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ALLOY STEEL AND CAST ROLL MADE THEREFROM

Roy J. Knoth, Deal, and Norman A. Matthews, Franklin Lakes, N.J., assignors to The International Nickel Company, Inc., New York, N.Y., a corporation of Delaware
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The present invention relates to low alloy steels and, more particularly, to cast roll steels for use as primary breakdown rolls, including blooming, slabbing and roughing mill rolls and the like, for heavy reduction from ingots to blooms or slabs.

As is well known, the production of rolling mill rolls is an exacting and highly specialized art requiring the application of considerable skill. Blooming mill rolls, for example, often weigh upwards of 100,000 pounds or more with diameters of four feet or more not being uncommon. Thus, it is not unexpected to find that considerable attention is given to the common problems of pouring, shrinkage, soundness, finishing, etc., in forming a roll and to the lengthy but rather critical heat treatment to which the roll is thereafter subjected, including such operations as soaking, homogenization, cooling, reheating and tempering. As can be appreciated, failure to observe tolerable margins of error can result in rather drastic consequences. With the many precautions undertaken in commercial operation, it is particularly troublesome to find that far too many blooming mill rolls and the like undergo deleterious breakage or fracture during use in too short a time and must be scrapped or removed from service for repair. In either case, costly "down time" is encountered on the rolling mill.

Many factors contribute to the satisfactory life of the primary breakdown blooming, slabbing and roughing rolls, including strength, impact toughness, wear resistance, resistance to deleterious fire cracking, etc. A blooming mill roll or roughing roll, as is known, is subjected to severe shock loading and to exceedingly high pressures. Under such conditions, a roll steel must be characterized by a combination of strength and toughness of such magnitude as to prevent or greatly minimize propagation of fire cracks resulting from the heat transmitted from a hot ingot to a roll (the heat transmitted results in an expansion differential of the surface causing the formation of small surface cracks). Actually, these fire cracks can be of benefit if propagation thereof can be prevented since these cracks tend to afford a "gripping power" to facilitate movement of an ingot through a roll. In addition, adequate hardness is required for good wear resistance, but the hardness cannot be at a level which would result in a brittle roll surface.

At one time, the plain carbon steels were used but operating conditions became overly severe which necessitated the use of stronger and more durable materials. Thus came the introduction of the low alloy steels. Low alloy steels for blooming mill rolls generally contain about 0.7% or 0.8% to about 1.2% carbon, chromium in an amount of up to about 1%, about 0.2% to 0.5% molybdenum, nickel in an amount up to 1.75%, about 0.4% or 0.5% to 1% manganese, up to 0.5% silicon, and on occasion, small amounts of other elements. To be sure, not all blooming mill roll steels have such compositions; e.g., some steels are reported to contain as little as 0.4% carbon and as high as 1.8% carbon and others are nickel-free. These prior art alloy steels, while

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characterized by a reasonably good combination of properties, have, nonetheless, been found to be quite susceptible to the aforementioned fracture problem, a problem which has seemingly become more acute in recent times and appears to be common to at least most, if not all, roll foundries and users. While the exact cause of the problem might not be understood, it is believed that the increase in the number of fractured rolls is somewhat attributable, inter alia, to the increasingly severe demands imposed on the rolls to meet commercial requirements under normal operating conditions; e.g., higher roll pressures under ambient temperature conditions result in an environment for propagation of cracks. In this connection, it is considered that the overall impact properties, including transition temperatures, of prior art steels are not at a level capable of withstanding, at least for a satisfactory period of time, increasingly stringent commercial conditions of operation.

Lowering the hardness of alloy steels for primary breakdown rolls in order to increase toughness (impact resistance, ductility, reduction of area) is one approach to the problem, but this is accomplished at the expense of wear resistance. The outlook is not for less stringent demands on such rolls and, thus, good wear resistance is an indispensable prerequisite.

A different approach would be to accept the result as rather inevitable. For example, it has been recently indicated that fractures in cast steel rolls can be welded. ("Steel," May 7, 1962, pp. 92 and 93.) This approach copes with the result but does not provide a solution to minimizing the frequency of occurrence of fracturing. Moreover, the welding process is not inexpensive, although it is preferable, other factors being equal, to scrapping the roll.

Although attempts have been made to overcome the brittle fracture of cast steel primary breakdown rolls, none, as far as we are aware, has been entirely successful when carried into practice commercially on an industrial scale.

It has now been discovered that alloy steels of special composition can be provided as cast steel primary breakdown rolls which are highly resistant to fracture in use.

It is an object of the present invention to provide cast alloy steels and primary breakdown rolls made thereof, including blooming or slabbing or roughing rolls and the like, which have a combination of properties including high strength, excellent overall impact toughness, good wear resistance, etc., such that markedly greater resistance to fracturing is achieved in comparison with prior art steel rolls.

Other objects and advantages will become apparent from the following description.

Generally speaking, the present invention contemplates cast steel primary breakdown rolls, i.e., blooming mill rolls, slabbing rolls and roughing rolls, formed of a low alloy steel of the following most advantageous composition: at least about 0.55% and up to about 0.65% carbon, about 0.2% to about 0.55% silicon and advantageously to not more than about 0.3% silicon, about 0.3% to about 0.7% manganese, about 3.4% to about 3.7% nickel, about 0.8% to about 1% chromium, about 0.35% to about 0.45% molybdenum, about 0.1% to about 0.15% vanadium, and the balance essentially iron. Sulfur and phosphorus should be kept as low as possible, e.g., not more than 0.035% (preferably not more than 0.03%) of sulfur and not more than 0.015% (preferably

not more than 0.01%) of phosphorus should be present. Upon heat treatment, alloy steel rolls provided in accordance with the instant invention are characterized by a bainitic microstructure, which microstructure is markedly more beneficial than the pearlitic microstructures characteristic of alloy steel rolls heretofore used.

Cast steel rolls in accordance with the invention have (in the heat treated condition described hereinafter) yield strengths (0.2% offset) of the order of 95,000 pounds per square inch (p.s.i.) or higher, e.g., up to at least 115,000 p.s.i., tensile strengths of the order of about 140,000 p.s.i., e.g., 145,000 p.s.i. or higher, a Brinell hardness of about 275 to 300 to insure satisfactory wear resistance properties, a good combination of ductility and impact toughness and a comparatively low impact transition temperature. Tensile elongations (2 inches gage length) of at least about 6% or 7% or higher, reductions of area of at least 9% or higher (11%) and Charpy V-notch impact values of more than 8 (up to at least 11) foot-pounds (ft.-lbs.) at room temperature together with impact transition temperatures of the order of about 195° F. are readily attained. Such properties afford a substantially higher degree of toughness than the prior art cast steel rolls heretofore used and greatly contribute to minimizing the occurrence of fracture, i.e., significantly inhibit the propagation of cracks normally causative of detrimental fracture. In this connection, prior art steels used as cast steel primary breakdown rolls have been characterized by brittle-ductile transition temperatures of well above 300° F., e.g., at least as high as 350° F., and it is believed that such high transition temperatures have been a positive contributing factor to the fracturing which has occurred. That is to say, under normal operating conditions the transition from a ductile to brittle state in prior art cast alloy steel rolls is at too high a temperature for effectively inhibiting the propagation of cracks.

Satisfactory results can also be achieved with alloy steels containing from 0.55% up to 0.7% carbon, 0.2% to 0.6% silicon, 0.3% to 0.7% manganese, 3.4% to 3.8% nickel, 0.8% to 1.2% chromium, 0.35% to 0.45% molybdenum, 0.08% to 0.25% vanadium and the balance essentially iron. Should the carbon content fall below 0.55%, inferior strength and wear resistance result whereas carbon in amounts above 0.7% leads to embrittlement. Thus, it is advantageous that the carbon content not exceed about 0.65%. The silicon content should not exceed about 0.6% and advantageously should not exceed 0.3% since it lowers impact resistance. Manganese over 0.7% also adversely affects impact resistance but at least 0.3% should be present to tie up any sulfur present and to contribute to the hardenability of the steel. Nickel in amounts above 3.7%, and particularly above 3.8%, is disadvantageous because of the occurrence of segregation and formation of retained austenite. Further, higher amounts of nickel undesirably depress the critical (transformation) temperatures. At least 3.4% nickel is required to insure necessary hardenability, to provide toughness and to provide desired transformation characteristics, i.e., to give a bainitic structure while retaining the benefits of nickel upon the toughness of the tempered structure. Chromium in amounts above 1%, and particularly above 1.2%, or molybdenum in excess of 0.45% causes grain boundary carbides to form. To avoid possible excessive grain boundary carbide formation, it is preferable that the sum of the chromium plus molybdenum be less than 1.4%. Should the chromium content fall much below 0.8%, difficulties associated with pearlite formation arise. If the molybdenum content falls much below 0.35%, the transformation characteristics are adversely affected; e.g., pearlite could form which provides a weak structure and/or induces embrittlement. Vanadium importantly contributes to toughness and to achieving low brittle-ductile transition temperatures. In addition, vanadium in comparison with alu-

minum, for example, is even preferred as a deoxidizing agent since it does not contribute to type-II inclusions.

In producing a cast steel roll in accordance with the invention, the rolls after shaking out at 800° F. to 1200° F., e.g., 1000° F., are heated (soaked) for 5 to 15 hours at 900° F. to 1100° F. to eliminate hydrogen and to effect equalization of temperature throughout. The rolls are then brought to homogenization temperature of about 1750° F. to about 1950° F. for 2 to 12 hours, e.g., about 2 hours at 1950° F. or about 12 hours at about 1750° F., and then cooled to and held within the range of about 1150° F. to 600° F. to effect transformation for grain refinement. The rolls are then reheated to an austenitizing temperature of 1400° F. to 1550° F., e.g., 1425° F. to 1500° F., and again cooled, preferably in air, to at least as low as 700° F. and down to about 425° F. but above the Ms temperature of the steel. The rolls are held in this temperature range for a period sufficient to substantially form the bainitic structure in a substantially isothermal manner, e.g., for about 10 hours. The rolls are thereafter tempered to obtain a desired hardness level. It is preferable to double temper at between 1000° F. and 1100° F. The tempering temperature should not exceed 1200° F. since some degree of transformation to austenite may occur in segregated regions which will then retransform to untempered, relatively brittle products or structures on cooling. It is important in accordance with the invention that the cooling treatment immediately subsequent to the aforementioned austenitization treatment be conducted at a rate not less than about 40° F./hr. in order that a bainitic and not a pearlitic structure be obtained. The cooling rate should not be so rapid as to cause the formation of martensite.

For the purpose of giving those skilled in the art a better understanding of the invention (and/or a better appreciation of the advantages of the invention), the following illustrative example is given:

EXAMPLE I

Three alloy steels A, B and C having compositions set forth in Table I, Alloy A being within the invention and Alloys B and C being outside the invention, were prepared using an air induction furnace with a low phosphorus pig iron, a commercially pure iron and electrolytic nickel. These ingredients were melted down and molybdenum chips and ferroalloys were added, i.e., ferromanganese, ferromanganese, ferrochromium, and ferrovanadium. The melts were deoxidized with 0.4% calcium silicon, and then tapped. After cooling, the ingots were shaken out at 1000° F. Alloy A was given the following heat treatment: (1) held at 1000° F. for 5 hours, (2) heated to 1750° F. and homogenized for 5 hours, (3) cooled to 600° F. in 20 hours, (4) heated to an austenitizing temperature of 1500° F. and held for about 2 hours, (5) cooled to 600° F. in 18 hours and thereafter double tempered at 1180° F. for a total of 12 hours (6 hours for each temper) followed by furnace cooling. Alloys B and C were similarly heat treated as follows: (1) held at 1000° F. for 5 hours, (2) heated to 1750° F. and held 3 hours, (3) cooled to 600° F. in 18 hours, (4) heated to 1600° F. and held 3 hours, (5) cooled to 600° F. in 15 hours, and thereafter tempered at 1050° F. for 10 hours followed by furnace cooling to 400° F. in 15 hours and then air cooled.

Table I.—Composition

Alloy	C, per cent	Si, per cent	Mn, per cent	Ni, per cent	Cr, per cent	Mo, per cent	V, per cent	S, per cent	P, per cent
A-----	0.63	0.52	0.4	3.4	0.8	0.4	0.12	0.028	0.009
B-----	0.58	0.33	0.47	2.5	0.4	0.22	-----	0.004	0.009
C-----	0.77	0.5	0.48	1.4	0.39	0.24	-----	0.013	0.017

The alloy steels were then subjected to testing at room temperature (duplicate specimens for Alloys A and C being tested for strength, elongation, reduction of area

and impact strength), the results of which are given in Table II.

sidered to be within the purview and scope of the invention and appended claims.

Table II

Alloy	Tensile Strength, p.s.i.	Yield ¹ Strength, p.s.i.	Elong. (2"), percent	Red. Area, percent	Hardness, Brinell	Charpy V-notch, ft.-lbs.	FATT, ² ° F.
A-----	{ 142,100 139,700	{ 99,500 97,800	{ 8 6	{ 11.5 9.5	{ 280 269	{ 8, 8, 9.5 4, 4.5, 5	220
B-----	{ 128,100 122,000	{ 67,400 61,000	{ 6 2.5	{ 6.5 5	{ 265 265	{ 2.5, 3 2.5, 3	300
C-----	{ 128,000 128,000	{ 60,600 60,600	{ 3.5 3.5	{ 5 5	{ 265 265	{ 2.5, 3 2.5, 3	360

¹ 0.2% offset.

² The FATT (Fibrous Appearance Transition Temperature) is, as is the customary standard, that temperature at which 50% fibrous fracture occurred.

The foregoing data illustrate that a relatively high strength alloy steel (Alloy A) is provided in accordance with the invention which is characterized by high strength and good toughness together with a brittle-ductile transition temperature which is markedly lower than that of the cast roll steels (Alloys B and C) heretofore used for blooming or slabbing or roughing rolls. The combination of properties obtained is not achieved at the expense of any specific property; e.g., the high degree of toughness is not achieved at the expense of inadequate hardness and/or strength. Alloys B and C, which are illustrative of compositions heretofore proposed, exhibited markedly lower toughness and substantially higher FATT temperatures (80° F. and 140° F. higher, respectively) in comparison with Alloy A. In addition, the yield strengths (67,100 p.s.i. and 61,600 p.s.i., respectively) of Alloys B and C are significantly lower than that of Alloy A (98,650 p.s.i.). Thus, the ability of Alloys B and C to resist crack propagation and, ultimately, fracture failure is much inferior in comparison with Alloy A.

The present invention is applicable to the production of primary breakdown rolls for heavy reduction applications as in the case of rolling ingots to blooms or slabs. In this connection, the rolls produced in accordance with the present invention should not be confused with intermediate or finishing rolls. Intermediate or finishing rolls would be of such a hardness that they would be brittle for heavy reduction rolling.

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

We claim:

1. A cast steel primary breakdown roll made of a cast steel consisting essentially of about 0.55% to about 0.65% carbon, about 0.2% to about 0.55% silicon, about 0.3% to about 0.7% manganese, about 3.4% to about 3.7% nickel, about 0.8% to about 1% chromium, about 0.35% to about 0.45% molybdenum, about 0.1% to about 0.2% vanadium, and the balance essentially iron.

2. The cast steel primary breakdown roll set forth in claim 1 wherein the silicon content thereof does not exceed about 0.3%.

3. A cast steel primary breakdown roll made of a cast steel consisting essentially of about 0.55% up to about 0.7% carbon, about 0.2% to about 0.6% silicon, about 0.3% to about 0.7% manganese, about 3.4% to about 3.8% nickel, about 0.8% to about 1.2% chromium, about 0.35% to about 0.45% molybdenum, about 0.08% to about 0.25% vanadium, and the balance essentially iron.

4. An alloy steel consisting essentially of about 0.55% up to about 0.7% carbon, about 0.2% to about 0.6% silicon, about 0.3% to about 0.7% manganese, about 3.4% to about 3.8% nickel, about 0.8% to about 1.2% chromium, about 0.35% to about 0.45% molybdenum, about 0.08% to about 0.25% vanadium, and the balance essentially iron.

5. An alloy steel consisting essentially of about 0.55% to about 0.65% carbon, about 0.2% to about 0.55% silicon, about 0.3% to about 0.7% manganese, about 3.4% to about 3.7% nickel, about 0.8% to about 1% chromium, about 0.35% to about 0.45% molybdenum, about 0.1% to about 0.2% vanadium, and the balance essentially iron.

6. The alloy steel as set forth in claim 5 wherein the silicon content thereof does not exceed about 0.3%.

No references cited.