate fast, then the alloy content may be toward the minimum values given for nickel and molybdenum. The important cooling rate is in the temperature range from about 1500° F. to about 400° F. When the cooling rate in this temperature range is about 275° F. per hour, the rate is considered fast while at 125° F. per hour the rate is considered slow. Accordingly, when the molten metal is to be cast in chill molds the alloy content should be less than when cast in sand molds. The usual practice is to cast in sand molds. It has been found that the maximum beneficial effect of molybdenum additions in average section sizes is obtained when the lower amounts of about 0.3% to about 0.8% are used. Incidental improvement in strengths above this amount are not very marked. In Table IV the effect of increasing molybdenum contents is clearly illustrated on arbitration bars subjected to a low temperature heat treatment after processing in accordance with the present invention.

Table IV

Cast iron No.	Nickel	Molybdenum	Tensile strength	Structure
	Per cent	*Per cent*	*P. s. i.*[1]	
1	1.0	0.3	72,200	Pearlitic.
2	1.0	0.8	95,000	Acicular.
3	1.0	1.3	98,000	Do.

[1] P. s. i.=pounds per square inch.

Cast iron No. 1 did not contain sufficient alloying elements to produce the required acicular constituent and did not respond to the low temperature draw. The greatest improvement in strength is obtained by increasing the molybdenum from 0.3% to 0.8%. Increasing the molybdenum content a like amount to 1.3% resulted in only a comparatively small increase in strength for this particular section size.

A chemical composition which would develop the optimum properties for a large section, say 30 inches, would not be very suitable for use in a small section, say 2 inches. In general, it may be stated that the composition which will produce optimum properties for a specific section will produce lesser values for either lighter or heavier sections. However, it is also true that with the proper composition for the specific section size, the optimum properties attainable are lower in very heavy sections than in very light sections because of mass effects.

It has been pointed out that the desired "as cast" microstructure is acicular with some residual austenite. Carbide-forming elements, such as chromium, offset the stabilizing effect of the austenite-retaining elements and are therefore undesirable when the highest possible strength level is desired. Thus, the maximum permissible amount of chromium in very heavy sections is about 0.25% when maximum strength properties are the primary consideration.

Melting technique

High quality cast iron may be obtained with equivalent ease in open-hearth, electric, air,

rotary and crucible furnaces or by duplex processes and little difficulty is obtained in producing the molten metal having the desired composition when tapped. The cupola process does have a difficulty not encountered in other processes in that carbon control is more difficult in this process. The satisfactory production of high quality cast iron having the selected chemistry or composition requires the selection of suitable materials for the charge, etc., and requires suitable melting equipment under the supervision of a skillful operator sufficiently experienced to keep the chemistry of the cast iron within the allowable tolerances during the melting process and at the proper temperatures. The aims of the melting technique should be to produce molten cast iron at the spout with the desired low carbon contents at a high temperature. The alloying elements including nickel and molybdenum may be added in any suitable form and at any convenient time that is in accordance with good cast iron practice. It is preferred to add the molybdenum and nickel in the furnace.

Ladling and metal handling

It is a preferred and rather important function of the metal handling and ladling technique to provide properly conditioned molten metal at the molds at a high temperature in excess of about 2575° F., preferably 2650° F. or higher. To accomplish this the spout and ladle should be preheated, e. g., to practically white heat. In foundry practice, it is common to re-ladle iron from one to four times and when this is done with ladle treated irons the final metal temperature may be low. Preferred practice is to preheat ladles to 2600° F. or more and work towards dispatch in the metal handling system. The preferred furnace temperature is dependent on the temperature losses incurred in the metal handling operations. Metal temperature losses may be as little as 50° F. when handling large masses of metal in one ladle which has been filled in a very short time or as much as 450° F. when handling small masses with re-ladling. Even in very large ladles the temperature loss may be as high as 10° F. per minute, with more than 50° F. per minute in very small ladles, so it is preferred that the metal handling operations be synchronized towards getting metal into molds at high temperatures, preferably 2650° F. or higher. Cold ladle additions also result in a temperature drop and should be restricted to those additions which cannot be economically added to the charge, e. g., vanadium, or whose effectiveness depends on being added to the ladle. On the average, every 1% of cold ladle addition results in a temperature drop of about 30° F. It is preferred to restrict the maximum cold ladle addition to less than about 1.5% of the molten metal.

Ladle inoculation

An essential operation of the present process is an inoculation treatment of the molten metal, preferably in the ladle. The molten cast iron prior to inoculation should be gray if cast at that time. That is, the purpose of inoculation is not to convert a white cast iron (or a mottled cast iron) to a gray cast iron by the addition of large amounts of graphitizers which reduce the combined carbon content of the cast iron by precipitating the carbon in the form of graphite. The present process, on the contrary, uses small ladle additions of silicon-containing inoculants such as ferro-silicon, calcium silicide and other alkaline earth metal silicides, silicon carbide, zirconium-silicon, and the like. The higher the specific gravity of the material used as an inoculant the more practical it is in use. Ladle inoculants of an exothermic nature, probably due either to reactions of metalloids with air at the surface of the metal or with oxides contained in the inoculant or melt, often form slags on the metal which should be skimmed from the metal before castings are poured. The addition of about 0.2% to about 1.0%, preferably about 0.3% to about 0.75%, of silicon as an inoculant has given satisfactory results. About 0.5% silicon as 50 to 97% ferro-silicon has given very satisfactory results. When possible, the solid inoculants are preferably of about one-quarter to three-quarter inch mesh, although finer meshes may be used. Thus, for example, when the mass of metal treated is approximately 2000 pounds or more, a preferred inoculant is the well known 50% grade of ferro-silicon of about one-quarter to one-half inch mesh. When the mass of metal treated is less than approximately 2000 pounds, the preferred inoculant is the well known 75% grade of ferro-silicon of about one-quarter to one-half inch mesh. When alloys in addition to ferro-silicon are added in the ladle, it is sometimes desirable to use the 75% grade of ferro-silicon in preference to the 50% grade in order to decrease the loss of metal temperature due to ladle additions. Upon occasion it may be desirable to use the 90% grade of ferro-silicon.

We have found that by adding the inoculant shortly before casting, usually in the ladle, the risk of dendritic graphite is avoided and randomly or uniformly distributed, medium-size to fine graphite flakes obtained in the final product. The small additions of the silicon-containing inoculants are believed to produce randomly distributed graphite flakes of medium to fine size not at the time of addition, but while the casting is cooling through the solidification range. The combined carbon content is not lowered but is apparently maintained at or near the eutectoid value by these additions.

The aluminum content of inoculants is important and it is preferred that the inoculant contain about 1.5% and more of aluminum. The beneficial effect of aluminum on cast iron is more pronounced when added in the diluted form, for example, as a constituent of ferro-silicon, than when metallic aluminum is used. When the residual aluminum content in cast iron increases from small but effective amounts up to about 0.1%, the grain fineness of the iron increases.

Most ladle inoculants contain appreciably high percentages of dissolved gases, for example, nitrogen. It has been found that when the temperature of the metal in a treated ladle exceeds about 2700° F. the resulting castings are free from gas inclusions, but that when the temperature is appreciably less, pin holes and other gas inclusions occur, increasing in amount with lower temperatures.

Casting and molding

It has been stated hereinbefore that in best practice it is preferred that the metal be poured into the molds at high temperatures. Satisfactory results are obtained with casting temperatures, as distinguished from superheating temperatures, of at least about 2575° F. and up to about 2800° F. Preferably, metal casting temperatures of about 2650° F. to about 2725° F. are used. Higher strengths and other properties are

related to the pouring temperature, speed of pouring and ferrostatic pressure. Thus, a bar of cast iron having the desired composition and poured at 2650° F. to 2725° F. showed a tensile strength, as cast, of about 75,000 pounds per square inch whereas another bar cast from metal from the same melt and same ladle but poured at 2500° F. showed a tensile strength, as cast, of only about 50,000 pounds per square inch.

The speed with which metal is poured into molds is an important consideration and should be the fastest practical. When the hot metal fills the mold rapidly the lowest possible thermal gradient exists between the various component parts of the casting and the lowest amount of internal strain is developed. Fast pouring speeds lessen the temperature differential existing in various parts of the mold and decrease the detrimental effects of localized hot spots in the mold. Castings are obtained with the least possible internal strain and exhibit the lowest tendency to show shrinkage in light sections while heavy sections are free of shrinkage.

Another preferred feature of the present invention is the use of high ferro-static pressures which should preferably exceed about five pounds per square inch. When the metal is poured rapidly at high temperatures the major portion of the metal filling the mold cavity is still fluid after the mold is filled, thereby permitting regulation of the height of metal above the uppermost part of the casting in the cope of the mold. This practice affords a means of regulating the amount of ferro-static pressure. Whenever practical, the height of riser above the uppermost part of the casting should exceed about 20 inches which is equivalent to about 5 pounds per square inch of ferro-static pressure. It has been found that a high ferro-static pressure is particularly effective in reducing the length of the graphite flakes in the casting and in producing metal of maximum density.

The treated molten cast iron may be cast in any suitable type of mold, for example, chill or permanent molds, sand lined chill molds, dry sand molds, oil sand molds, green sand molds, cement bonded molds, etc. As is well known to those skilled in the art the cooling rates of the metal being cast will depend to a considerable extent upon the type of mold used, and accordingly, as pointed out hereinbefore, the composition should be correlated with the rate of cooling for any particular type of mold. In addition to exercising good molding practice, e. g., good sand control, the castings should be gated for quick pouring, and adequately risered.

Heat treatment

It has been found that the strength of cast irons produced in accordance with the present invention are markedly improved by a draw treatment or tempering treatment at temperatures below about 800° F. without a prior quenching operation. According to the present invention, a cast iron is produced which in the solidified "as cast" condition is characterized by a transformable partially austenitic microstructure containing an acicular constituent. A casting having this "as cast" microstructure possesses markedly improved tensile properties after being subjected to a low temperature heat treatment below about 850° or 800° F. and above about 350° F. for a period of time ranging from about one hour to about 100 hours to transform the austenite in the casting to an acicular constituent. It is preferred that a low temperature not exceeding about 800° F. be used. Thus, a treatment for 3 hours at about 1100° F. resulted in over-tempering as exhibited by practically complete sorbitization of the acicular structure. The time at heat treating temperature will ordinarily be longer the larger the section size of the casting. An empirical rule which has given satisfactory results in estimating a suitable heat treating time is that the total heat treating time is equal to about one hour for each inch of thickness or section size. It is preferred to increase the heat treating time estimated in accordance with this rule an additional interval up to about 5 hours or 10 hours or even more. Thus for a 30-inch roll the heat treating time may be of the order of about 35 or about 40 hours. In general it is desirable to over-estimate the heat treating time rather than to under-estimate the time. Arbitration bars having tensile strengths as high as 105,000 pounds per square inch have been obtained by proper selection of chemistry, correlation with section size, ladle inoculation, and casting and molding conditions followed by the low temperature draw or tempering treatment and it is believed that the maximum strength level may be as much as or more than 150,000 pounds per square inch. Tensile strengths corresponding to at least about 85,000 pounds per square inch and often in excess of about 90,000 pounds per square inch in arbitration bars are readily obtained by subjecting the castings to a low temperature draw treatment at temperatures of about 500° F. to about 700° F. for about 5 hours to about 15 hours for smaller sections and as high as about 75 hours for 30 inch sections. Larger sections may require still longer heat treating periods. The proper low temperature draw treatment has increased the tensile strength as much as 30,000 pounds per square inch, and usually at least 10,000 pounds per square inch, above what it was "as cast." If the highest possible tensile strengths are desired then as much as possible of the austenite is transformed to the acicular structure by means of the low temperature draw treatment but if highest possible impact resistances are desired, then some residual austenite should be permitted to remain in the microstructure. The low temperature heat treatment is a preferred step in the process when the highest tensile values combined with moderately high impact values are desired. The wide flexibility in tensile strength values and impact resistance values permits a producer of cast iron using the present invention to make castings such as crankshafts, in which high values of tensile strength must be combined with high values of impact resistance. Heretofore, cast iron crankshafts have been made according to specifications for tensile properties but such specifications did not include a value for impact. Consequently, the art concentrated on higher tensile values whereas in this particular application, i. e., cast crankshafts, the importance of the impact resistance value may far outweigh the tensile value desires of the art, so that a sacrifice in tensile values to obtain maximum impact resistance values may be desirable. Under certain circumstances where maximum impact values are the primary consideration it may be desirable to use the high quality cast iron products in the as cast condition. Where maximum hardness is desired, the composition is adjusted to give a maximum of low temperature transformation product.

The term "heat treatment" as applied to cast iron has generally referred to an annealing treatment either to break down the combined carbon in white cast iron to temper carbon, or to relieve the stresses in a casting, i. e., stress relief annealing. As used in the present specification, "heat treatment" refers to neither of the aforesaid treatments, nor to a treatment which might comprise heating the metal above the critical temperature, say 1500° to 1550° F., from which temperature it would be quenched. The low temperature heat treatment contemplated by the present invention eliminates the necessity for a quench treatment and eliminates the hazards of heat treatment. When intricate castings are subjected to complicated heat treatments involving a quench operation they are often defective due to cracks, etc., and in many cases the castings break up into many pieces. The cast irons provided by the present invention do not require a quench prior to a tempering or drawing treatment, a feature which is of great value particularly in large section sizes, or in intricate castings, thereby eliminating the great tendency to crack, etc., due to stresses set up by quenching. In addition, the elimination of the quench treatment greatly simplifies the heat treatment and removes the practical difficulties encountered in attempting to quench large castings. The low temperature heat treatment of the present invention differs from the ordinary conception of heat treatment in that the initial cooling rate is obtained in the mold and not by quenching or the like and that the tempering treatment does not require special furnaces not ordinarily part of foundry equipment and does not require high temperatures. Any means of accelerating the initial cooling rate of the casting between the time of casting and its first approach to room temperature by such obvious means as "chill casting" or removing the casting from the mold while red hot and then air cooling is within the contemplation of the present invention. The low temperature heat treatment is readily carried out in the ordinary core ovens and mold drying ovens available in most foundries.

Microstructure

The unetched microstructure of the high quality cast irons of the present invention shows a random distribution of small graphite flakes. The "as cast" etched sections are characterized by a microstructure which includes the acicular constituents and austenite. These two basic constituents of the microstructure may be present in varying amounts, i. e., there may be a relatively large amount of austenite and a relatively small amount of the acicular constituent when the amount of nickel and molybdenum alloying elements are high and/or the cooling rates are fast, or the microstructure may show a relatively large amount of the acicular constituent with a relatively small amount of austenite when the amount of nickel and molybdenum alloy elements are lower and the cooling rates are slower. The impact resistance of the present high quality cast irons is at the ultimate when the maximum amount of austenite is present. The low temperature draw treatment may be carried out for such a period of time and at such a temperature that the microstructure is fully converted to an acicular structure or the low temperature draw treatment may be so controlled that the microstructure is not fully converted to the acicular structure depending upon the desired combination of properties, especially tensile strength and impact resistance. Thus, in the fully acicular structure there is substantially no pearlite, sorbite or austenite present. The impact resistance associated with a fully acicular structure is still of a very high order when compared with pearlitic or pearlitic-ferritic microstructures. For example, in a highly alloyed and quickly cooled microstructure having a large amount of austentite in the microstructure, the impact resistance might be as much as 120 foot pounds or more, whereas the impact value of the same iron after the draw treatment to give a fully acicular structure might be of the order of about 70 to 80 foot pounds. The magnitude of the impact value of ordinary cast iron containing some pearlite is of the order of about 20 to 30 foot pounds and that of a fully pearlitic cast iron would be of the order of about 30 to 40 foot pounds.

More specifically, the "as cast" structure under the microscope appears to comprise alpha needles in a matrix of austenite with martensitic markings. With high alloy contents, the alpha needles become few in number and the entire structure has an austenitic-martensitic appearance. After the low temperature draw the alpha needles begin to lose their sharply acicular characteristics. Some of the austenite is transformed during this treatment. It is believed that the increase in strength is due to this transformation combined with a matrix adjustment. No great hardness increases take place with the low temperature heat treatment. At temperatures above about 800° F., e. g., at 1100° F., the acicular structure loses its identity, although in some areas, ferrite needles may remain.

It is to be clearly understood that the final microstructure is substantially devoid of pearlite and sorbite and is primarily acicular but may contain some austenite and related transformation products of higher order than sorbite.

The acicular constituent referred to herein has been given various names in the past such as "troosto-martensite," "intermediate structure," "pseudo-martensite," "acicular troostite," "acicular constituent," "bainite," etc. While its nature is as yet somewhat problematical, it is readily distinguishable from true martensite by its etching characteristics, its appearance and its difference in hardness.

Properties

Cast iron has been evaluated mainly on the property of tensile strength but other properties may be as important or more important than tensile strength in the selection of this material for various applications. The cast irons provided by the present invention are more properly termed high quality cast iron than high strength cast iron since tensile strength is not necessarily indicative of the high resistance to impact or high resistance to mechanical wear or other high properties possessed by the cast irons obtained in accordance with the present invention. The present moderately alloyed cast irons possess excellent machining properties, high resistance to mechanical wear, etc., at a greatly increased strength level with outstanding properties in high fatigue strength, increased hardness while retaining good machining qualities, uniformity of hardness throughout metal sections, high resistance to impact, high torsional strength, high compressive strength, high strength at elevated temperatures, high resistance to heat checking or thermal shock, high vibration damping prop-

erties, high modulus of elasticity or Young's modulus, increased rigidity, increased total deflection before failure, etc. As will be readily understood by those skilled in the art, these various properties will not all be at the highest levels under one set of conditions. Thus, the property of impact resistance is highest when the microstructure retains some austenite in the acicular matrix whereas the tensile strength is highest when substantially all the residual austenite is transformed into the acicular constituent. That is, the high strength iron may be so treated to give highest impact resistance at a reduced strength level or to give highest tensile strength at a reduced level of impact resistance. In like manner certain desired maximum properties may be obtained at slightly lower levels for other properties, but in general the cast irons provided by the present invention possess a markedly improved combination of properties at high strength levels. It is to be understood that when tensile strengths of at least about 85,000 pounds per square inch are referred to in the present application, these values relate to arbitration bars and are only given as an illustration of the high properties obtainable under standard conditions and that other improved high properties, e. g., high impact resistance, may be obtained at somewhat lower strength levels where desired.

In general, most technical data on the physical properties of cast iron are obtained from cast arbitration bars of relatively small cross section, usually 1.2 inches in diameter. Such data are of some value for comparative purposes but do not accurately represent the properties of large sections. It is generally considered that the physical properties improve with decreasing section size. However, it is possible in the present invention to obtain optimum properties in a specific section and lesser values in either lighter or heavier sections by proper control of composition, etc. For purpose of illustration and comparison, the tensile strengths referred to in the present invention are based mostly on tests on standard 1.2 inch diameter cast arbitration bars, but the improved high properties of the cast irons provided by the present invention over other cast irons have been confirmed by actual large castings. In certain applications the section size of cast iron products may be 25 to 40 times the section size of the arbitration bars. Other methods have been attempted to obtain physical property data representative of heavy sections. One method has been to cast small diameter bars which are cooled at controlled rates, from high temperatures, to approximate conditions existing in heavy sections but this method often suffers from the disadvantage that the graphite occurrence is not accurately representative of the heavy sections and that the cooling rates of various large castings are not readily available or easily ascertained. Another method has been to obtain specimens from heavy sections by means of a hollow drill, i. e., trepanning, but this method involves destruction of a large casting or sampling from an undesirable location, e. g., a riser, and there is no precedent for comparison of the properties obtained.

The cast irons provided herein having tensile strengths as cast of about 70,000 to 80,000 pounds per square inch, in standard arbitaration bars of 1.2 inch section, which are raised by low temperature heat treatment to values in excess of about 85,000 pounds per square, often about 90,000 to 105,000 pounds per square, with corresponding Brinell hardnesses of about 310 to about 410, or even more if desired. Tables V and VI give illustrative examples of cast irons produced in accordance with the present invention and of the high tensile strengths possessed by the high quality cast irons.

Table V

Cast iron No.	% T. C.	% C. C.	% Si	% Ni	% Mo
4	2.31	0.76	2.30	1.04	0.81
5	2.30	0.75	2.34	1.03	1.36
6	2.28	0.74	2.31	2.06	0.82
7	2.30	0.77	2.32	2.03	1.31
8	2.33	0.73	2.36	3.00	0.31
9	2.25	0.60	2.35	3.05	0.81
10	2.29	0.70	2.30	4.05	0.30
11	2.17	-------	2.64	1.27	1.11

% T. C. = percentage total carbon. % C. C. = percentage combined carbon.

Table VI

Cast iron No.	As cast		Properties after heat treatment for 5 hours					
			At 500° F.		At 600° F.		At 700° F.	
	B. H. N.	T. S.	B. H. N.	T. S.	B. H. N.	T. S.	B. H. N.	T. S.
4	321	80,600	-------	-------	321	95,000	-------	-------
5	321	71,800	-------	-------	340	98,000	364	97,200
6	340	74,400	364	95,600	364	97,600	321	-------
7	387	82,000	-------	-------	382	[1]98,000	387	89,200
8	375	-------	-------	-------	375	[1]88,000	-------	-------
9	418	-------	-------	-------	387	[1]98,200	395	105,200
10	444	-------	-------	-------	412	[1]92,200	-------	-------
11	-------	74,400	-------	92,200	-------	-------	-------	-------

T. S. = tensil strength in pounds per square inch.
B. H. N. = Brinell hardness number.
[1] 15 hour draw at indicated temperature.

Melting in the cupola

It has been pointed out hereinbefore that cast iron made by the cupola process presents the difficulty that the attainable carbon level and control band at any level is more difficult. However, a major portion of the gray iron castings produced is by the cupola process. It is preferred that a special melting procedure be used in the manufacture of the high quality cast iron by the cupola process. This preferred process provides for complete control of the charge make-up, the melting procedure and the tapping sequence in cupola operation.

Although steel has been used in the cupola charge, usually in amounts greater than 60% of the charge, to aid in obtaining lower carbon cast irons than would be possible if the cupola charge containing no steel, it has not been clearly recognized that the use of steel in the charge is only one of a number of factors involved in attaining definite or low percentages of carbon in cast iron.

Furthermore, unless the steel content of the cupola charge is controlled within reasonable limits the foundry is not able to recirculate all gates, sprues, risers and scrap castings from previous heats back to the cupola charge so that the costs of the process are increased. In most foundry areas, steel scrap is more costly than other usable materials, and if used in greater amounts than the minimum required, adds to the cost. Steel scrap is also deficient in one of the essential elements of cast iron, silicon, so that the use of excessive amounts of steel scrap in the cupola charge also adds to the cost by requiring excessive amounts of silicon replenishment. The preferred procedure contemplated herein permits the use of lower amounts of steel scrap than is normally used.

The cupola charge includes metals and alloys, coke, and flux. The metal charge is limited by size of pieces and percent of steel scrap or low carbon iron to be used. The longest dimension of any metal piece should be less than about one-third of the effective diameter of the cupola. This provides quick and simultaneous melting of the charge and more uniform analyses. The steel scrap should not be more than about 60% of the charge.

The type, size and amount of coke used are important factors in carbon control. A hard, dense, high ash coke should be used to give a strong bed and a minimum of carbon solution in the iron, i. e., a low solubility rate coke. There are many suitable cokes available such as the coke sold under the trade name of "Special A. B. C." Only sufficient amounts of a low solubility rate coke should be used to produce the required temperatures of about 2700° F. to 2900° F., e. g., 2825° F. to 2850° F. Coke size should be close to one-twelfth the effective diameter of the cupola. The iron to coke ratio should be 10:1 with no steel scrap, 9:1 with about 20% steel scrap, 8.5:1 with about 40% steel scrap, and 8:1 with about 60% steel scrap in the charge. The weight of coke charges should be such that the in-between coke layers are not greater than about 5 inches in depth and the weight of individual metal charges should be governed by this coke weight. This procedure gives a more constant bed height due to more frequent replenishment than when the usual heavy charges are used, and therefore a greater depth of incandescent coke and improved melting.

A pure limestone flux is preferred in amounts equal to about 30% to about 40% of the coke charge. This forms a protective slag which both insulates the metal in the well from the cooling currents of the blast and serves as a filter for iron entering the well.

The objectives of the melting procedure are to obtain iron at the cupola spout with the lowest carbon content and at the highest temperature for any given charge. In the preferred procedure a low water content green sand is used for the cupola bottom. Next, an incandescent coke bed is obtained by lighting up a small portion, about one-quarter of the bed coke first and then charging the remaining quarters only after the preceding quarter has become white hot. This should be done with natural draft. When the bed is burned through and of the correct height, depending upon the wind box pressure as illustrated in Table VII, the charging is done quickly in the following sequence: bed flux of about 3 to about 4 usual flux charges; metal charge of steel, alloys, scrap, etc.; coke charge; flux charge; etc. Without soaking the charge, which would increase carburization and sulfur pick-up, the blast then is raised at once to the correct pressure. The correct blast pressure and coke bed height relationship gives the fastest melting, lowest carbon, and hottest iron.

Table VII

Pressure, in ounces per square inch	4	8	12	16	20	24	28	32	36
Minimum bed, in inches above tuyères	21	30	36	42	47	52	56	60	63
Recommended bed, in inches above tuyères	27	36	42	48	53	58	62	66	69

The molten iron should be removed from the cooling and carburizing conditions present in the cupola well as soon as possible and this is accomplished by frequent and well-timed tapping, or by a calibrated tap hole, or by using a front slagging spout. The first method is to alternately tap and bot the cupola, allowing the metal to accumulate in the cupola. The second method stores a fixed head of metal in the cupola while metal flows continuously through the tap hole. The third method is to allow the metal to flow continuously through the tap hole without accumulating any storage of metal in the cupola, which is accomplished by means of a special tap spout known as a "front slagging spout" or a "syphon spout." The front slagging spout method of tapping a cupola is well suited to the production of high quality cast iron. When the method is alternate tapping and botting of the cupola, the tapping sequence may be frequent enough to approximate 30 taps per hour. The sequence of tapping may be speeded up to about 40 or slowed down to about 10 taps per hour depending on conditions, such as the desired carbon level, the relationship of the tap hole diameter to the melting rate, the size of ladles used, etc. The molten metal obtained from the cupola is then subjected to the same processing as described hereinbefore.

Illustrative example

In order that those skilled in the art may have a better understanding of the present invention the following example is given to illustrate the production of a medium size roll 30 inches in diameter made of the high quality cast iron provided by the present invention. A roll of such diameter might be used in a three high mill for rolling various shapes, such as angles, channels and T's. Such a roll might have a body length as short as about 30 inches or as long as about 60 inches and would have necks cast on both ends. Wobblers might be cast on either one or both necks. In general, rolls and other articles produced in accordance with the present invention are not characterized by the usual chill layer present in many rolls and the like produced by other methods.

In selecting the composition for the 30-inches diameter roll, a suitable carbon content is about 1.7% to about 2.05%, as indicated in Table II. The desired carbon content within this range is preferably about 1.85% to about 1.95%. The co-present silicon content is selected within the range about 1.25% to about 2.25%, preferably about 1.8% to about 2.0%. Provision is made to tap the molten metal from the furnace with about 1.3% to about 1.5% silicon, a subsequent ladle addition of approximately 0.5% silicon as ferro-silicon bringing the total silicon content up to the desired amounts. As indicated in Table

III, a suitable nickel content for the roll is about 3.0% to about 5.0%, and preferably about 3.25% to about 3.75% nickel. A suitable molybdenum content is about 0.6% to about 0.9%, the preferred amounts being about 0.7% to about 0.8%. It is a common occurrence in the roll industry to have chromium-bearing scrap and accordingly the specifications on the chemistry or composition of the roll provide for a maximum of about 0.25% chromium.

In the present example, the charge is to be melted in an air furnace (reverberatory type furnace) but any other suitable melting furnace might be used, for example, an electric furnace, an open hearth furnace, duplexing between cupolas and electric furnaces or air furnaces, etc.

In calculating the furnace charge provision is made for losses of carbon, silicon, manganese, etc., as determined from the melting loss characteristics of the specific furnace with its particular method of firing. For example, when the desired carbon in the tapped metal is about 1.85 to about 1.95% and the furnace characteristic loss in melting is about 0.6% carbon, the ingoing carbon content of the charge should be about 2.45% to about 2.55%. A suitable furnace charge might be comprised of scrap rolls, some steel scrap and some pig iron, the amounts of these charge components depending on the composition of the scrap materials available with each specific producer, e. g., the scrap roll charge might be about 50 to 60% of the charge, the steel component about 15 to 20%, and the balance pig iron. However, satisfactory charges have been melted where no scrap rolls have been available, for example, a charge made up of approximately equal quantities of pig iron and steel scrap.

The ladle to receive the molten metal should be preheated and the probable metal temperature loss due to ferro-silicon inoculating additions and ladle radiation losses checked. The loss of temperature due to the ferro-silicon additions might be of the order of about 30° F. and the loss of temperature due to other causes might be at the rate of about 10° F. per minute or more. A representative value for the total metal temperature losses is about 100° to 150° F. between the temperature at the tap spout of the furnace and the mold. Thus in order to pour the molten metal from the ladle at a temperature of about 2650° F., the metal in the furnace should be tapped at a temperature of about 2750° F. to about 2800° F. for the particular conditions set forth. When the furnace is tapped at the proper temperature, about 0.5% of silicon is added as ferro-silicon to inoculate the molten metal, the inoculant being added to the metal in the furnace spout as the metal flows towards the ladle.

When the ladle is filled, it is poured with the least possible delay between tapping and pouring into the mold. A roll of the size contemplated herein would weigh between 10,000 and 20,000 pounds, depending upon its length, and the pouring speed would be about 60 to about 90 seconds. By pouring speed is meant the time from the beginning of pouring until the mold is completely filled. It is desirable practice to pour rolls through a bottom swirl gate and completely fill the mold with all the metal required to make the casting plus sufficient metal to form a riser for feeding purposes, etc. It is recommended that bottom pouring be discontinued when metal reaches the riser portion of the mold and that the balance of the metal be poured from the ladle into the riser in order to have the hottest metal therein.

A roll of the size described takes about 12 hours to cool to about 1500° F., at which temperature all portions of the mold are removed thereby accelerating the cooling rate down to below 500° F. or less. The roll is then subjected to a heat treatment at temperatures between about 500° F. to 700° F., preferably about 600° to about 650° F., for about 35 to about 75 hours and then furnace cooled, after which it may be machined to the desired dimensions.

Applications

The present invention may be applied to the manufacture of any product made of a high quality gray cast iron, but is particularly applicable to gray cast iron products having heavy section sizes, such as is used in industrial and high pressure machinery. Illustrative examples of high quality gray cast iron products which may be produced by the present process include such articles of manufacture as rolls, including still mill rolls, Fourdrinier rolls and other paper mill rolls, and rolls for grinding cereals and grain; newspaper and printing press machinery; machine tool frames and beds; press heads and bases for sheet metal working, leather working, etc.; dies, including forging dies, automotive body and fender dies, wire drawing dies, stamping dies, and forming dies; cylinders and superheaters, including locomotive superheaters, locomotive cylinders, steam turbine cylinders, gas engine cylinders, hydraulic cylinders, cylinder blocks, and cylinder heads; aeroplane engines; car wheels; brake drums; locomotive driving axle boxes; rear axle housings for trucks and the like; heavy bearings and bushings; heavy cams; crankshafts, such as Diesel engine crankshafts; high pressure pumps; valves; large gears, V-belt pulleys, sprockets, sheaves, etc.; scale parts and levers; and the like. As is well known to those skilled in the art, it is possible in certain applications, e. g., rolls, to use special casting methods to form the shell of a metal of particular composition such as by centrifugal casting or sweeping out or otherwise removing the molten core portion, and, if desired, filling or replacing the core portion by another molten metal of different composition. It is to be understood that special casting methods known to those skilled in the art are within the purview and scope of the present invention.

It is to be observed that the present invention provides a process of producing a high quality cast iron containing about 1.5% to about 3.4% total carbon, of which about 0.4% to about 1% of said total carbon is in the non-graphitic form, about 1% to 4.75% silicon, about 1% to about 6% nickel, about 0.2% to about 1.5% molybdenum, and the balance substantially all iron, the lower carbon and silicon contents and the higher nickel and molybdenum contents being associated with the larger section sizes of the final product, said process comprising establishing a molten mass of cast iron containing carbon, silicon, nickel and molybdenum; tapping said molten mass, preferably at temperatures in excess of about 2575° F.; inoculating said molten mass with about 0.2% to about 1% of silicon as a silicon-containing inoculant; and casting said molten mass having the desired composition, preferably at a temperature of about 2575° F. to about 2800° F., whereby a cast iron is produced

having a partially austenitic "as cast" microstructure, the austenite in said microstructure being transformable to an acicular constituent upon heat treatment at low temperatures of about 800° F. to about 350° F. for about 1 to about 100 hours, thereby imparting improved properties to the cast iron. In carrying out the process it is advantageous to maintain a ferro-static pressure in excess of about 5 pounds per square inch.

Furthermore, it is to be noted that the present invention provides a process which is particularly advantageous for the production of heat treated cast iron having an acicular microstructure interspersed with fine graphite and comprised of about 2.5% to 1.25% silicon, about 3% to 1.5% carbon, about 2% to 6% nickel, about 0.5% to 1.3% molybdenum, and the balance substantially all iron.

It is further to be noted that the present invention provides a process of producing the high quality cast iron containing controlled amounts of carbon, silicon, nickel and molybdenum in a cupola, said process comprising melting in a cupola a charge containing metal, low solubility rate coke and flux and of which not more than about 60% is steel scrap, the iron to coke ratio of the charge exceeding about 8:1; tapping the molten mass at a high temperature; inoculating said molten mass with a silicon-containing inoculant in an amount sufficient to introduce about 0.2% up to about 1% silicon into the molten mass; and casting said molten mass having the desired composition, preferably at a temperature of about 2575° F. to about 2800° F., whereby a cast iron is produced having a partially austenitic "as cast" microstructure, the austenite in said microstructure being transformable to an acicular constituent upon heat treatment at low temperatures of about 800° F. to about 350° F. for about 1 to about 100 hours, thereby imparting improved properties to the cast iron.

Moreover, it is to be noted that the present invention provides a high quality cast iron possessing high tensile strength and impact resistance and comprising about 1.5% to about 3.4% of total carbon, about 0.4% to about 1% of said total carbon being in the non-graphitic form, about 1% to about 4.75% silicon, the lower carbon and silicon contents being associated with the larger average section sizes of the final product, about 1% to about 6% nickel, about 0.2% to about 1.3% molybdenum, the higher nickel and molybdenum contents being associated with the larger average section sizes of the final product, and the balance substantially all iron. The present invention also provides as articles of manufacture, gray cast iron products for use in industrial and high pressure machinery made of the aforesaid high quality cast irons. Preferably the cast iron is subjected to heat treatment.

It is likewise to be noted that the present invention provides articles of manufacture having a large section size, especially gray cast iron products for use in industrial and high pressure machinery, made of a high quality cast iron comprising about 2.5% to 1.25% silicon, about 3% to 1.5% carbon, about 2% to 6% nickel, about 0.5% to 1.3% molybdenum, and the balance substantially all iron, said cast iron being characterized by a microstructure containing an acicular constituent and by an improved combination of properties including strength and impact resistance.

It is also to be noted that the present invention provides a roll made of a high quality cast iron comprising about 2.5% to 1.25% silicon, about 3% to 1.5% carbon, about 2% to 6% nickel, about 0.5% to 1.3% molybdenum, and the balance substantially all iron, said cast iron being characterized by a microstructure containing an acicular constituent.

The invention also provides a method of heat treating cast iron containing about 1.5% to 3.4% total carbon, about 1% to 4.75% silicon, about 6% to 1% nickel, about 1.3% to 0.2% molybdenum, and the balance substantially all iron, the heat treatment comprising subjecting the solidified metal to a low temperature heat treatment within the range of about 800° F. to 350° F. for about 1 to 100 hours, whereby austenite in the microstructure is transformed to an acicular constituent, thereby imparting improved strength in the cast iron. The aforesaid heat treatment may be applied to high quality cast irons which are substantially in the "as cast" condition.

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 variations and modifications apparent to those skilled in the art are considered to be within the purview and scope of the appended claims.

We claim:

1. In the method of producing high quality cast iron comprising 1.5% to 3.4% total carbon, of which 0.4% to 1% is in the non-graphitic form, 1% to 4.75% silicon, 6% to 1% nickel, 1.5% to 0.2% molybdenum, and the balance substantially all iron, the step which comprises subjecting the solidified metal substantially in the "as cast" condition to a low temperature heat treatment within the range of about 800° F. to 350° F. for about 1 to 100 hours, whereby austenite in the microstructure is transformed to an acicular constituent, thereby imparting improved strength to the cast iron.

2. The process of producing high quality cast iron containing 1.5% to 3.4% total carbon, of which 0.4% to 1% is in the non-graphitic form, 1% to 4.75% silicon, 1% to 6% nickel, about 0.2% to 1.5% molybdenum, the lower carbon content and the higher nickel and molybdenum contents being associated with the larger section sizes of the final product to obtain a partially austenitic microstructure in the as cast condition, which comprises inoculating a molten mass of cast iron containing carbon, silicon, nickel and molybdenum with 0.2% to 1% of silicon as a silicon-containing agent, casting said inoculated molten mass having the desired composition, and subsequently subjecting the solidified metal substantially in the as cast condition to a low temperature heat treatment within the range of about 800° F. to 350° F. to transform retained austenite in the as cast microstructure to an acicular constituent whereby a high quality cast iron is obtained having an improved combination of properties and a microstructure containing an acicular constituent.

3. In the method of producing high quality cast iron containing 1.5% to 3.4% carbon, 1% to 4.75% silicon, 6% to 1% nickel and 1.5% to 0.2% molybdenum, the step which comprises subjecting the solidified metal in a substantially unquenched partially austenitic condition to a low temperature heat-treatment within the range of 500° F. to 700° F. for 1 to 100 hours to transform retained austenite to an acicular constituent.

4. As an article of manufacture, a heat-treated roll made of a high quality cast iron containing 2.5% to 1.25% silicon, 3% to 1.5% carbon, 2% to 6% nickel and 0.5% to 1.5% molybdenum, said roll having been subjected in a substantially unquenched partially austenitic condition to a low temperature heat-treatment within the range of about 800° F. to 350° F. for about 1 to 100 hours, and said roll being characterized by a microstructure containing an acicular constituent.

5. As an article of manufacture, a heat-treated roll made of a high quality cast iron containing 2.5% to 1.25% silicon, 3% to 1.5% carbon, 2% to 6% nickel and 0.5% to 1.3% molybdenum, said roll having been subjected in a substantially unquenched condition to a low temperature heat-treatment within the range of 500° to 700° F. to transform retained austenite to an acicular constituent.

6. The process of producing high quality cast iron possessing an improved combination of properties which comprises establishing a molten mass of cast iron; inoculating said molten mass with up to about 1% of silicon as a silicon-containing agent; casting the inoculated molten mass containing controlled amounts of carbon, silicon, nickel and molybdenum within the ranges of about 1.5% to 3.4% total carbon, of which 0.4% to 1% is in the non-graphitic form, 1% to 4.75% silicon, 6% to 1% nickel, 1.3% to 0.2% molybdenum and the balance substantially all iron whereby a cast iron is produced having a partially austenitic "as cast" microstructure; and heat treating said cast iron at a temperature within the range of about 500° to 700° F. in a substantially unquenched condition to transform austenite in said microstructure to acicular constituent thereby imparting improved properties to the cast iron.

7. The process of producing high quality cast iron which comprises preparing an inoculated molten mass of cast iron containing substantially 1.5% to 3.4% total carbon, 1% to 4.75% silicon, 1% to 6% nickel, 0.2% to 1.5% molybdenum, the carbon content being so correlated with the section size of the final product that the lower carbon content and higher nickel and molybdenum contents are associated with larger section sizes, said mass having been inoculated with silicon-containing material to introduce 0.2% to 1% of silicon; casting and solidifying said mass to obtain a cast iron which in the as cast and unquenched condition will be characterized by a partially austenitic microstructure; subjecting the solidified metal in a substantially unquenched condition to a low temperature heat-treatment within the range of about 800° F. to 350° F. to transform retained austenite to an acicular constituent whereby a high quality cast iron is obtained having an improved combination of properties and a microstructure containing an acicular constituent.

8. In the method of producing high quality cast iron comprising 4.75% to 1% silicon, 3.4% to 1.5% carbon, 1% to 6% nickel, 0.2% to 1.3% molybdenum and the balance substantially all iron, the step which comprises subjecting the solidified metal in a substantially unquenched condition to a low temperature heat treatment within the range of about 800° F. to 350° F. for about 1 to 100 hours, whereby austenite in the microstructure is transformed to an acicular constituent thereby imparting improved properties to the cast iron.

9. High quality cast iron possessing high tensile strength and impact resistance comprising 1.5% to 3.4% of total carbon, 0.4% to 1% of said total carbon being in the non-graphitic form, 1% to 4.75% silicon, the lower carbon and silicon contents being associated with larger average section sizes of the final product, 1% to 6% nickel, 0.2% to 1.5% molybdenum, the higher nickel and molybdenum contents being associated with a final product of larger average section sizes, and the balance substantially all iron, said cast iron being in a condition resulting from heat treatment in a substantially unquenched state to transform retained austenite to an acicular constituent at low emperatures within the range of about 800° F. to about 350° F.

10. An article of manufacture having a large section size made of a high quality cast iron comprising 2.5% to 1.25% silicon, 3% to 1.5 carbon, 2% to 6% nickel, 0.5% to 1.3% molybdenum, and the balance substantially all iron, said cast iron being in a condition resulting from low temperature heat treatment in a substantially unquenched condition at temperatures of about 350° F. to about 800° F. and being characterized by a microstructure containing an acicular constituent.

11. An article of manufacture made of a heat treated high quality cast iron comprising 1.5% to 3.4% of total carbon, 0.4% to 1% being in the non-graphitic form, 1% to 4.75% silicon, the lower carbon and silicon contents being associated with larger average section sizes of the final product, 1% to 6% nickel, 0.2% to 1.5% molybdenum, the higher nickel and molybdenum contents being associated with a final product of larger average section size, and the balance substantially all iron, said cast iron having an acicular structure, having been subjected to a heat treatment in a substantially unquenched condition at low temperatures of about 800° F. to about 350° F. to transform retained austenite to an acicular constituent.

12. As articles of manufacture, gray cast iron products of large section size for use in industrial and high pressure machinery made of a high quality cast iron comprising 2.5% to 1.25% silicon, 3% to 1.5% carbon, 2% to 6% nickel, 0.5% to 1.3% molybdenum, and the balance substantially all iron, said cast iron being in a condition resulting from heat treatment in a substantially unquenched condition at temperatures of about 500° F. to about 700° F. to transform retained austenite to an acicular constituent.

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