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Hachisu et al. [45] **May 2, 1972**

[54] **A METHOD OF PRODUCING COMPOUND CAST ROLLS**

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[21] Appl. No.: **844,038**

[30] **Foreign Application Priority Data**

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July 26, 1969 Japan..................................44/52442

[52] U.S. Cl.......................**29/148.4 D,** 29/527.6, 29/DIG. 8, 29/DIG. 21, 164/76, 164/95
[51] **Int. Cl.** **B21d 53/12,** B21h 1/12
[58] **Field of Search**.....................29/148.4 D, DIG. 8, 527.6, 29/527.5, DIG. 21; 164/95, 96, 98, 76

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Primary Examiner—John F. Campbell
Assistant Examiner—Donald C. Reiley, III
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[57] **ABSTRACT**

A compound cast roll comprising a shell made of a steel having excellent rolling properties, an arbor having a body portion made of a steel or iron having high toughness and a cylindrical partition member interposed between said shell and said core, said three members being metallurgically connected together into an integral body and subjected to a heat treatment to impart desired properties to said shell and said core.

11 Claims, 19 Drawing Figures

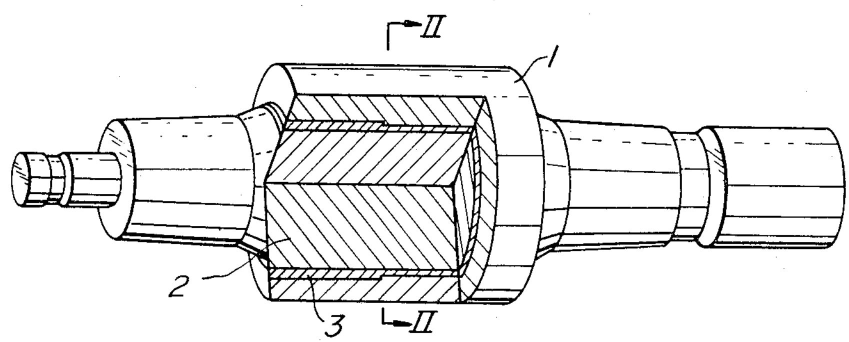

FIG. 1

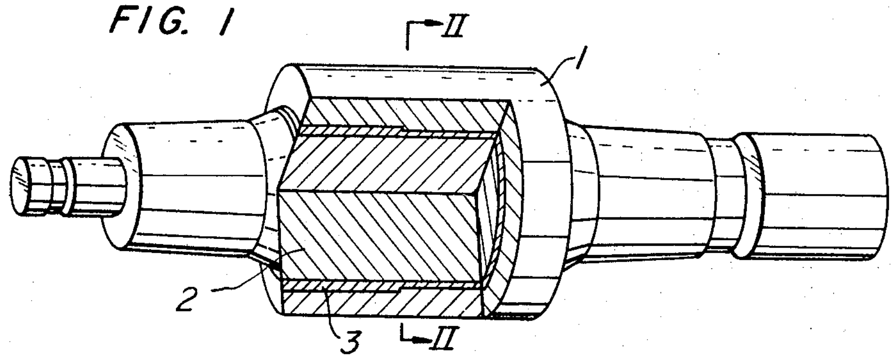

FIG. 5

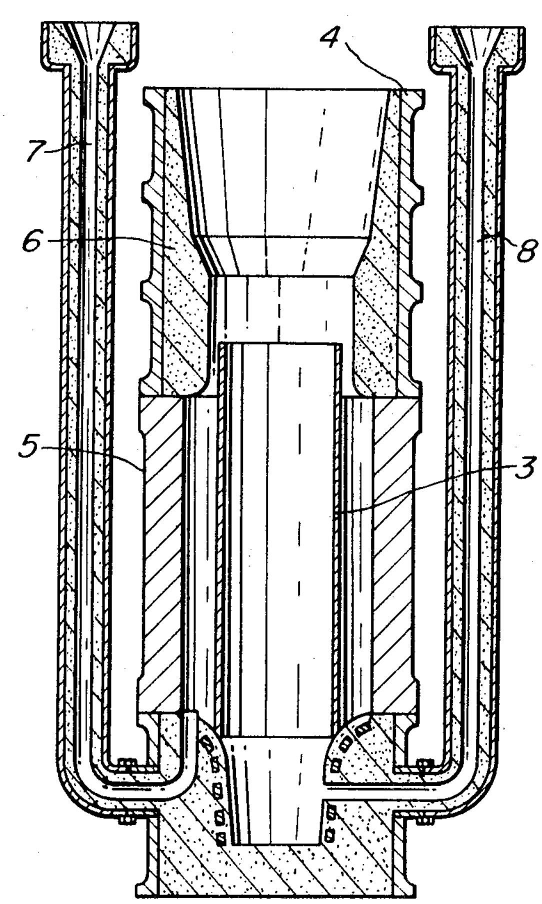

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FIG. 2

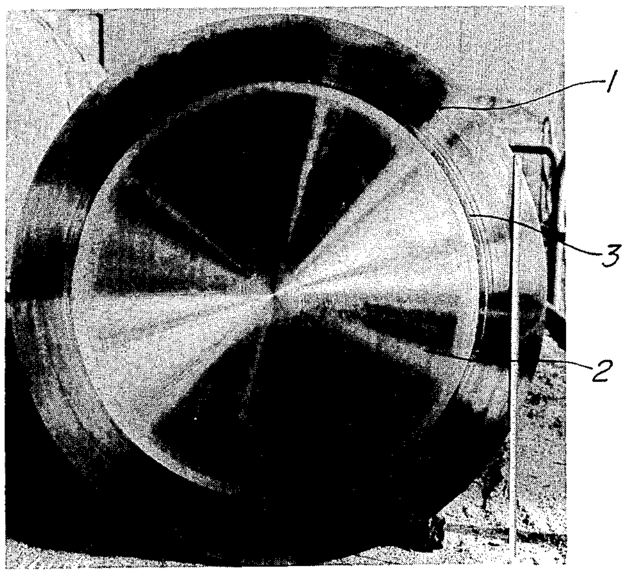

FIG. 3

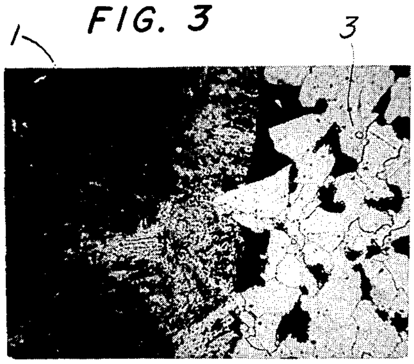

FIG. 4

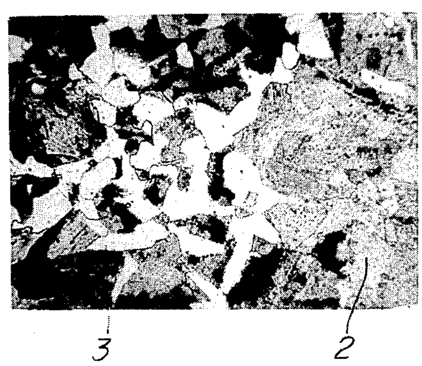

FIG. 6

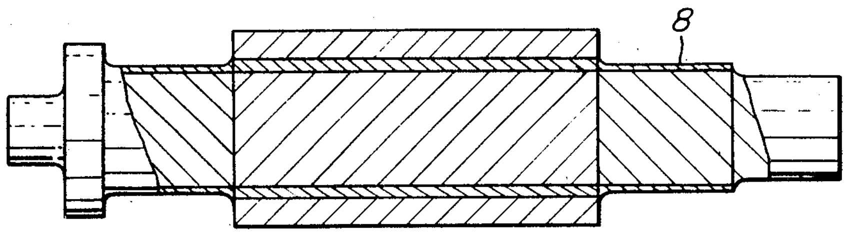

FIG. 7

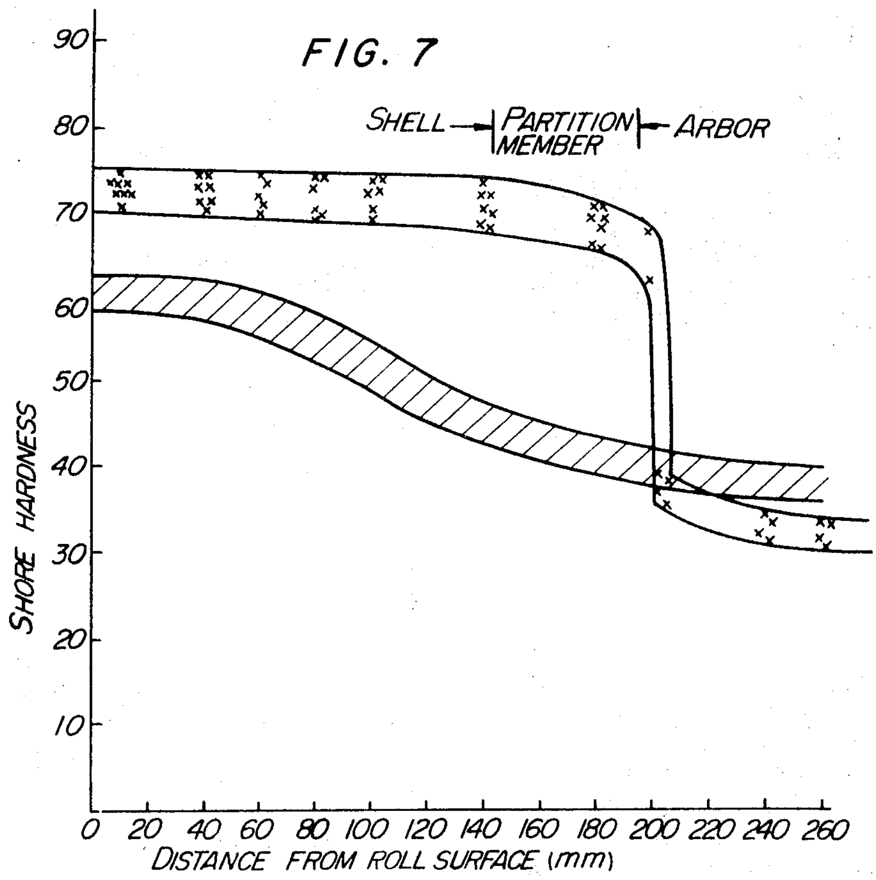

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FIG. 8

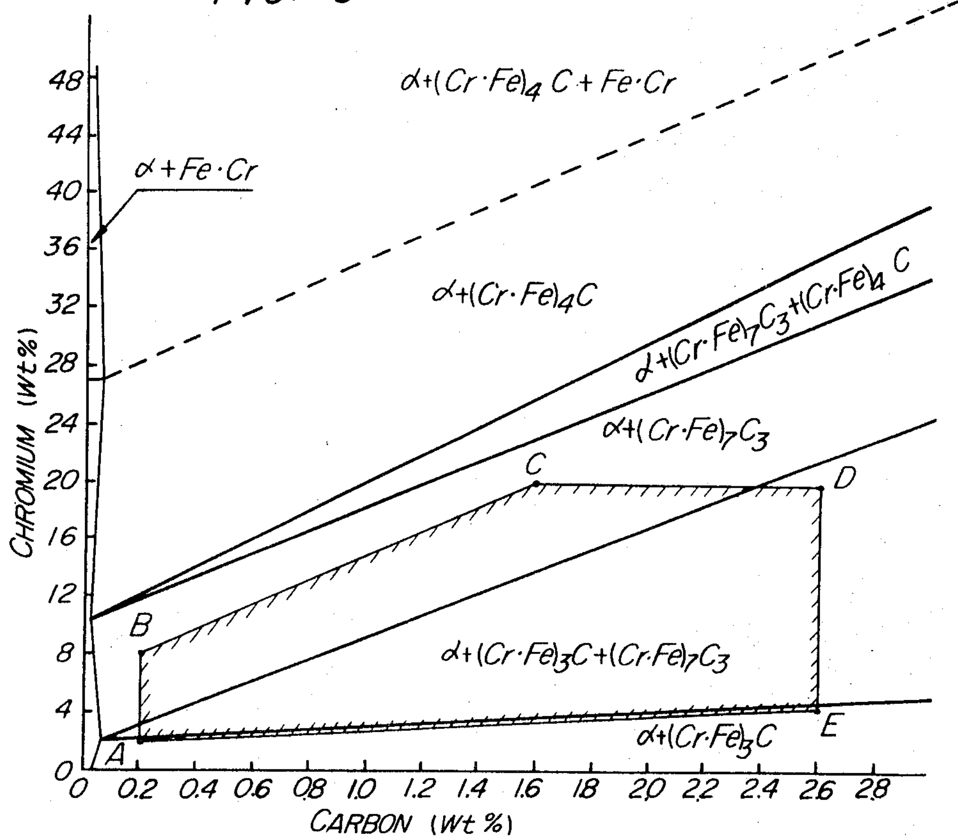

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FIG. 9

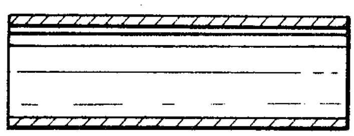


FIG. 12

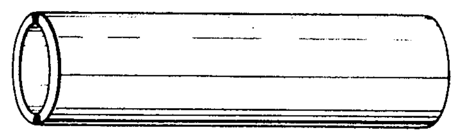


FIG. 10

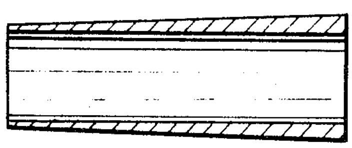


FIG. 13

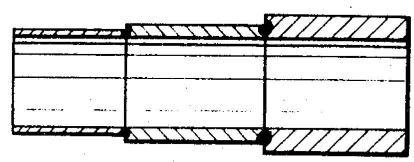
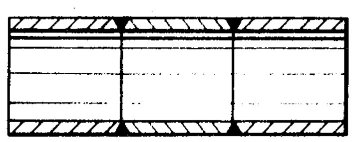


FIG. 11



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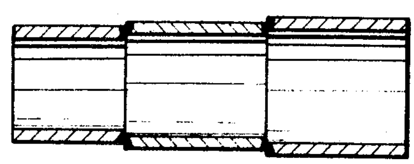

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FIG. 15

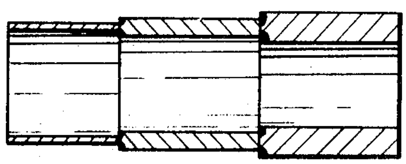


FIG. 17

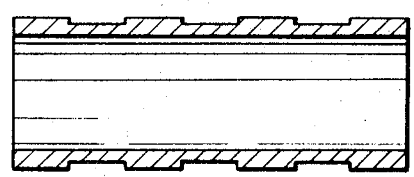


FIG. 16

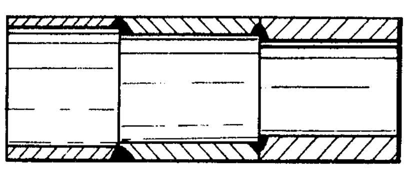


FIG. 19

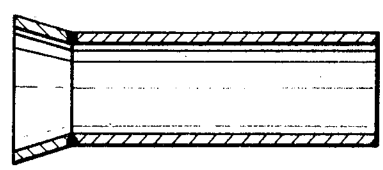
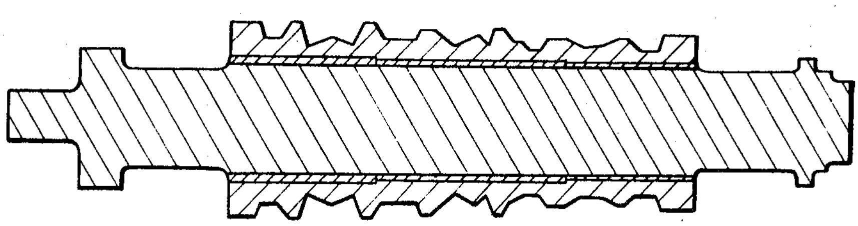


FIG. 18



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A METHOD OF PRODUCING COMPOUND CAST ROLLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to compound cast rolls adapted for use in rolling mill facilities.

2. Description of the Prior Art

Rolling mill rolls are mostly produced in the form of one body by pouring a molten metal into a mold of a shape conforming to the shape of a desired roll. Further, the rolling mill rolls are required to have various properties which are variable depending upon the type of roll, but regardless of the type, they are unexceptionally required to be highly resistive against fire crack, wear, spalling, surface roughening and breakage. In this view, materials of which the rolling mill rolls are made are desirably of such a chemical composition which will afford these properties.

As a material which is satisfactory with respect to the aforesaid requirements, high alloy cast steel may be named. In general, however, cast steel because of poor castability of a high alloy steel material, one body cast rolls tend to have internal shrinkages and internal cracks. It is said that such drawback becomes more apparent when the cast steel is a high carbon steel and as the amounts of alloy elements, such as nickel, chromium, molybdenum, etc., increase. In fact, it has been acknowledged through the experiment conducted by the present inventors that it is extremely difficult to produce a roll of 800 mm. or larger in diameter, using a cast steel which contains 0.2 to 2.6 percent by weight of carbon and 5 percent by weight or more of alloy elements, and further that it is essentially impossible to use such cast steel for the production of a practical roll by reason of a problem involved in the heat treatment. The use of high alloy cast steel for the production of one body type roll is also undesirable from the standpoint of economy.

Under the circumstances, plain steels and low alloy steels have come to be used which are satisfactory in respect of castability and are relatively inexpensive. It cannot be said that these materials are entirely satisfactory with respect to all properties required for the rolls, however. For instance, slabbing mill rolls and blooming mill rolls have commonly been produced by a method comprising casting a low alloy steel consisting generally of 0.6 to 1.2 percent by weight of carbon, 0.4 to 2.0 percent by weight of chromium, 0.2 to 0.6 percent by weight of molybdenum, 0.4 to 1.2 percent by weight of nickel, 0.4 to 1.2 percent by weight of manganese, 0.3 to 1.0 percent by weight of silicon and the remainder of iron, and subjecting the cast roll to a heat treatment. The rolls thus produced have a hardness of Hs 27 to 40. It has frequently been experienced in the past, however, that a heat crack occurs in the surface of the rolls, upon contact with a heated ingot during rolling operation, and said heat crack provides a cause of breakage of the rolls.

The major properties which are required for the above-mentioned slabbing mill rolls and blooming rolls are resistances to firecrack, wear and breakage, but these properties are incompatible with hardness and strength. Therefore, it is almost impossible for a one body type roll singly to have all of these properties.

On the other hand, work rolls of one body type used in hot rolling have been produced using low alloy steels consisting of 1.0 to 2.4 percent by weight of carbon, 1.0 to 2.0 percent by weight of chromium, 1.5 percent by weight or less of nickel, 0.3 to 0.5 percent by weight of molybdenum and the remainder of iron, and have a hardness of Hs 45 to 55. These work rolls, however, had the drawback that a massive carbide present in the structure of the rolls provides a cause of heat crack which in turn causes a premature roughening of the roll surface. These work rolls used in hot rolling are mainly required to be resistive to fire crack, wear and surface roughening, but again it is impossible for a work roll of one body type to have all of these properties in the light of its composition.

Further, in case of back up rolls which are particularly required to be resistive to wear and spalling, it is known to be essential to increase the hardness as high as possible but increasing the hardness undergoes a limitation because if a high alloy steel is used to increase the hardness of a back up roll of one body type, the casting and heat-treating operations are rendered difficult. In this view, alloy steels consisting of 0.4 to 1.2 percent by weight of carbon, 1.0 to 3.0 percent by weight of chromium, 0.3 to 0.6 percent by weight of molybdenum, 2.0 percent by weight or less of nickel and the remainder of iron, have been used for the production of back up rolls. Because of such composition of the alloy steels used, the product back up rolls had a hardness of not higher than Hs 65 and were susceptible to wear and spalling.

For the foregoing reasons and in the light of the fact that the depth of a roll which is required to be resistive against fire crack, wear, spalling, surface roughening and breakage is 1.1 to 3 times the available thickness of the roll at largest, in consideration of the safety factor of the roll, or more specifically is 30 to 100 mm. for the work rolls for use in a hot strip mill, 100 to 250 mm. for the back up rolls and 100 to 300 mm. for the slabbing mill rolls and blooming rolls, the production of compound rolls, including a shell constituting a surface layer of the roll, is already started in the field of cast iron rolls. As this type of rolls, cast iron compound rolls which comprise a shell made of a cast iron containing a relatively large amount of alloy elements, and a core made of plain cast iron or ductile cast iron, and sleeve fitting rolls or sleeve rolls which comprise a sleeve and an arbour mechanically combined with each other, are presently available.

A shell-core type compound roll has not been put in use in which the shall is made of a high alloy cast steel and the core is made of plain cast iron, plain cast steel or a low alloy steel, however. This is because of the following reason: Namely, a cast iron compound roll is usually produced by pouring a molten metal into a casting mold of a shape conforming to the shape of the compound roll, allowing the molten metal to remain in said mold until a portion of the molten metal adjoining the inner surface of the mold or a portion which will constitute the shell of the compound roll has been solidified, thereafter removing the unsolidified metal in the central portion of said mold therefrom to provide for the formation of the core of the compound roll and finally pouring a core-forming molten metal into the unsolidified shell-forming metal. However, the pouring temperature of the high alloy cast steel is so high that it is difficult to adjust the molten high alloy cast steel to a suitable pouring temperature, and moreover the solidification speed of the high alloy cast steel is so high that it is extremely difficult to remove the central portion of the molten steel to form a uniform shell.

However, a cast iron compound roll, the shell of which is made of a cast iron containing a relatively large amount of alloy elements, is inferior to a compound roll whose shell is made of high alloy cast steel in respect of toughness, and cannot be used in recent rolling mills which are required to be operable under severe rolling conditions. Hence, the range of use of the cast iron compound roll is considerably limited.

The term "high alloy steel" as used in the description is general reference to those steels which contain 0.2 to 2.6 percent by weight of carbon and 3 percent by weight or more in total amount of alloy elements; the term "low alloy steel" to those steels in which the total amount of alloy elements is 3 percent by weight or smaller; the term "plain steel" to those steels which contain alloy elements in only such an amount as that of impurities; and the term "plain cast iron" to those cast irons which contain 3.0 to 3.6 percent by weight of carbon and no alloy element or 3 percent by weight or less alloy elements as required.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a novel compound cast roll which comprises a shell and a body portion of an arbor clearly separated from each other by a cylindrical partition member.

Another object of the invention is to provide a compound cast roll in which the shell is made of a high alloy cast steel.

Still another object of the invention is to provide a compound cast roll in which the shell and the body portion are rigidly combined with each other.

Still another object of the invention is to provide a compound cast roll in which the rolling characteristic of the roll is uniform substantially throughout the width of the shell.

A further object of the invention is to provide a compound cast roll in which the shell has properties suitable for rolling, such as resistances to fire crack, wear, spalling, surface roughening and breakage, while the arbor has high toughness.

An additional object of the invention is to provide a novel method of producing a compound cast roll in which the shell is made of a high alloy cast steel.

The compound cast roll according to the present invention is composed of a steel shell having excellent rolling characteristics and a highly tough arbor. The shell and the arbor are metallurgically bonded with each other through the intermediary of a cylindrical partition member, and said shell is formed such that the hardness thereof is not substantially reduced over a portion of its width from the surface of the shell at least to a portion adjacent the cylindrical partition member.

In the past, it has been believed that a compound roll cannot be made of high alloy cast steel but according to the present invention such compound roll can be produced by interposing the cylindrical partition member between the shell and the body portion of the arbor, as described above. A preferable compound cast roll according to the present invention which comprises a shell of high alloy cast steel, is composed of a shell made of a high alloy cast steel which contains 0.2 to 2.6 percent by weight of carbon and 3 percent by weight or more in total amount of alloy elements, and a core made of a member selected from the group consisting of low alloy steel, plain cast iron and plain carbon steel, said shell and said core being metallurgically bonded with each other through the intermediary of a cylindrical partition member and said shell being formed such that the hardness thereof is not substantially reduced over a portion of its width from the surface of the shell at least to a portion adjacent said cylindrical partition member.

As stated previously, it is almost impossible to produce a one body roll of high alloy cast steel of 800 mm. or larger in diameter, due to the properties of said cast steel relative to casting and heat treatment. However, high alloy cast steel has excellent resistance to fire crack, wear, spalling, surface roughening and breakage, and further these properties are required for a thickness 1.1 to 3 times the available thickness of the shell. Therefore, it will be of great practical advantage as well as of economical significance if only the shell of the entire roll could be made of high alloy cast steel. Based on this idea, according to the present invention the shell is made of high alloy cast steel and arbor of a member selected from the group consisting of low alloy steel, plain cast iron and plain carbon steel.

However, if attempt is made to produce such compound roll by the same method as that used for the production of the conventional cast iron compound rolls, i.e., by pouring a molten high alloy cast steel into a mold of a shape same as the shape of the product roll, after formation of a solidified layer in a predetermined thickness and then with removal the central unsolidified metal from the mold pouring an arbor forming molten metal into the cavity surrounded by said solidified layer, it would be impossible to obtain a homogeneous shell of uniform thickness because the solidification speed of the high alloy cast steel is very high and removal of the unsolidified metal after formation of the solidified surface layer would be difficult due to the high viscosity of said cast steel, and further internal shrinkage would result in the contacting surfaces of the shell and the arbor. According to the present invention, therefore, not only is to shell formed of a high alloy cast steel and the body portion of the arbor formed of a member selected from the group consisting of low alloy steel, plain cast iron and plain carbon steel, but also a cylindrical partition member is interposed between the shell and the body portion of the arbor.

The partition member is preferably cylindrical in shape to uniformalize the thickness and rolling properties of the shell. This cylindrical partition member serves to produce a metallurgical connection between the shell and the body portion of the arbor and to prevent migration of said shell and said arbor. In order for the partition member to serve such purposes, it must be capable of metallurgical connection with both the shell and the body portion of the arbor. The present inventors have found that the degree of metallurgical connection between the partition member and the shell and arbor depends upon the thickness, composition, properties and surface condition of the partition member. Speaking practically of the properties, the tensile strength of the partition member may be 30 kg./mm.^{2} or greater for said partition member to withstand a stress imposed thereon. Further, the tensile strength of the metallurgical connection must be 10 kg./mm.^{2} or greater in the radial direction of the roll.

Preferably, the proportion of the cross sectional area of the partition member to that of the entire roll is from 2 to 15 percent. As for the composition of the partition member, the melt-bonding property of the partition member is improved as the carbon content increases, but excessively high carbon content results in melting-away of the partition member, allowing inter-mixing of the shell and the core. Therefore, selection of the partition member must be made based on the pouring temperatures and the pouring times of both the shell and the arbor. As for the surface condition, carbon is coated or aluminum is applied to the surface of the partition member so as to prevent formation of an oxide film thereon. Occasionally, the surface of the partition member may be subjected to such a treatment as carbonization, nitrification or aluminization, which is effective to improve the bonding property of the partition member.

It is also an important feature of the compound cast roll according to the present invention that the hardness of the shell is not substantially reduced from the surface thereof to at least a portion adjacent the partition member. Such feature is essential to obtain a stable rolling performance of the roll over an extended period. Because of the presence of the partition member, the solidification of the shell can be attained adequately and the effect of heat treatment can be extended uniformly throughout the shell. The thickness of the shell must be at least as large as the effective thickness of the roll, but in practice it is desirable that the thickness is 1.1 to 3 times the effective thickness of the roll, in consideration of the safety factor of the roll. Therefore, the partition wall is preferably located at a depth from the roll surface 1.1 to 3 times, particularly 1.2 to 2.5 times, the available thickness of the roll.

In order to afford desired properties to the shell, a high alloy cast steel of which said shell is formed must contain 0.2 to 2.6 percent by weight of carbon and 3 percent by weight or more in total of alloy elements. This is because, if the carbon content is smaller than 0.2 percent by weight, a desired strength cannot be obtained, whereas if the carbon content is larger than 2.6 percent by weight, the wear-resisting property of the shell is degraded to the level of the cast iron. On the other hand, the alloy elements form carbides upon being compounded with carbon or are dissolved into the matrix to strengthen said matrix. They also improve the quenching effect and provide necessary properties to the shell. As these alloy elements, Ni, Cr, Mo, V, Ti, W, Si, Mn, etc., are usually used and these elements are effectively combined with each other to afford desired properties to the shell. If the content of these elements is 3 percent or less in total, a satisfactory rolling properties of the roll cannot be obtained as has been experienced with the conventional one body roll, because the hardness of the shell cannot be made uniform throughout the thickness thereof, due to insufficient quenching effect. On the other hand, if the content of these elements is 2.5 percent or more, the castability of the steel is generally degraded unless the elements used are incorporated in the steel with particular care. The present invention proposes to use, as a material of the shell, a cast steel based on C-Cr. Cr is used in many tool steels as a carbide-forming element for promoting the quenching effect and, therefore, has sufficient properties as a roll material. By changing the amount of Cr in the range from 3 to 20 percent with respective to a carbon content of 0.2 to 2.6 percent, Cr can be applied to many rolls. Cr is also one of economical elements. The more the contents of C and Cr are, the more the amount of carbide formed will be and thus a roll material of excellent wear-resistance can be obtained. However, the toughness of the roll material is degraded on the other hand. For this reason, Ni, Mo, V, Ti, Mn, Si, W, etc. are incorporated in the steel as alloy elements, each in an amount of not more than 3 percent, whereby a roll material can be obtained which is tough and enables the quenching effect to be promoted and further has excellent rolling properties.

Namely, Ni and Mn serve to strengthen the matrix and promote the quenching effect; Mo, W and Si serve to improve the mechanical properties of the matrix at elevated temperatures and form carbides to improve the wear-resistance; and V and Ti serve to produce a fine structure of the cast steel to increase the strength thereof. By suitably incorporating these elements in a C-Cr base steel, it is possible to obtain an excellent high alloy shell material.

The properties required for a roll are variable depending upon the type of the roll since the conditions in which the roll is used are variable. Accordingly, the chemical composition of a high alloy cast steel of which the shell is formed should be adjusted in accordance with the type of a desired roll, while refraining from making the material cost unduly high. In case, for example, of a blooming roll or the like for which a breakage-resisting property is required in particular, a high alloy cast steel is used for the formation of the shell which comprises 0.2 to 0.8 percent by weight of carbon, 3 to 6 percent by weight of chromium and substantially the same amounts of other elements as contained in the conventional roll. In case of a work roll for which a fire crack-resisting property and a surface roughening-resisting properties are required in particular, a high alloy cast steel is used which comprises 0.8 to 2.0 percent by weight of carbon, 6 to 12 percent by weight of chromium and substantially the same amounts of other elements as contained in the conventional roll. Further, in case of a roll which is particularly required to be resistive against wear, a high alloy cast steel is used which comprises 1.5 to 2.6 percent by weight of carbon, 10 to 15 percent by weight of chromium and substantially the same amounts of other elements as contained in the conventional roll.

The partition member must be of such a material which is capable of producing a metallurgical connection between the shell and the arbor. Since the partition member is used essentially for the purpose of preventing the formation of internal shrinkages in the contacting surfaces of the shell and the body portion of the arbor, and simultaneously of preventing the excess migration of the shell-forming material and the arbor forming material, it may be required to be in a length equal to the length of the roll body. The journals of a roll are usually made of the same material as the body portion but since they are rotatably supported by parts of a rolling mill in frictional engagement therewith, they are susceptible to wear. In order to deal with this, according to the present invention the partition member may be made of a material more resistive to wear than the core material and the length of such partition member may be extended to a length equal to the overall length of the arbor, so that the journals of the roll may be covered with the partition member.

It is essential that a portion of the partition member which is subjected to the heat of a shell-forming molten metal at first in the casting operation, that is, a portion of the partition member located in the bottom of a casting mold, is not deformed or molten away during the casting operation. The present inventors have found that it is advantageous from the standpoint of roll performance to reduce the wall thickness of the partition member from the bottom to top so as to produce a positive temperature gradience in the solidification of the shell-forming molten metal. In other words, it is necessary to change the wall thickness of the partition member progressively from one end to another. Namely, the present inventors have found that when the partition member is disposed in the casting mold with the thicker wall end thereof located in the bottom of said mold, a portion of the partition member which is held in contact with the molten metal for the longest time during casting operation is thicker in wall thickness than the other portion, so that said portion of the partition member will not be molten and the solidification of the molten metal will take place with a positive temperature gradience. By forming concaves and convexes in the surface of the partition member, a mechanical connection can be produced simultaneously with the metallurgical connection. Where it is technically difficult to give a taper to the partition member or the operation of tapering the partition member requires large labor, a plurality of partition member sections, respectively having different wall thicknesses, may be arranged longitudinally and welded together. In this case, assembly of such partition member sections may be facilitated by making either the outer or inner diameter thereof same. In order to insure smooth flow of the shell-forming molten metal, it is preferable to make the inner diameter of the partition member uniform, while forming steps on the outer surface thereof. The space between the top end of the partition member and the inner surface of the mold should be reduced to minimum, so as to avoid excessive mixing of the shell-forming molten metal with the arbor-forming molten metal. As stated previously, to subject the partition member to a surface treatment so as to avoid the formation of an oxide film or to form a carbon film on the surface of the partition member is advantageous for facilitating the metallurgical connection among the partition member, the shell and the arbor. The experiments conducted by the present inventors have revealed that formation of a carbon film (includes graphite film) is most effective for this purpose.

The partition member must have a certain mechanical strength per se, to provide the connection between it, and the shell and the arbor, with a mechanical strength sufficient to withstand a stress applied thereto during rolling operation. In this view, the material of which the partition member is formed is preferably selected from the group consisting of plain carbon steel, low alloy steel and cast iron which have a tensile strength of about 30 kg./mm.^{2} or greater. Where it is desired to constitute the surface layer of the journal of a roll with the partition member, a high carbon steel excelling in wear resistance may be used for the formation of the partition member, and in this case, lowering of machinability becomes a problem. Such problem can be solved by employing the centrifugal casting method, however.

In practice, the compound cast roll according to the present invention is produced by setting a cylindrical partition member having a predetermined diameter in a casting mold, pouring a shell-forming molten metal of steel having excellent rolling properties into an annular space between the casting mold and the partition member and pouring a core-forming melt of steel or iron having high toughness into the hollow of the partition member.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view, partly in section, showing the appearance of a rolling mill roll according to the present invention;

FIG. 2 is a photograph showing a cross-sectional view taken along the line II—II of FIG. 1;

FIG. 3 is a microscopic photograph of the cross-section of FIG. 2, showing the structure at the border of the shell and the partition member;

FIG. 4 is a microscopic photograph, similar to FIG. 3, showing the structure at the border of the body portion and the partition member;

FIG. 5 is a perspective view showing in cross-section the construction of a mold used for practicing the present invention;

FIG. 6 is a transverse cross-sections view of a roll in which the partition member is extended over the journals thereof;

FIG. 7 is a diagram graphically showing the hardness distributions of a one body cast steel roll and a compound cast roll, relative to the distance from the roll surface;

FIG. 8 is a diagram graphically showing the forms of chromium carbides in relation to the amounts of chromium and carbon; and

FIGS. 9 to 19 are cross-sectional views showing the partition members used in the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

EXAMPLE 1

A compound cast roll for use as a back up roll, having a diameter of 1,250 mm., a total length of 4,300 mm., a roll body length of 1,500 mm., a shell thickness of 200 mm. and a partition member thickness of 25 mm. was produced.

The chemical compositions of the molten metals poured for the formation of the shell and arbor, and the chemical composition of the partition member, are shown in Table 1 below:

TABLE 1

	Chemical composition (percent by weight)									
	C	Si	Mn	P	S	Ni	Cr	Mo	V	Fe
Shell	0.52	0.81	0.65	0.020	0.011	1.42	4.60	0.91	0.23	Remainder.
Arbor	0.62	0.34	0.51	0.015	0.013	0.21	0.35			Do.
Partition member	0.21	0.38	0.58							Do.

FIG. 1 shows the appearance of the finished roll and the body portion of the roll has a cross-sectional structure as shown in FIG. 2 which is a transverse sectional view taken along the line II—II of FIG. 1. FIG. 3 is a microscopic photograph showing the structure at the border of the shell and the partition member, while FIG. 4 is a microscopic photograph showing the structure at the border of the partition member and the core, the magnification being 400 for both photographs. The roll was produced by the bottom casting method using the apparatus shown in FIG. 5.

Referring to FIG. 2, the shell 1 and the arbor 2 are connected through the intermediary of the partition member 3. The partition member 3 remains in its original shape even after completion of the casting and serves to prevent migration of the shell-forming molten metal and the core-forming molten metal. As may be seen in FIGS. 3 and 4, the shell and the partition member, and the arbor and the partition member, are metallurgically bonded with each other on their borders.

As shown in FIG. 5, the body of a mold, defining a cavity conforming to the shape of the roll, is provided with a riser gate 4 and the shell portion is composed of a metal mold 5, while the journal-forming portions are composed of sand molds 6. A down sprue 7 is provided for pouring a shell-forming molten metal into the space between the mold and the partition member, while another down sprue 8 is provided for pouring an arbor-forming molten metal into the hollow of the partition member.

Before pouring, the shell- and core-forming metals of the compositions shown in Table 1 were molten in an electric furnace, respectively. In casting, the shell-forming high alloy cast steel molten at 1,515° C. was first poured into the body of the mold through the down sprue 7 and the arbor-forming low alloy steel molten at 1,505° C. was concurrently poured into the cylindrical member, corresponding to the arbor 2, through the down sprue 8. Upon completion of the pouring, the respective metals poured were left to stand in the mold for 7 days for cooling and then removed from the mold upon completion of cooling. The temperature of the roll body portion at the time of removal was 110° C. After cutting the gates, the casting was machined to the dimensions mentioned earlier and thereafter the machined roll was heated to 1,050° C. at the rate of 25° C./hour, maintained at said temperature for 20 hours, cooled to 400° C., heated again to 830° C., maintained at that temperature for 20 hours, allowed to cool to 750° C. and maintained at that temperature for 20 hours. In the above process, the roll was heated to and maintained at 830° C. and 750° C. respectively for the purpose of homogenizing the structures of the shell 1 and the core 2, of deforming the carbides into spherical shape and of removing the casting stress.

Thereafter, the roll was again heated to 980° C. at the rate of 25° C./hour, maintained at that temperature for 10 hours, cooled to 400° C. rapidly in a period of 45 minutes and then cooled slowly to 300° C. The roll was again heated slowly to 550° C. at the rate of 20° C./hour, maintained at that temperature for 10 hours, left to stand in the atmosphere for 2 days, again heated and maintained at 550° C. for 10 hours and then subjected to furnace cooling. The rapid cooling from 980° C. and the slow cooling from 600° C. are the steps to effect normal quenching and tempering for imparting hardness and toughness to the shell.

The hardness of the shell was 70 to 75 in Shore hardness. The tensile strength of the shell was measured on a sample piece cut away from the shell, to find that the tensile strength was 150 to 180 kg./mm.^{2}. The tensile strength of the connection between the partition member, and the shell and the core, was about 15 to 25 kg./mm.^{2} which is sufficient to withstand the rolling conditions. It was also noted that no internal shrinkage nor internal crack was formed at the boundary between the shell and the partition member and between the core and the partition member, and that the compound cast roll thus produced was less inferior to a solid roll.

EXAMPLE 2

A compound cast roll for use as a blooming roll having a diameter of 1,200 mm., a total length of 6,500 mm., a body length of 2,400 mm., a shell thickness of 200 mm. and a partition member thickness of 30 mm. was produced, said partition member extending over the journals of the roll.

The chemical compositions of the molten metals poured for the formation of the shell and the core, and the chemical composition of the partition member, are shown in Table 2 below:

TABLE 2

	Chemical composition (percent by weight)									
	C	Si	Mn	P	S	Ni	Cr	Mo	V	Fe
Shell	0.41	0.45	0.70	0.020	0.009	0.60	5.15	1.00	0.30	Remainder.
Arbor	0.43	0.38	0.51	0.018	0.010					Do.
Partition member	0.73	0.40	0.53	0.020	0.010	0.10	0.20			Do.

The vertical cross-sectional view of the compound cast roll produced, after finishing, was as shown in FIG. 6. The production process is the same as described in Example 1. Namely, a partition member long enough to cover the journals of the roll was set in a mold at a location 200 mm. spaced from the inner surface of the mold portion corresponding to the body of roll, and then a shell-forming high alloy cast steel, molten at 1,520° C., was poured into a portion of the mold cavity corresponding to the shell and immediately thereafter a core-forming carbon steel, molten at 1505° C., was poured into the hollow of the partition member.

Upon completion of the pouring, the mold was left to stand for 7 days with the metals cast therein, to allow the cast roll to cool and then the cast roll was removed from the mold. The temperature of the roll removed from the mold was 100° C. at the body portion thereof. After cutting the gates, the cast roll was machined to the prescribed dimensions and the compound roll thus machined was heated to 1050° C. at the rate of 25° C./hour, maintained at that temperature for 20 hours, cooled to 400° C., heated again to 830° C., maintained at that temperature for 20 hours, cooled to 770° C., maintained at that temperature for 30 hours, again heated to 980° C. at the rate of 25° C./hour, maintained at that temperature for 10 hours, cooled rapidly to 400° C. in a period of 50 minutes and then cooled slowly to 300° C. Thereafter, the compound roll was slowly heated to 600° C. at the rate of 20° C./hour, maintained at that temperature for 10 hours, left to stand in the atmosphere for 2 days, again heated to 600° C., maintained at that temperature for 10 hours, cooled to 98° C. by furnace cooling, removed from the furnace and then allowed to cool to room temperature, whereby the roll was subjected to a heat treatment.

In FIG. 6 which shows a vertical cross-sectional view of the roll, reference numeral **8** designates the journal of the roll. As seen, the thickness of the portion of the partition member constituting the surface layer of the journal differs from the thickness of the remaining portion of the same covering the roll body portion, because the portion of the partition member at the journal was ground after the roll had been cast.

The compound roll thus produced showed a Shore hardness of 57 to 62 on the surface of the shell, a Shore hardness of 40 to 45 at the journals and a Shore hardness of 26 to 29 at the core. It has been verified that the shell and the journals shown sufficiently stable performances as a roll. It was also revealed that the shell and the partition member, and the core and the partition member were connected completely metallurgically, and no internal shrinkages were observed at the connections.

EXAMPLE 3

A compound cast roll adapted for use as a blooming roll and having a diameter of 1,200 mm., a total length of 6,000 mm., a roll body length of 2,000 mm., a shell thickness of 200 mm., and a partition member thickness and length of 25 mm. and 200 mm. respectively, was produced by the following process.

Namely, a partition member was set in a mold at a location 200 mm. spaced from the inner surface of the roll body-forming cavity of the mold and then a shell-forming high alloy cast steel, molten at 1,510° C., was poured into a portion of the cavity, corresponding to the shell of the roll, by down casting and successively thereafter a core-forming low alloy steel, molten at 1,500° C., was poured into a portion of the cavity corresponding to the core of the roll.

Upon completion of the pouring, the mold was left to stand for 7 days, with the metals cast therein, and then the cast roll was removed from the mold. After cutting the gates, the cast roll was machined to the prescribed dimensions, and then heated to 1,050° C. at the rate of 25° C./hour, maintained at that temperature for 20 hours, cooled to 400° C., heated again to 850° C., maintained at that temperature for 25 hours, and cooled by furnace cooling, to effect annealing of the roll for homogenization of the casting structure, deformation of carbides into spherical shape and removal of the casting stress. Then, the roll was again heated to 980° C., cooled 620° C. in air, maintained at that temperature for 40 hours and then cooled by furnace cooling, to effect quenching and tempering, whereby a necessary hardness and toughness were imparted to the shell.

It was found that the shell and the partition member, and the core and the partition member, in the thus produced compound cast roll for blooming, had been completely connected with each other metallurgically and that the roll was completely free of internal shrinkage or internal crack. The shell has a bainite structure and the surface hardness thereof was about 62 in Shore hardness. This hardness is extremely high as compared with the Shore hardness of 27 to 40 of the conventional blooming rolls. It was also accertained that the compound cast roll thus produced had excellent resistance against fire crack, wear and breakage. Table 3 below shows the chemical compositions of the shell, the core and the partition member.

TABLE 3

	Chemical composition (percent by weight)									
	C	Si	Mn	P	S	Ni	Cr	Mo	V	Fe
Shell	0.48	0.55	1.20	0.019	0.011	0.68	7.23	0.41	0.21	Remainder.
Arbor	0.61	0.36	0.61	0.015	0.009	0.18	0.38			Do.
Partition member	0.51	0.32	0.41	0.018	0.010	0.20	0.30	0.15		Do.

EXAMPLE 4

A back up roll adapted for use in hot rolling and having a diameter of 1,350 mm., a total length of 5,000 mm., a roll body length of 1,700 mm., a shell thickness of 230 mm., and a partition member thickness of 25 mm., was produced in the same manner as in Example 1.

After casting, the mold was left to stand for 9 days, with the cast metals therein, and then the cast roll was removed from the mold by breaking said mold. After cutting the gates, the cast roll was machined into the prescribed dimensions, and then heated to 1,050° C., maintained at that temperature for 30 hours, cooled to 400° C. in air, heated again to 830° C., maintained at that temperature for 30 hours and cooled by furnace cooling, whereby annealing of the roll was effected for homogenization of the casting structure, deformation of carbides into spherical shape and removal of the casting stress.

Then, the roll was again heated to 950° C., cooled in air to 560° C., maintained at that temperature for 60 hours and then cooled by furnace cooling. Upon examining the compound cast roll thus produced, it was found that the shell and the partition member, and the core and the partition member, had been completely connected with each other metallurgically, and no internal shrinkages nor internal cracks were found at the boundaries between the shell and core, and the partition member. The surface hardness of the shell was 65 or higher in Shore hardness as desired. The chemical compositions of the shell, the core and the partition member are shown in Table 4 below:

TABLE 4

	Chemical composition (percent by weight)									
	C	Si	Mn	P	S	Ni	Cr	Mo	V	Fe
Shell	0.89	0.33	0.61	0.020	0.013	0.68	4.32	0.81	0.19	Remainder.
Arbor	0.65	0.38	0.69	0.019	0.010	0.13	0.98	0.31		Do.
Partition member	0.28	0.31	0.40	0.020	0.010					Do.

EXAMPLE 5

A compound cast roll adapted for use as a work roll and having a diameter of 800 mm., a total length of 4,500 mm., a roll body length of 2,060 mm. and a shell thickness of 80 mm. was produced by the same casting process and heat-treating process as in Example 1.

The chemical compositions of the molten metals poured in the mold for the formation of the shell and the core, and the chemical composition of the partition member used, are shown in Table 5 below:

As contrasted, the compound cast roll according to the present invention has a surface hardness of 70 to higher in Shore hardness and the hardness does not substantially decrease up to a point 200 mm. from the roll surface, where the partition member is located. This is because the roll contains a large amount of elements, such as chromium, which have good heat-treatment property and according to the present invention it is possible to obtain a stable rolling performance constantly until the effective thickness of the roll is exhausted.

TABLE 5

	Chemical composition (percent by weight)									
	C	Si	Mn	P	S	Ni	Cr	Mo	V	Fe
Shell	0.60	0.80	0.50	0.013	0.010	0.20	11.20	0.80	0.30	Remainder.
Arbor	0.55	0.40	0.60	0.015	0.009	0.20	0.80	0.30		Do.
Partition member	0.12	0.30	0.30	0.020	0.013					Do.

The compound cast roll thus produced was completely free of internal shrinkage or internal crack, and the boundaries between the shell and the partition member and between the core and the partition member showed a complete metallurgical connection.

REFERRING EXAMPLE 1

A solid cast steel roll having the same diameter, total length and roll body length as those of the roll in Example 1 and containing the largest possible amount of alloy elements as allowed by the castability of the roll material into solid roll, was produced in the following manner:

Namely, first of all the cast steel, molten at 1,500° C., was poured into a mold having a shape conforming to the shape of the product roll by down casting and upon completion of the pouring the mold was left to stand for 7 days with the cast steel therein. After removing the cast roll from the mold, the gates were cut off and thereafter the roll was subjected to a heat treatment in the same manner as in Example 4. The chemical composition of the cast steel used is shown in Table 6 below:

TABLE 6

	Chemical composition (percent by weight)								
	C	Si	Mn	P	S	Ni	Cr	Mo	Fe
One body roll	0.50	0.50	0.50	0.014	0.010	0.50	2.20	0.30	Remainder.

FIG. 7 is a graph showing the hardness distributions of the compound cast roll obtained in Example 1 and the solid cast steel roll obtained in Control Example 1. The hardness distribution was obtained by measuring the hardness at various spots and the distances of the respective spots from the roll surface. As seen, the hardness distribution of each roll has a certain width because since, even when the distance is the same, the hardness was not the same at different spots of measurement, the measurements were taken 8 times in average at a spot and the maximum and the minimum values of hardness at the respective spots were plotted. From the chart of FIG. 7, it will be seen that the surface hardness of the solid cast steel roll is about 60 in Shore hardness, which is slightly low for the roll to be used as a back up roll but is sufficiently high for the roll to be used as a blooming roll and a work roll. This solid cast steel roll has a tendency that the hardness decreases rapidly with the radial distance and such tendency becomes particularly apparent from a distance of 70 mm. and onwards from the roll surface. Such a sharp decrease in hardness at a short distance from the roll surface is objectionable from the standpoint of performance of the roll for the following reason: Namely, supposing that the effective thickness of the roll is, say 100 mm., there should not be a substantial hardness decrease in said thickness because, if otherwise, the properties of the roll would vary as the rolling operation proceeds and the roll would be cracked or rapidly worn off before the effective thickness is exhausted even if the rolling operation is performed under the same conditions.

The properties required for the shell depend largely on chromium which has a good heat-treatment property and increases the hardness of the shell by forming a carbide. In this respect, it is desirable to use a high alloy cast steel, containing a large proportion of chromium, for the formation of the shell, but on the other hand, the amount of carbon is restricted which is an important element of the shell-forming cast steel having excellent rolling properties. Therefore, the content of chromium is inevitably subjected to a limitation. The present inventors conducted a study on the structure of chromium carbide with respect to the relative amounts of chromium and carbon, the result of which in FIG. 8.

The cast steel hitherto used for the production of a solid cast roll contains not more than 3 percent by weight of chromium and its structure consists of a mixture of α and $(Fe{\cdot}Cr)_3$. In a region defined by a line connecting a point representing 0.06 percent by weight of carbon and 2.0 percent by weight of chromium with a point representing 2.6 percent by weight of carbon and 4.5 percent by weight of chromium, and a line connecting said first point with a point representing 2.6 percent by weight of carbon and 22.0 percent by weight of chromium, the structure of the cast steel consists of a mixture of α, $(Fe{\cdot}Cr)_3C$ and $(Cr{\cdot}Fe)_7C_3$, and the amount of carbide formed is more than in the case when the chromium content is not more than 3 percent by weight. This substantiates the fact that the hardness of the cast steel increases with the amount of chromium.

Now, in a region wherein the amount of chromium is more than above-mentioned region and which is defined by a line connecting a point representing 0.06 percent by weight of carbon and 2.5 percent by weight of chromium with a point representing 2.6 percent by weight of carbon and 22.0 percent by weight of chromium, a line connecting said first point with a point representing 0.02 percent by weight of carbon and 10.0 percent by weight of chromium, a line connecting said second point with a point representing 2.6 percent by weight of carbon and 30.0 percent by weight of chromium, the structure of the cast steel consists of a mixture of α and $(Cr{\cdot}Fe)_7C_3$, and the amount of chromium carbide formed further increases. When the amount of chromium is further increased, $(Cr{\cdot}Fe)_4$b83 comes to be formed, rendering the cast steel extremely fragile. In addition, the castability of the steel is degraded and the toughness of the same is reduced, with the result that the steel cannot be used for the production of a roll.

The present inventors conducted a further study to determined a region wherein the amount of chromium carbide can be increased without jeopardizing the castability of the steel, and found that the one defined by a line connecting a point A representing 0.2 percent by weight of carbon and 3.0 percent by weight of chromium with a point B representing 0.2 percent by weight of carbon and 8.0 percent by weight of chromium, a line connecting said point B with a point C representing 1.6 percent by weight of carbon and 20.0 percent by weight of chromium, a line connecting said point C with a point D representing 2.6 percent by weight of carbon and 20.0 percent by weight of chromium, a line connecting said point D with a point E representing 2.6 percent by weight of carbon and 4.2 percent by weight of chromium, and a line connecting said point E with said point A, is most preferable. Namely, in case of a composition falling in a region above the line BCD in FIG. 8, not only does Cr form a carbide with C but also a large amount of Cr is dissolved in the matrix, rendering the matrix itself fragile. Further, in case of a composition falling in a region on the right side of the line DE, the amount of carbide formed so large that the steel becomes fragile and cannot be used for the production of a roll. For the reasons set out above, the composition range of the steel which can be used for roll is naturally limited.

The partition member used in the present invention may be provided in the shapes shown in FIGS. **9** to **16**. A partition member shown in FIG. **9** is in the shape of a jointless cylinder of uniform wall thickness and can be produced simply as by centrifugal casting method. A partition member shown in FIG. **10** has a cylindrical inner surface of uniform diameter and a tapered outer surface, and can also be produced simply as by centrifugal casting method. A partition member shown in FIG. **11** has a cylindrical inner and outer surfaces of uniform diameter and consists of a plurality of sections connected with each other by welding. A partition member shown in FIG. **12** has welded joints, not in a longitudinal direction but in a circumferential direction thereof. A partition member shown in FIG. **13** consists of a plurality of sections connected together into a unitary piece by welding, which sections are uniform in inner diameter but different in outer diameter. A partition member shown in FIG. **14** consists of a plurality of sections connected together into a unitary piece by welding, which sections are substantially uniform in wall thickness but different in inner and outer diameters. A partition member shown in FIG. **15** consists of a plurality of sections connected with each other by welding into a unitary piece, which sections have parallel inner and outer surfaces but are different in inner and outer diameters, the outer diameter becoming larger as the inner diameter becomes smaller. A partition member shown in FIG. **16** consists of a plurality of sections connected together into a unitary piece by welding, which sections have a uniform outer diameter but different inner diameters. A partition member shown in FIG. **17** has a plurality of peripheral grooves formed in the outer surface thereof so as to produce a mechanical connection in addition to a metallurgical connection. As a modification, a partition member having such grooves formed in the inner surface or in both the inner and outer surfaces may also effectively be used.

The principle of the present invention can of course be applied to a roll, such as a die steel roll, which has a concavo-convex surface. In this case, the partition member may simply be incorporated in the roll in a manner as shown in FIG. **18**, without excerting a special ingenuity, as the effective roll thickness is experientially known to be several millimeters from the roll surface. FIG. **19** shows a partition member having a flared top end which is effective for preventing excessive migration of the shell-forming molten metal and the core-forming molten metal into each other through a space between the partition member and the mold surface.

We claim:

1. A method of producing a compound cast roll with an outer metal shell having excellent rolling properties and a metal core having excellent toughness, comprising the steps of placing a cylindrical partition member having a predetermined diameter in a casting mold, the length of the partition member being approximately equal to that of said shell; pouring a shell-forming molten metal into an annular space between said partition member and said mold; pouring a core-forming molten metal into an interior space formed by said partition member; forming the resultant casting into a desired roll shape by machining and subjecting the formed roll to a heat-treatment operation for imparting the desired rolling properties to the shell and the desired toughness to the core, said partition member having a wall thickness that is reduced from the lower end adjacent the bottom of the mold toward the upper end adjacent the top of the mold whereby solidification of the molten shell-forming and core-forming metals takes place under a positive temperature gradient.

2. A method of producing a compound cast roll as defined in claim **1**, in which said partition member is set in the mold in such a manner that the shell formed will have a thickness 1.1 to 3 times the available thickness of the roll.

3. A method of producing a compound cast roll as defined in claim **1**, in which said partition member has a flared portion at its upper end to reduce the space between said partition member and said mold, whereby excessive migration of said shell-forming molten metal and said core-forming molten metal into each other is prevented.

4. A method of producing a compound cast roll as defined in claim **1**, in which said partition member has a carbon film formed on the surface thereof.

5. A method of producing a compound cast roll as defined in claim **1**, in which said partition member consists of a plurality of sections connected into a unitary structure by welding.

6. A method of producing a compound cast roll as defined in claim **1**, in which said partition member is a centrifugally cast tube.

7. A method of producing a compound cast roll as defined in claim **1**, in which the wall thickness of said partition member at the lower portion thereof is so selected that said lower portion of the partition member may not be deformed or melted away during the steps of pouring the shell-forming and core-forming metals into said mold.

8. A method of producing a compound cast roll as defined in claim **1**, in which the predetermined diameter and the wall thickness are so selected that the proportion of the cross-sectional area of said partition member to the cross-sectional area of the entire compound cast roll is 2 to 15 percent.

9. A method of producing a compound cast roll as defined in claim **1**, in which said partition member prevents migration of the shell-forming molten metal into the core-forming molten metal and provides a metallurgical bond between said molten metals.

10. A method of producing a compound cast roll as defined in claim **1**, in which said shell-forming cast steel comprises carbon, chromium, other alloy elements as required and iron, the amounts of carbon and chromium falling within a range which is defined, in an orthogonal coordinate system having the ordinate axis scaled by the amount of chromium and the abscissa axis scaled by the amount of carbon, by a line connecting a point A representing 0.2 percent by weight of carbon and 3.0 percent by weight of chromium with a point B representing 0.2 percent by weight of carbon and 8.0 percent by weight of chromium, a line connecting point B with a point C representing 1.6 percent by weight of carbon and 20.0 percent by weight of chromium, a line connecting point C with a point D representing 2.6 percent by weight of carbon and 20.0 percent by weight of chromium, a line connecting point D with a point E representing 2.6 percent by weight of carbon and 4.2 percent by weight of chromium, and a line connecting point E with point A, said core-forming metal being a metal selected from the group consisting of low alloy steel, plain cast iron and plain carbon steel.

11. A method of producing a compound cast roll as defined in claim **1**, in which said heat-treatment operation includes annealing of the roll for homogenization of the structure, deformation of carbides into spherical shape and removal of the casting stresses.

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