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(54) **Centrifugally cast roll for last finishing stands in hot strip mills**

(57) The invention relates to a process for producing a centrifugally cast composite roll intended for last finishing stands in hot strip mills and its shell composition composed of (weight %); C: 2.5-4.0%, Nb: 1.1-6.0%, V: 0.7-3.0, Ni: 4.2-4.6%, Mo:0.3-1.3%, Cr: 1.5-2.2%, Si: 0.7-1.6%, Mn:0.7-1.0%, Zr: 3% or less, Ti: 3% or less, P: 0.08% or less, S: 0.08% or less and balance with Fe and unavoidable impurities and its use.

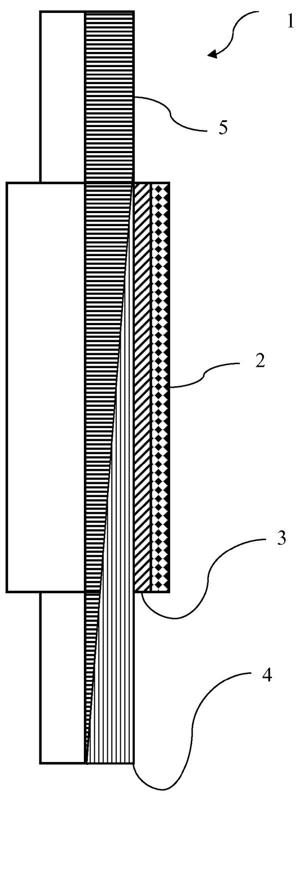

Figure 1

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Description

FIELD OF THE INVENTION

[0001] The invention relates to a process for producing a centrifugally cast composite roll intended for last finishing stands in hot strip mills having surface properties, oxidation properties and wear resistance that are highly desirable for use in the hot rolling of steel. The present invention also relates to a method for producing such a roll.

BACKGROUND OF THE INVENTION

[0002] In the continuous hot rolling of steel strip, a continuously moving steel workpiece (the strip) is passed through a rolling mill which commonly consists of several stands of rolls arranged in a straight line (in tandem) or reversing (steckel). The strip cools as it passes through the rolling mill, such that each succeeding stand is at a lower temperature than its predecessor stand. Typically, when the strip reaches the rolls of the last few mill stands there is a tendency of the strip to stick to the rolls through which it passes because of the lower temperature of the roll. The results of such behavior can be a catastrophic failure of the rolling process which may cause damages to the rolling mill stands and surrounding structures, not to mention the grave threat to workers in the area.

[0003] It is evident, therefore, that the selection of the proper grade of roll to be used in the latter stands of tandem style rolling mills is important. The problem of roll selection is complicated by the fact that mill conditions vary widely, but in general the finishing rolls on a tandem hot mill should have an outer skin which is dense and hard, and yet provide sufficiently low friction in the areas that contact the work piece.

[0004] It is known in general that a harder roll has higher wear resistance. Vanadium and Niobium is known to form extremely hard MC carbides and it is also known that these carbides tend to segregate during centrifugal casting.

Specific background

[0005] There is a need for a roll intended for last finishing stands with improved roll performance and which allows longer rolling campaigns and which has further improved hardness and wear resistance but still with high reliability, superior surface properties and with optimal oxidation properties. Oxidation properties are of great importance in late finishing stands. There is also a need of a production method for such a roll.

RELATED ART

[0006] WO96/39544 discloses an IC roll alloy composition with Niobium and a method of producing such a roll.

[0007] EP 0559899 A1 discloses a material of outer layer of the roll for rolling containing the following elements at respective ratio: C: 1.5-3.5 %; Si: 1.5 % or under; Mn: 1.2 % or under; Cr: 5.5-12.0 %; Mo: 2.0-8.0 %; V; 3.0-10.0 %; and Nb: 0.6-7.0 %, on condition that the following formulas: $V + 1.8\ Nb \leq 7.5\ C - 6.0$ (%) and $0.2 \leq Nb/V \leq 0.8$ must be satisfied and, further, containing Fe and irremovable impurities as the remainder. This invention solves the problem of providing a roll shell composition and a centrifugal cast composite roll which has excellent wear resistance and crack resistance without any segregation even when productive and cost advantageous centrifugal casting method is employed by optimizing chemical compositions of the shell composition and controlling composition of proeutectic carbide.

[0008] EP O 560 210 Al discloses a roll which provides a compound roll having a shell portion having a fine metal structure with excellent uniformity.

[0009] US 2009/0092852 Al discloses a roll comprising vanadium which is developed to have high amounts of carbides in the outer layer. A centrifugally cast composite roll comprising an outer layer having a composition comprising by mass 2.5-9 % of C, 0.1-3.5 % of Si, 0.1-3.5 % of Mn, and 11-40 % of V, the balance being Fe and inevitable impurities.

[0010] Other prior art disclosing rolls with Vanadium and/or Niobium are;

[0011] Development of New type of IC double poured cast iron work roll with higher wear resistance, author; Hajime Morikawa, abstract presented at University de Liége, by Material and R&D department Hirakata Plant, Kubota. Published at conference: Abrasion 2011.

[0012] WO9314931, US5403670, EP593408A1, EP1975265, EP560210 A1, US5484372, JP11043735, JP2005232519, US2009/0092852 A1, EP00665068 A1.

OBJECT OF THE INVENTION

[0013] One object of the invention is to find a roll with improved wear resistance and improved surface properties. Another object is to provide a centrifugally cast composite roll comprising an outer layer containing a large amount of uniformly dispersed MC carbide, thereby exhibiting excellent wear resistance, surface roughening resistance and crack propagation resistance, as well as excellent spalling resistance.

[0014] Another object of the invention is to find a roll suitable for last finishing stands with special surface properties and also improved crack resistance compared to rolls suitable for earlier finishing stands.

[0015] Further, an object of the invention is to find a roll with a high quality which is crucial for rolls suitable for last finishing stands with optimal oxidation properties is also desired in combination with improved wear resistance.

[0016] There is a need for a roll which decreases the number of roll changes that has to be made when using such roll in the last finishing stands in the hot strip mill.

[0017] The objects if the invention is fulfilled with the invention described in claim 1.

FIGURES

[0018]

Figure 1 shows an exemplifying embodiment of the casting sequence according to the invention

Figure 2 shows an exemplifying embodiment of how the basic principle of an analysis of three different scenarios of a thermal test sample.

Figure 3 shows an exemplifying embodiment of hardness of the roll according to the invention relative to the surface distance and comparison with a comparative roll.

Figure 4 shows an exemplifying embodiment of accumulated performance of the roll according to the invention and in comparison with a comparative roll.

Figure 5 shows an exemplifying embodiment of oxidation behavior of the roll according to the invention and in comparison with a comparative roll.

Figure 6 shows an exemplifying embodiment of a comparative study comparing thermal expansion of a roll according to the invention and a comparative roll.

Figure 7 shows an exemplifying embodiment of particle size distribution in the roll according to the invention and a comparative roll.

Figure 8 shows an exemplifying embodiment of the micro structure in the shell material of a roll according to the invention.

Figure 9 shows an exemplifying embodiment of the distribution of hard particles along the shell depth of the roll according to the invention.

SUMMARY OF THE INVENTION

[0019] The invention relates to a process for producing a centrifugally cast composite roll intended for last finishing stands in hot strip mills and its shell composition composed of (weight %); C: 2.5-4.0%, Nb: 1.1-6.0%, V: 0.7-3.0, Ni: 4.2-4.6%, Mo:0.3-1.3%, Cr: 1.5-2.2%, Si: 0.7-1.6%, Mn:0.7-1.0%, Zr: 3% or less, Ti: 3% or less, P: 0.08% or less, S: 0.08% or less and balance with Fe and unavoidable impurities and the produced roll and its use.

[0020] Further the invention comprises the following alternatives and combinations.

[0021] A shell composition for a roll according to the invention wherein the composition further satisfies the following formulae:

$$(V + Mo) / Nb \geq 0.35$$

[0022] A shell composition for a roll according to the invention wherein the composition further satisfies the following formulae:

$$0.95 \leq Mo / V \leq 1.16$$

[0023] A shell composition for a roll according to to the invention wherein the composition further satisfies the following formulae:

$$0.69 \leq V/ Nb \leq 0.84$$

[0024] A shell composition for a roll according to the invention wherein the composition further satisfies the following formulae:

a relationship between Carbon/Silicon and the carbide forming elements; Mo, Cr, V and Nb, elements comprised in the composition according to the invention and
expressed in weight %:

$$A = 52{*}Cr + 96{*}Mo + 51{*}V + 93{*}Nb \text{ and } B = 12{*}C + 4{*}Si$$

The following relationship must be maintained: 8.0 < A/B < 8.8 or for example

$$8.0675 < A/B < 8.7699.$$

[0025] A centrifugal cast roll formed with a shell composition according to the invention 1-6 and a core selected from nodular cast iron and wherein the shell composition comprises 1-5 area % or 0.5-3-2 area % of graphite.

[0026] A centrifugal cast roll according to the invention formed with a shell composition according to any of the claims 1-6 and a core and wherein the shell composition comprises 2-3 % of MC carbides with a particle size of 7-35 μm.

[0027] A centrifugal cast roll according to the invention formed with a shell composition according to any of the claims 1-6 and a core and wherein the shell composition comprises MC carbides and wherein at least 65 % of said MC carbides have a particle size larger than 8 μm or wherein at least 65 % of said MC carbides have a particle size larger than 9 μm and is evenly spread within the shell material.

[0028] A centrifugal cast roll according to the invention formed with a shell composition according to any of the claims 1-6 and a core selected from nodular iron and wherein the shell composition has oxidation kinetics measured at 900 seconds of 2-7 mg/cm^2 or 3.4-4.5 mg/cm^2 or 7 mg/cm^2 or less or 4 mg/cm^2.

[0029] A centrifugal cast roll according to to the invention formed with a shell composition according to any of the claims 1-6 and a core and wherein the shell composition comprises 25-30 area % of cementite (200) and a total amount of 60-70 area % of bainite (202), martensite (204) and some residual austenite.

[0030] A centrifugal cast roll according to the invention formed with a shell composition according to any of the claims 1-6 wherein the roll according to the invention 1 has a density between 7400 and 7500 kg/m3 or wherein the Young modulus is around 170-190 GPa or wherein the tensile strength is between 375-475 MPa or 375 MPa or wherein the thermal conductivity is 18-22 W/mK or 20 W/mK or wherein the specific heat is 495-505 J/kgK or 500 J/kgK.

[0031] A centrifugal cast roll according to the invention formed with a shell composition according to any of the claims 1-6 and a core selected from nodular iron and wherein the shell composition has a hardness drop of 0.5-1,5 ShC per 10 mm shell depth.

[0032] A production method for a centrifugal cast roll according to the invention comprising the shell composition of any of claims 1-6, comprising the steps of;

a) providing a roll shell composition according to the invention and
b) produce a molten batch comprising the shell composition according to the invention casting the molten batch comprising the shell composition according to the invention
c) casting another molten batch of core composition to form a roll according to the invention

[0033] A production method for a centrifugal cast roll according to the invention comprising the shell composition to the invention, comprising the steps to the invention and wherein the core material is nodular iron.

[0034] A production method for a centrifugal cast roll according to the invention comprising the composition according to the invention and wherein the production of said molten batch involves controlling melt inoculation by testing that said molten batch has a temperature increase during solidification which is 3-50°C above the liquidus temperature of said batch.

[0035] A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, comprising roll according to the invention and wherein said testing is performed at a temperature of 1500-1520 °C of the melt.

[0036] A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, wherein the casting of the shell composition is performed at a centrifugal force of 110-130G or at 120G.

[0037] A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, and wherein the casting of the shell composition further comprises a step of applying flux material in 7-20 l/m^2 thickness on the inner part of the shell composition (106) which gives the roll a protective surface during casting of the core.

[0038] A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, and wherein the production method further comprising a tempering step performed by selecting a combination of hardness and residual austenite obtained optimum condition in the temperature range of 450-600 °C .

[0039] A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, comprising and wherein the casting of the shell composition further comprises a step of applying flux material in 5-12 l/m^2 or 7-8 l/m^2 thickness on the inner part of the shell composition (106) which gives the roll a protective surface during casting of the core.

[0040] A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, and wherein the shell composition (2) in the casted roll has a thickness of 6-12% of the roll diameter.

[0041] A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, wherein the method further comprising a solidification step and wherein the average solidification rate of the casted roll is 2-3mm/min A production method for a centrifugal cast roll according to the invention comprising the shell composition according to the invention, wherein the tempering of the roll shall be performed twice at a tempering temperature, TA, in the interval of 450-475 °C, or at 450 °C, during a retention time of 10-305 h with intermediate cooling to room temperature.

[0042] Use of a centrifugal cast roll according to the invention in a hot rolling mill in the late finishing stands.

[0043] Use of a centrifugal cast roll according to the invention in a hot rolling mill in the last finishing stands.

DETAILED DESCRIPTION OF THE INVENTION

[0044] A centrifugal cast roll and its shell composition are disclosed. The roll with the shell composition according to the invention may be used in steel hot rolling applications in steckel and late finishing stands of hot strip mills for example suitable for last finishing stands.

[0045] The benefit of the roll according to the invention is that it allows longer rolling campaigns due to its improved wear resistance. This is achieved without compromising on its reliability and surface properties. This grade can be implemented in the mill without any changes in rolling parameters compared to standard or enhanced IC rolls.

[0046] The roll according to the invention is a roll suitable for last finishing stands. Last finishing stands need to have special surface properties and also improved crack resistance compared to rolls suitable for earlier finishing stands. The quality is crucial for rolls suitable for last finishing stands and there is a need for improving work performance and wear resistance to be able to improve the productivity in the mill. Optimal oxidation properties are also desired in combination with improved wear resistance. There is a need for a roll which decreases the number of roll changes in the last finishing stands in the mill.

ALLOY COMPOSITION ACCORDING TO THE INVENTION

[0047] As used herein, the term "shell composition" shall mean an iron-based alloy intended for use in centrifugal casting the shell of a rolling mill roll and generally having a composition comprising (in weight %);

Table 1

Element	Weight %
Carbon (C)	2.5 - 4.0
Niobium (Nb)	1.1 - 6.0
Vanadium (V)	0.7 - 3.0
Nickel (Ni)	4.2 - 4.6
Molybdenum (Mo)	0.3 - 1.3

(continued)

Element	Weight %
Chromium (Cr)	1.5 - 2.2
Silicon (Si)	0.7 - 1.6
Manganese (Mn)	0.7 - 1.0
Phosphorus (P)	< 0.08
Sulfur (S)	< 0.08
Titanium (Ti)	< 3
Zirconium (Zr)	< 3
Iron (Fe) & impurities	Balance

[0048] The shell of the centrifugal cast roll according to the invention comprises the shell composition and has a microstructure after casting that comprises MC carbides with a particle size between 7-35 μm in 2-3 area fraction %, where at least 65% of said carbides have a particle size larger than 9 μm or for example wherein less than 35% of the said carbides have a smaller size 9μm. which gives the roll according to the invention improved wear and abrasion resistance.

[0049] The skilled practitioner will appreciate that minor changes to the elemental ranges in the shell composition and also substitution of comparably active elements can be made to the indefinite chill roll composition, while maintaining the desired properties characteristic of said shell compositions containing MC carbides with a particle size between 7-35 μm in 2-3 area fraction %.

<u>Below is reasoning for the limitation of the alloying elements in the present invention:</u>

Carbon: 2.5 - 4.0 %

[0050] C is an element for increasing for example hardness, and wear resistance in the roll material because it forms a hard carbide and is therefore required 2.5 %, preferably 3.3 % or more. The crack resistance of the roll is however significantly lowered with a carbon content exceeding 4.0 %. Therefore, 4.0 % is set as the upper limit. A preferred range is 3.3 - 3.8 % and even more preferred 3.4-3.8 %.

Silicon: 0.7-1.6 %

[0051] Si is a deoxidation agent. Si is an element necessary to maintain the casting ability, therefore 0.7% is set as lower limit. When the Si content is exceeding 1.6 % the crack resistance is not as effective and Si in larger quantities may promote defective graphite shapes in the structure. Si increases the carbon activity and promote carbide formation. A preferred range is 0,9-1.6%, and even more preferred 1.1-1.5 %.

Manganese: 0.7-1.0 %

[0052] Mn is necessary for the same purpose to Si. The lower limit is chosen due to the fact that it promotes phase transformations occurring during heat treatment. However, it is not desirable to contain Mn in the content exceeding 1.0 % for lowering of the crack resistance. Therefore, 1.0 % is set as the upper limit. A preferred range is 0.8-1-0%.

Chromium: 1.5 - 2.2 %

[0053] Cr is an essential element for a number of properties in the material but most important is to control the oxidation behavior in the material. Cr decreases the tendency of carbon to solidify as graphite. A preferred range is 1.6-2.2 %.

Molybdenum: 0.3 % - 1.3 %

[0054] Mo is effective for forming the carbide and increasing wear resistance similarly to Cr, and, in addition, effective for strengthening the matrix by increasing hardenability. Therefore, Mo is added in the content of 0.3 %, preferably 0,5 % or more. However, when Mo content exceeds 1.3 %, the crack resistance is lowered. Therefore, 1.3% is set as the upper limit. A preferred range is 0.5-1.3, %, and even more preferred 0.7-1.2 %.

Nickel: 4.2-4.6 %

[0055] Ni is effective for promoting the phase transformation in the material matrix during cooling. The lower limit is chosen in order to avoid precipitation of unfavorable phases such as pearlite. Therefore, the lower amount is set to 4.2 %, preferably 4.3 %. Ni serves for example for increasing the hardenability and strength of the matrix. It is though undesirable to contain Ni in a content exceeding 4.6 % for formation of unstable structure, such as retained austenite. Therefore, 4.6 % is set as the upper limit. A preferred range is 4.3-4.6 % and even more preferred 4.4-4.6 %

Ti: 3.0 % or less, Zr: 3.0 % or less

[0056] Ti and Zr are optional elements and may be added to suppress formation of large eutectic carbide and to improve wear resistance and crack resistance. However, when the contents of Ti and Zr exceed 3.0 %, it may deteriorate configuration of composite carbide of V and Nb and conversely lower the wear resistance. Therefore, the upper limits of Ti and Zr are respectively set at 3.0 %. Preferably, Ti and Z are only present as not intentionally added and are only present as unavoidable residuals from the raw material.

V: 0.7-3.0 % or 0.8-3.0 % Nb: 1.1-6.0 %

[0057] V and Nb are important elements in the present invention together with Mo. The combined addition of these elements in the composition and conditions for their relations limits therefore important features of the invention.

[0058] The composition according to the present invention may for example satisfy at least one of the following formulas:

$$(1001) \quad (V + Mo) / Nb \geq 0{,}35$$

$$(1002) \quad 0.95 \leq Mo / V \leq 1.16$$

$$(1003) \quad 0.69 \leq V/Nb \leq 0.84$$

[0059] V is an essential element for forming MC or M4 C3 carbides which are the most effective carbides for increasing the wear resistance. In order to attain the effect, it is required to be added in the content of 0.8 % or more. However, if it exceeds 3.0 %, the material becomes excessively brittle and difficult to handle. Therefore, the upper limit is set at 3.0 %. A preferred range is 0.8-1.2 %, and even more preferred 0.8-1.1 %.

[0060] Nb also forms MC carbide similarly to V, which is effective for increasing the wear resistance. However, when Nb is solely added, it forms large size carbide block that due to its size and density tend to segregate towards the outer periphery making impossible to obtain an even distribution. Therefore, Nb shall be added in combination with V in order to provide a desired carbide distribution.

[0061] Further, the graphite to carbide ratio may be regulated by Nb. A preferred range is 1.1-1.4 %, and even more preferred 1.2-1.4 %.

[0062] Phosphorus < 0.08 %, should be kept as low as possible.

[0063] Sulphur< 0.08 %, should be kept as low as possible.

[0064] The composition according to the present invention may for example satisfy the following formulae in order to get the desired balance between hard wear resistant carbides and a tough matrix. The following relation between Carbon/ Silicon and the carbide forming elements (Mo, Cr, V and Nb) is preferred:

$$A = 52{*}Cr + 96{*}Mo + 51{*}V + 93{*}Nb \text{ and } B = 12{*}C + 4{*}Si \quad (1004)$$

[0065] The following relation is preferably maintained:

8.0 < A/B < 8.8 or for example 8.0675 < A/B < 8.7699.

MICROSTRUCTURE

[0066] By using the shell composition in an IC roll results in a shell containing MC carbides which are homogenously distributed in the matrix of the roll shell. The shell composition in the roll according to the invention comprises 2.-3 area % of MC carbides having a particle size between 7- 35 μm, M being mainly V and Nb, and some Mo. The MC carbides with particle size between 7- 35 μm gives the roll according to the invention improved wear and abrasion resistance. Occasional Mo-rich M2C carbides were also observed, which also contained some Nb and V. A comparison of the particle size distribution of the MC carbides in an IC roll according to the invention and a comparative roll is seen in figure 7 and it is seen that the amount of carbides having maximum size of 6 μm has been reduced in favour for higher amounts of carbides having larger sizes. Hereby, an improved distribution over the shell depth is achieved which results in better roll performance and increased lifespan. The composition of the comparative roll 12 is seen in Table 2 in this patent. The comparative roll 12 is also further disclosed in patent WO96/39544.

[0067] The shell of a roll made from the shell composition according to the invention further has a matrix having an even distribution of 25-30 area % of cementite 200 and a total amount of 60-70 area % of bainite 202 and martensite 204 and some residual austenite, see figure 8. Figure 8 shows the micro structure in the shell material of a roll according to the invention, the light dots are MC carbides 206 and the deep black pattern are graphite 208 darker gray pattern is cementite 200 and lighter grey pattern is bainitic 202 and martensitic 204 matrix. The bainite and martensite balance is controlled so that the amount of martensite is larger than the amount of bainite in order to reduce the amount of retained austenite, which is undesired since roll performance is deteriorated. The shell of an IC roll made from the shell composition according to the invention further contains 2.0-3.0 area % MC carbides 206 and 0,5-3 area % graphite 208 homogenously distributed in the matrix 210. The microstructure in the shell of the roll according to the invention is showed in figure 13. The composition of the comparative roll 12 is evident from Table 2. The comparative roll 12 is also further disclosed in patent WO96/39544.

Table 2

Elements in comparative roll (roll disclosed in patent WO96/39544)	Weight %
Carbon (C)	3.3-3.7
Niobium (Nb)	0-5.82
Nickel (Ni)	4.5-4.6
Molybdenum (Mo)	0.4 - 0.5
Chromium (Cr)	1.9- 2.0
Silicon (Si)	0.7 - 0.8
Manganese (Mn)	0.9 - 1.0
Phosphorus (P)	0.03-0.04
Sulfur (S)	0.05-0.06
Iron (Fe) & impurities	balance

Preparation method of the IC roll according to the invention

[0068] The present invention further includes a centrifugally casted IC roll formed from the shell composition alloy according to the invention produced by a method according to the invention including several steps:

(i) providing an indefinite chill roll shell composition according to the invention, and
(ii) adjusting said shell composition in the melting furnace; and
(iii) centrifugally casting the molten batch of shell composition to form the shell of the roll according to the invention; and
(iv) casting at least one molten batch of a core composition to form the core part of the roll; and
(v) cooling the roll in the casting mould, thereby obtaining a hardening of the roll shell; and
(vi) tempering the formed roll.

[0069] The roll according to the invention is prepared in several steps using centrifugal casting technique. The shell material in the roll according to the invention is the outermost 6-12% of the total roll diameter. The rest of the roll comprises of core material for example nodular iron.

[0070] The product is manufactured by centrifugal casting. Prior to the actual casting the melting and alloying procedure is performed in order to achieve the optimal balance between the different phases present in the shell material. One feature in the new material is the increased amount of hard particles, i.e. more carbides having larger sizes (see figure 7). Additionally, the hard particles are more homogenously distributed long the shell depth. Another feature is that the material shows a more even distribution of the different phases in the matrix (cementite, graphite and bainite/martensite) long the shell depth. A controlled balance between martensite and bainite is also beneficial for the properties of the roll shell. Yet another feature is an increased hardness of the shell material. The fundamental properties such as overall hardness are determined by the balance between cementite and graphite. This balance is controlled by the casting procedure.

[0071] The microstructure is controlled by adjusting the level of inoculation in the melt. Additionally, by carefully controlling the tapping temperature a roll having improved shell properties is obtained. For the shell material, the tapping temperature is 150-300 degrees above the material liquidus temperature. Moreover, the tapping sequence is further carefully timed to specified set points between the different parts of the roll. The processing of the blank consists of a heat treatment where the temperature and holding times have been selected in order to obtain high toughness and stability in the matrix as well as a low residual stress level.

[0072] The size distribution of the hard particles in the shell material 2 determines its wear resistance. In the roll according to the invention a modification of the size has been achieved without compromising its distribution long the shell depth. The matrix in the shell of the roll 1 according to the invention consists of similar amounts of the existing phases in as in a comparative roll (see Table 2). However the matrix hardness is approximately 20% higher in the roll according to the invention compared to the comparative roll (which roll composition is described in Table 2).

<u>Preparation of the shell composition according to the invention while controlling inoculation according to the process according to the invention:</u>

[0073] The casting sequence is described in relation to figure 1. The roll comprises mainly two parts: a core and a shell. The shell 2 comprising the shell composition according to the invention is tapped first. The shell 2 is prepared using a casting pipe and is cast at a high rotational speed. The rotational speed is selected depending on the size of the roll and the diameter of the roll in order to obtain a force of gravitation of approximately 100-150 G, which is required for obtaining an even thickness of the roll shell. The shell 2 is allowed to solidify and the temperature of the solidified shell 2 is allowed to cool to a certain temperature. The core is then tapped in three steps with intermediate solidification and cooling while forming three core parts. The different parts may be seen in figure 1; the roll bottom core part 4, a top-neck core part 5, and an outer core part 3 and the shell 2.

[0074] Casting sequence of the roll according to the invention:

1. Casting of shell (2)

2. Casting of outer core part (3)

3. Casting of roll bottom core part (4)

4. Casting of top-neck core part (5)

[0075] The casting of the outer shell and the core is made by casting in sequence from two (or more) different furnaces. The casting from the different furnaces is controlled by controlling a set point (500) and the tapping into the casting ladle from the different furnaces is timed so that the casting of the core starts when the shell 2 has a desired temperature in order to avoid undesired remelting of the shell but still allow sufficient bonding between the core and the shell. When the shell temperature reaches the desired setpoint, casting of outer core part 3 of the core starts. Tapping of the bottom core part 4 into the casting ladle starts before the setpoint for the outer core part 3 is reached so that casting of the roll bottom core part 4 may start when the setpoint is reached. Casting of the top-neck core part 5 is controlled in an analogous manner. The set point timing depends on thickness of core and heating capacity of the material.

[0076] The present invention includes an enhanced roll produced by a method comprising, but not limited to the following steps:

(i) providing an steel melt having a composition according to the invention

(ii) casting the molten batch of shell composition according to the invention, and

(iii) casting at least one, preferably at least two other molten batches of core composition to form a bottom core part

4, a top-neck core part 5 and optionally an outer core part 3 to achieve a roll according to the invention.

[0077] In another embodiment, the present invention includes a roll produced by a method comprising the following steps:

(i) providing a roll shell composition according to the invention, and

(ii) adding Niobium in the induction furnace at a temperature of 1400-1600 °C, a temperature where all Niobium is dissolved, and in an amount sufficient to produce a molten batch containing 1.1 to 6.0% niobium based on the total weight of said molten shell batch, providing a stoichiometric amount of excess carbon to form niobium carbide. The molten batch is kept at this temperature for 10-60 minutes or until an analysis of the molten metal indicates that the niobium content is within the specification and

(iii) Controlling the chemical composition of the molten shell batch at a temperature between 1400-1500°C,

(iv) Optionally adjusting the content of alloying elements except Niobium (xi) Performing a thermal analysis test for indication of the hardness of the roll shell by checking behavior of cooling curve for a test sample taken from the molten shell batch at a temperature between 1500-1520 °C, optionally adjusting the behavior of the cooling curve so that the temperature increase during solidification does not deviate more than 50°C from the aimed liquidus temperature by adjusting the molten shell batch composition by adding elements selected from Cr, C, Si depending on test results.

(v) Casting the molten shell batch at a centrifugal force of 110-130G and allowing it to solidify,

(vi) Casting a molten batch of core composition using for example nodular cast iron or gray cast iron or ductile cast iron at a temperature 20-100°C above its liquidus temperature to form the bottom core part 4.

(vii) Solidification by allowing the molten batch to cool in the mould for 2 to 5 days to reach room temperature, RT, at an average solidification rate of 2 to 3 mm/min. in order to obtain a roll comprising a roll shell having a matrix having an even distribution of 25-30 area % of cementite (200) and a total amount of 60-70 area % of bainite (202), martensite (204) and some residual austenite. The bainite and martensite balance is controlled so that the amount of martensite is larger than the amount of bainite in order to reduce the amount of retained austenite, which is undesired because it deteriorates roll performance. The shell of a roll made from the shell composition according to the invention further contains 2.5-3.0 area % MC carbides (206) and 0.5-3 area % graphite.

[0078] Exemplified embodiment of the casting method according to the invention:

[0079] The preparation of the alloy requires heating a metal charge having an overall compositional range (selected from table 1) required for a roll shell according to the invention.

[0080] The preparation method of the shell alloy according to the invention comprises a step for controlling melt inoculation

[0081] An exemplified but not limiting embodiment according to the invention is described below and shows the temperature curve in the melting furnace before casting over time. The melting comprises several steps (a-g). The composition according to the invention is in step a heated up to 1550°C and is then kept at 1550°C for 20 minutes in step b. During this time Niobium is added in an amount sufficient to produce a molten batch containing 1.1 to 6.0% niobium based on the total weight of said molten batch. In step c the molten batch is cooled and kept at a temperature of 1450°C for 10 minutes and the amount Niobium is checked during this period. In step d amounts of other elements (except Niobium) is adjusted. After this, the composition is heated to 1510°C in step e and kept at this temperature for about 1 minute in step f. Finally, a thermal test is performed in step g in order to determine the need of possible adjustment of the level of inoculation in the shell alloy in order to determine final hardness of the shell.

[0082] The thermal test (performed in step g, figure 2) is a test which allows for adjustment of carbide formers. A small sample of the melt is taken out and solidification rate is analyzed by analyzing the course of cooling of the sample melt.

[0083] Details about the thermal test parameters are further described with reference to figure 2. Figure 2 shows the basic principles of three different scenarios (3a-3c) when a thermal test sample is analyzed. The thermal test is made in order to be able to adjust the composition before casting. Scenario b) in figure 2 shows an "ideal scenario" and allows for the melt to be cast without any adjustments of the composition.

[0084] In the ideal scenario b, the solidification of the sample takes place during generation of a certain amount of excessive heat (exothermic reaction) resulting in a temperature increase in the sample. In the ideal scenario the temperature increase amounts to max 30 above or for example 50°C above the liquidus temperature.

[0085] Scenario shows a thermal test wherein the composition needs to be adjusted or the shell will have insufficient hardness. In this scenario, the solidification of the sample takes place during continued temperature reduction of the sample, i.e. no heat generation. In this scenario, the molten batch may be adjusted by addition of a suitable amount of chromium.

[0086] Scenario c shows a thermal test wherein the composition needs to be adjusted, or the shell will become too hard. In this scenario, the solidification takes place during too high generation of excessive heat, resulting in an increase of the sample temperature in the order of more than 50 °C. In this scenario, the molten batch may be adjusted by the addition of a suitable amount of silicon.

[0087] Further the roll may comprise flux material (108), of a thickness of 5-20 l/m^2. The flux material (108) may be applied on the inner part of the outer shell (106) before casting of the core (112) and gives the roll a protective surface during casting of the core.

Heat treatment:

[0088] Tempering of the roll according to the invention should be performed by selecting an optimum condition in the temperature range of 400 - 600 °C. More precisely, the tempering of the roll shall be performed at a tempering temperature, TA, in the interval of 450-475 °C, preferably at 450 °C, during a retention time, ta, of 10-305 h.

[0089] The heat treatment mainly consists of a tempering process. In this process stress are relieved and the final adjustment of the hardness and residual austenite are done. The cycle consists of a heating step (10-30 °C/hour depending on barrel diameter), a holding step at 470 °C and a cooling step (20-30 °C per hour depending on diameter). This cycle can be repeated in order to achieve the desired hardness at temperatures between 400-450°C.

The roll according to the present invention

EXAMPLES

[0090] The present invention will be explained in detail by way of the following examples without intention of restricting the scope of the present invention.

[0091] An alloy according the invention was prepared in the aforementioned manner having the following compositional range: See experiment 54 and 55 in Table 3.

[0092] The roll made according to the described method greatly enhances the abrasion resistance of the type of roll without reducing its resistance to welding to the strip or its resistance to initiation of cracks under shock loading, by maintaining a balance between free graphite and carbides in the chilled zone during eutectic solidification. The roll according to the invention shows a more even distribution of the different phases (cementite, graphite and bainite/ martensite) long the shell depth.

[0093] In accordance with the present invention, the use of niobium and vanadium in the roll according to the invention allows the addition of a relatively large amount of a strong carbide forming element to a roll alloy which will retain its essential partially graphitized chilled structure evenly distributed in the roll. Thus, the present invention provides a roll composition that overcomes the problems associated with the prior art. These and other details, objects, and advantages of the invention will become apparent as the following detailed description of the present preferred embodiment thereof proceeds.

[0094] Alloys of this composition are well known in the art and will produce a proper balance or equilibrium between carbide formers and free graphite formers at the eutectic solidification temperature.

[0095] Alloys having graphite present in quantities greater than 8% of the total volume are generally too soft to be employed as the outer shell of the rolling mill roll, while alloys containing less than 0.5 % free graphite are not suitable to be deployed as a chill roll outer shell because they are not sufficiently resistant to thermal shock and do not have sufficient graphite to reliably prevent welding of the workpiece to the roll.

[0096] The roll has a hardness drop of 0.5-1.5 ShC per 20 mm in shell (see figure 3). See figure 5 for a comparison of the hardness profile between the roll according to the invention (see for example table 1) and a comparative roll (see Table 2, for a comparative roll 12).

[0097] The roll according to the invention 1 has a density is between 7400 and 7500 kg/m3. The Young modulus is around 170-190 GPa and tensile strength is 375-475 MPa.

ROLL WEAR TESTING

[0098] In the following comparative examples below, a roll according to the invention is compared with a roll composition according to prior art.

[0099] As shown in figure 4 the rolls according to the invention 1 greatly increase the life expectancy compared to the prior art rolls. In addition to increasing the length of time between shutting down the mill in order to regrind the roll, the roll according to the invention results in a more consistent surface finish to the strip between regrinding because of the lower amount of wear of the surface of the roll.

[0100] Those of ordinary skill in the art will appreciate that the present invention provides significant advantages over the prior art. In particular, the subject invention overcomes the problems in the prior art, such as to provide rolls that have increased abrasion resistance, thereby allowing for longer periods of operation before regrinding of the roll is necessary. The invention also provides for the production of a smooth workpiece due to improved abrasion resistance. The subject invention also increases the hardness of the roll, which further provides for a smoother workpiece. The improvement in oxidation behavior prevents the degradation of the roll surface and prolongs the roll initial profile.

[0101] While the subject invention provides these and other advantages over the prior art, it will be understood, however, that various changes in the details, compositions and ranges of the elements which have been described and illustrated herein in order to explain the nature of the invention may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

[0102] Comparison of thermal expansion for a roll according to the invention 1 with a comparative roll 12 is showed in figure 6.

Table 3

Test	Chemical composition (wt%)						Heat treatment	Outcome
	Si	Cr	Ni	V	Nb	Ti		
Test 8	1.7	1.9	4.7	3.2	0.5	-	Normal Tempering	Hardness homogenity not satisfactory
Test 11	0.7	3.2	4.0	-	1.8	0.5	Normal Tempering	Uneven carbide distribution
Test 12	1.7	2.0	5.5	2.9	0.2	-	Normal Tempering	Surface aspect not satisfactory
Test 15	2.3	6.0	3.6	0.1	0.3	-	Normal Tempering	Oxidation behaviour not satisfactory
Test 28	1.2	2.0	3.5	0.1	2.1	0.1	Hardening + normal tempering	Multiple cracks
Test 41	1.3	1.9	2.3	-	1.4	-	Hardening +normal tempering	Low hardness
Test 51	1.6	1.9	5.5	1.4	0.9	-	Modified tempering	Longitudinal cracks
Test 53	1.3	1.8	5.0	0.7	1.0	0.1	Modified tempering	Multiple cracks
Exp 54	1.2	2.1	4.2	0.7	0.8	0.5	Modified tempering	10-15% performance improvement
Exp 55	1.3	2.0	4.4	1.0	1.3	0.5	Modified tempering	10-15% performance improvement

[0103] Comments to table 3: The other elements not mentioned in these comparative examples are within the specification according to the composition of the invention. The performance improvement mentioned in the last examples are figures obtained when comparing the roll performance against the average of the entire population of rolls used in that application. Experiments named "test" are examples of further comparative roll testing. Exp 54 and 55 are examples of a roll according to the invention.

[0104] Normal tempering means tempering at a temperature between 300-400°C

[0105] Modified tempering means a tempering according to the invention at 450-530 °C.

ROLL OXIDATION TESTING

[0106] The oxidation behavior of the new grade has been altered. It is known that the roll surface degradation is related to the oxidation of the material in contact with the rolled product. It is believed that slower kinetics of oxidation (see Figure 5) prevents the degradation of the roll surface and therefore prolongs the roll initial profile. In Figure 5 is shown a comparative study comparing oxidation of a roll, in terms of weight gain per unit of exposed area in a thermogravimetric test at high temperature, according to the invention (1) and a comparative roll (12). As seen in the figure, the roll according to the invention 1 is significantly improved in respect of oxidation properties seen as lower weight increase and thinner oxide scale compared to a comparative roll 12 (composition described in table 2). A roll according to the invention has oxidation kinetics at the roll surface which results in less oxidation of the material, measured as increase of the weight in the surface of the shell layer. The improvement is at least 50% when measured for a time period of 3600 seconds at simulated operation conditions for late finishing stands of a hot strip mill. The weight increase due to oxidation of the shell material is in the order of 3.4-4.5 mg/cm2 measured after 900 seconds which is the average contact time between every specific spot of a shell roll and the hot strip during a normal rolling campaign.

EVEN ROLL PERFORMANCE ALONG ENTIRE ROLL LIFE

[0107] An important feature of the roll according to the invention is the even performance along its entire roll life. This offers the possibility to plan for extended campaigns even when the roll reaches the last part of its life. For example the accumulated performance of the roll according to the invention is between 3660 tons/mm and average performance of the roll according to the invention is 3200mm/tons compared to the accumulated performance of a comparative roll (12) which is 2200 tons/mm and which has an average performance of 2500mm/tons, see figure 4.

Claims

1. A shell composition for a roll composed of (weight %); C: 2.5-4.0%, Nb: 1.1-6.0%, V: 0.7-3.0, Ni: 4.2-4.6%, Mo: 0.3-1.3%, Cr: 1.5-2.2%, Si: 0.7-1.6%, Mn:0.7-1.0%, Zr: 3% or less, Ti: 3% or less, P: 0.08% or less, S: 0.08% or less and balance with Fe and unavoidable impurities.

2. A shell composition for a roll according to claim 1 wherein the composition further satisfies the following formulae:

$$(V + Mo) / Nb \geq 0.35$$

3. A shell composition for a roll according to any previous claims wherein the composition further satisfies the following formulae:

$$0.95 \leq Mo / V \leq 1.16$$

4. A shell composition for a roll according to any previous claims wherein the composition further satisfies the following formulae:

$$0.69 \leq V / Nb \leq 0.84$$

5. A shell composition for a roll according to any previous claims wherein the composition further satisfies the following formulae:

   a relationship between Carbon/Silicon and the carbide forming elements; Mo, Cr, V and Nb, elements comprised in the composition according to the invention and expressed in weight %:

$$A = 52*Cr + 96*Mo + 51*V + 93*Nb \text{ and } B = 12*C + 4*Si$$

   The following relationship must be maintained: 8.0 < A/B < 8.8 or for example 8.0675 < A/B < 8.7699.

6. A centrifugal cast roll formed with a shell composition according to any of the claims 1-5 and a core selected from nodular cast iron and wherein the shell composition comprises 1-5 area % or 0.5-3-2 area % of graphite.

7. A centrifugal cast roll according to any previous claims formed with a shell composition according to any of the claims 1-5 and a core and wherein the shell composition comprises 2-3 % of MC carbides with a particle size of 7-35 μm.

8. A centrifugal cast roll according to any previous claims formed with a shell composition according to any of the claims 1-5 and a core and wherein the shell composition comprises MC carbides and wherein at least 65 % of said MC carbides have a particle size larger than 8 μm or wherein at least 65 % of said MC carbides have a particle size larger than 9 μm and is evenly spread within the shell material.

9. A centrifugal cast roll according to any previous claims formed with a shell composition according to any of the claims 1-5 and a core selected from nodular iron and wherein the shell composition has oxidation kinetics measured at 900 seconds of 2-7 mg/cm^2 or 3.4-4.5 mg/cm^2 or 7 mg/cm^2 or less or 4 mg/cm^2.

10. A centrifugal cast roll according to any previous claims formed with a shell composition according to any of the claims 1-5 and a core and wherein the shell composition comprises 25-30 area % of cementite (200) and a total amount of 60-70 area % of bainite (202), martensite (204) and some residual austenite.

11. A centrifugal cast roll according to any previous claims formed with a shell composition according to any of the claims 1-5 wherein the roll according to the invention 1 has a density between 7400 and 7500 kg/m3 or wherein the Young modulus is around 170-190 GPa or wherein the tensile strength is between 375-475 MPa or 375 MPa or wherein the thermal conductivity is 18-22 W/mK or 20 W/mK or wherein the specific heat is 495-505 J/kgK or 500 J/kgK.

12. A centrifugal cast roll according to any previous claims formed with a shell composition according to any of the claims 1-5 and a core selected from nodular iron and wherein the shell composition has a hardness drop of 0.5-1,5 ShC per 10 mm shell depth.

13. A production method for a centrifugal cast roll according to any of claims 6 -12 comprising the shell composition of any of claims 1-5, comprising the steps of;

d) providing a roll shell composition according to any of claims 1-5 and
e) produce a molten batch comprising the shell composition in any of claims 1-5
f) casting the molten batch comprising the shell composition according to any of the claims 1-5
g) casting another molten batch of core composition to form a roll according to claims 6-12

14. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising the steps of claim 13 and wherein the core material is nodular iron.

15. A production method for a centrifugal cast roll according to any of claims 6-12 comprising any of the claims 13-14 and wherein the production of said molten batch involves controlling melt inoculation by testing that said molten batch has a temperature increase during solidification which is 3-50°C above the liquidus temperature of said batch.

16. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising any of the claims 13-15 and wherein said testing is performed at a temperature of 1500-1520 °C of the melt.

17. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising any of the claims 13-16 and wherein the casting of the shell composition is performed at a centrifugal force of 110-130G or at 120G.

18. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising any of the claims 13-17 and wherein the casting of the shell composition further comprises a step of applying flux material in 7-20 l/m^2 thickness on the inner part of the shell composition (106) which gives the roll a protective surface during casting of the core.

19. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising any of the claims 13-18 and wherein the production method further comprising a tempering step performed by selecting a combination of hardness and residual austenite obtained optimum condition in the temperature range of 450-600 °C.

20. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising any of the claims 13-19 and wherein the casting of the shell composition further comprises a step of applying flux material in 5-12 l/m^2 or 7-8 l/m^2 thickness on the inner part of the shell composition (106) which gives the roll a protective surface during casting of the core.

21. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising any of the claims 13-20 and wherein the shell composition (2) in the casted roll has a thickness of 6-12% of the roll diameter.

22. A production method for a centrifugal cast roll according to any of claims 6-12 comprising the shell composition of any of claims 1-5, comprising any of the claims 13-21 wherein the tempering of the roll shall be performed twice at a tempering temperature, TA, in the interval of 450-475 °C, or at 450 °C, during a retention time of 10-305 h with intermediate cooling to room temperature.

23. Use of a centrifugal cast roll according to any of the previous claims in a hot rolling mill in the late finishing stands.

24. Use of a centrifugal cast roll according to any of the previous claims in a hot rolling mill in the last finishing stands.

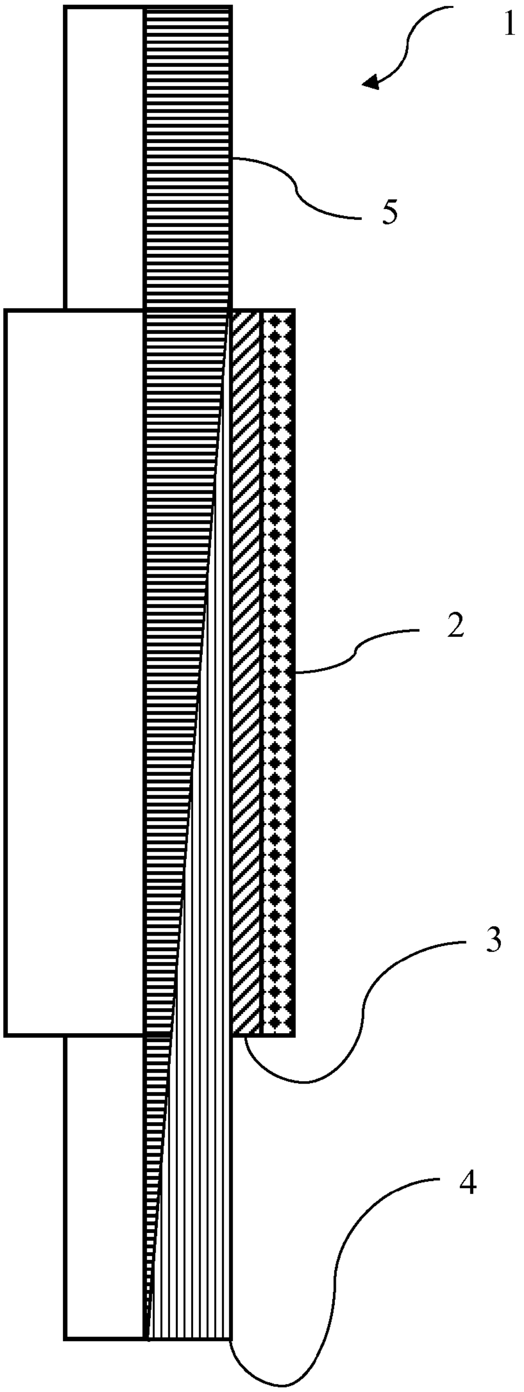


Figure 1

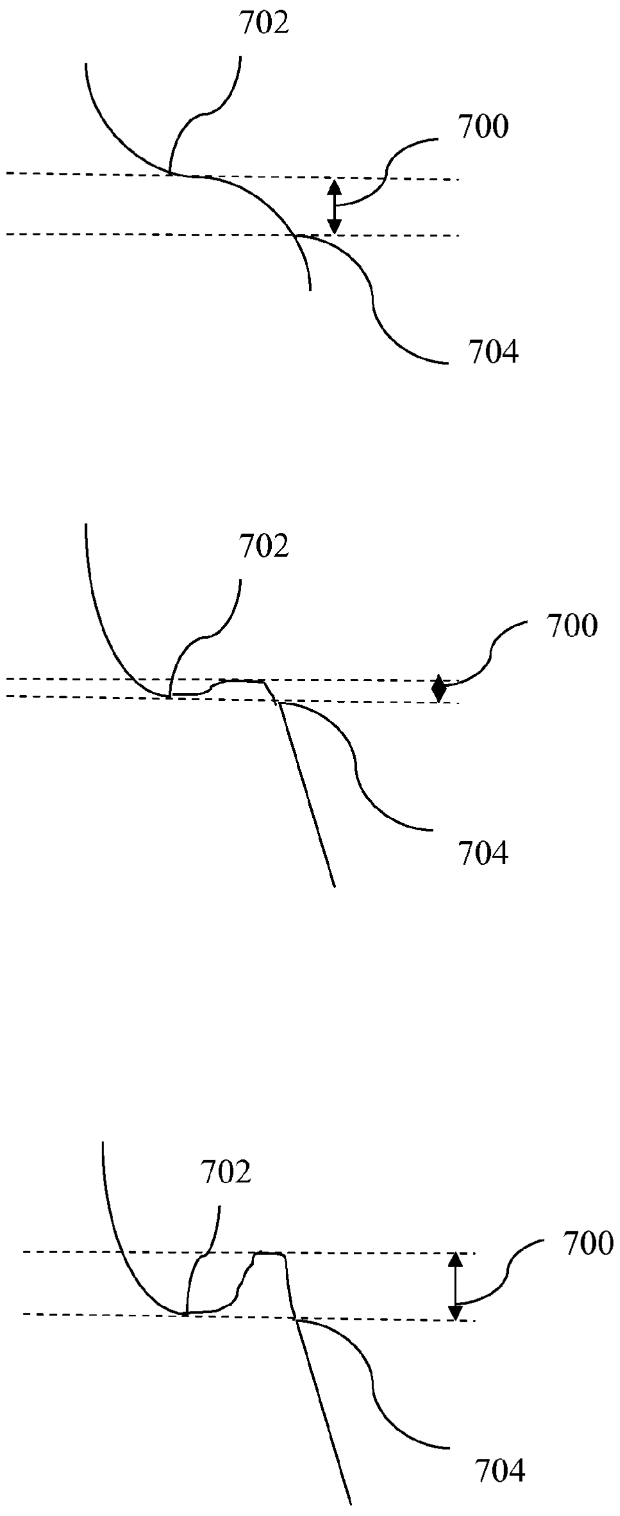


Figure 2

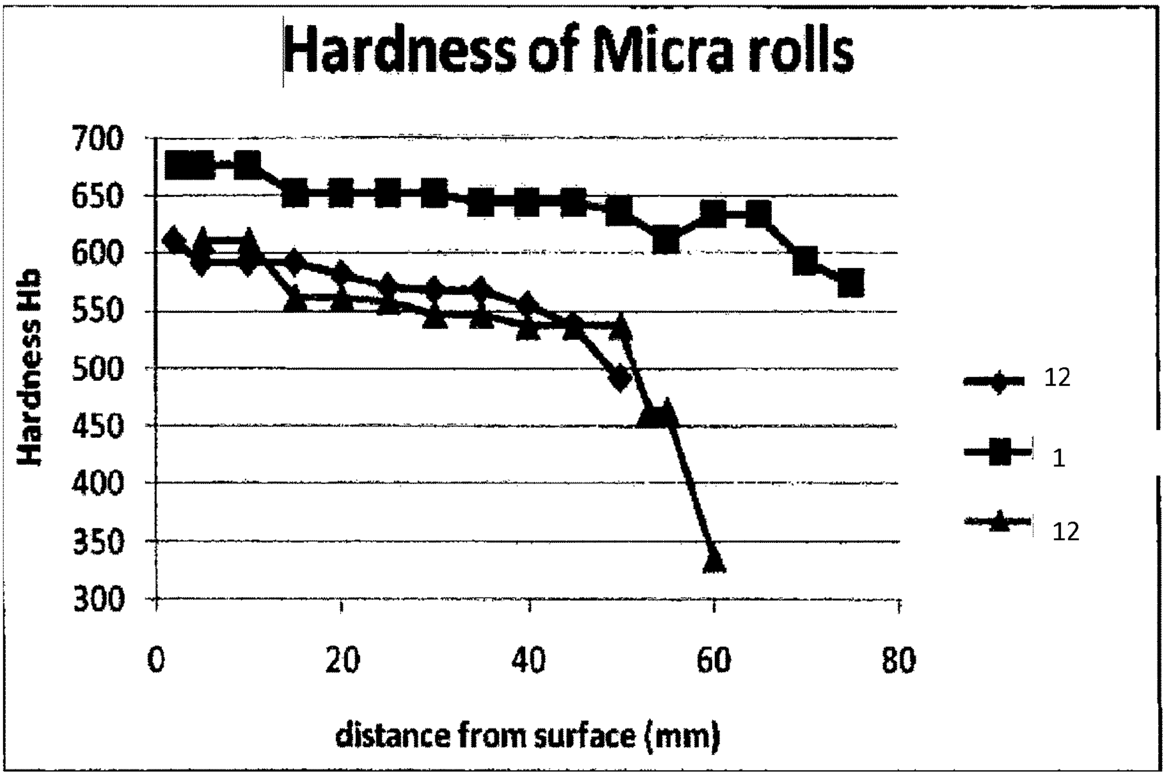
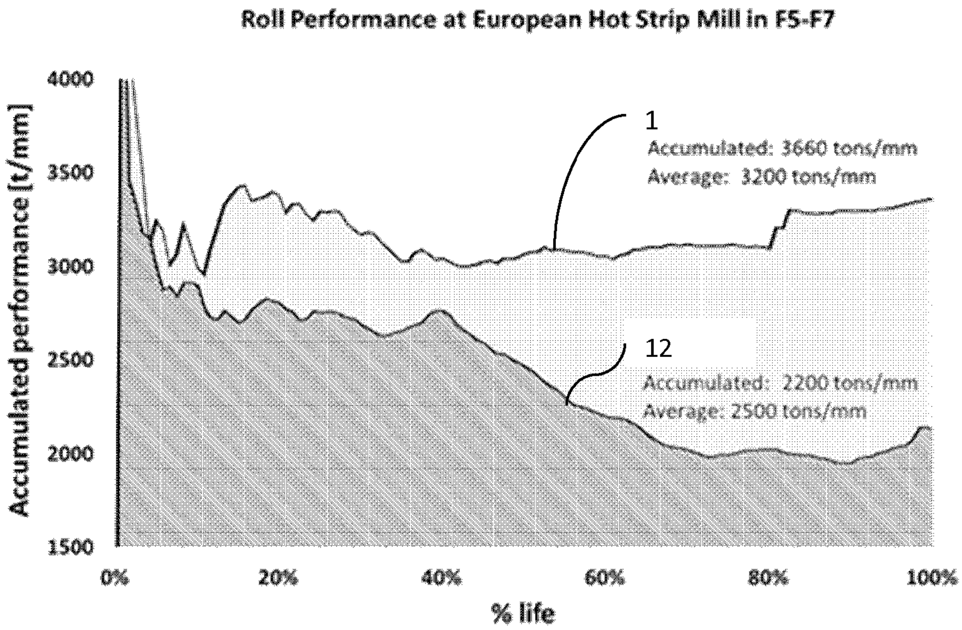

Hardness of Micra rolls
700
650
600
550
500
450
400
350
300
Hardness Hb
0
20
40
60
80
distance from surface (mm)
12
1
12

Figure 3



Roll Performance at European Hot Strip Mill in F5-F7
Accumulated performance [t/mm]
4000
3500
3000
2500
2000
1500
0%
20%
40%
60%
80%
100%
% life
1
Accumulated: 3660 tons/mm
Average: 3200 tons/mm
12
Accumulated: 2200 tons/mm
Average: 2500 tons/mm

Figure 4

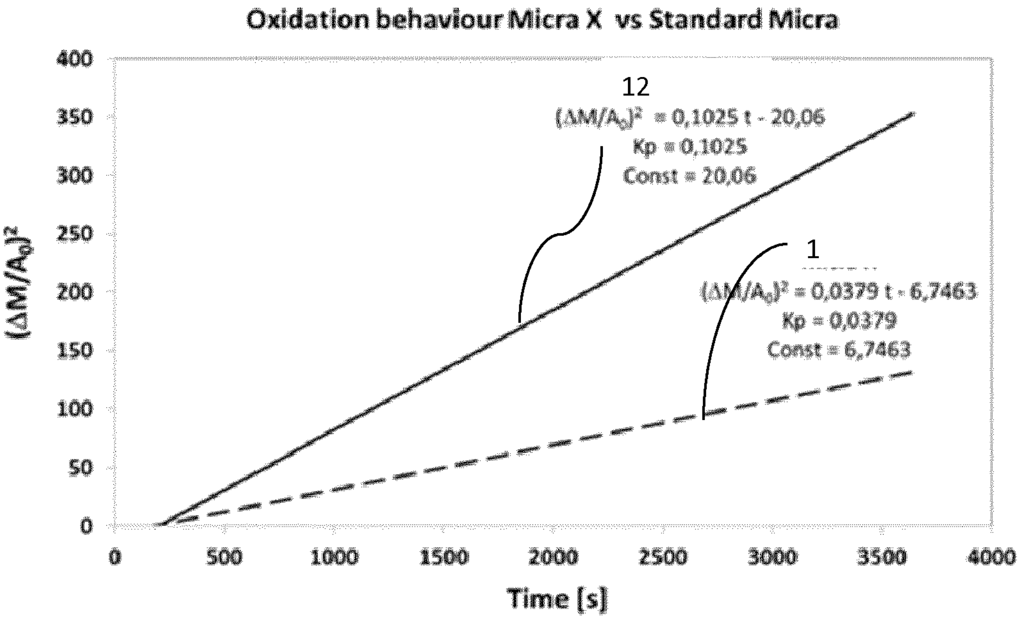

Oxidation behaviour Micra X vs Standard Micra
400
350
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
Time [s]
$(\Delta M/A_0)^2$
12
$(\Delta M/A_0)^2$ = 0,1025 t - 20,06
Kp = 0,1025
Const = 20,06
1
$(\Delta M/A_0)^2$ = 0,0379 t - 6,7463
Kp = 0,0379
Const = 6,7463

Figure 5

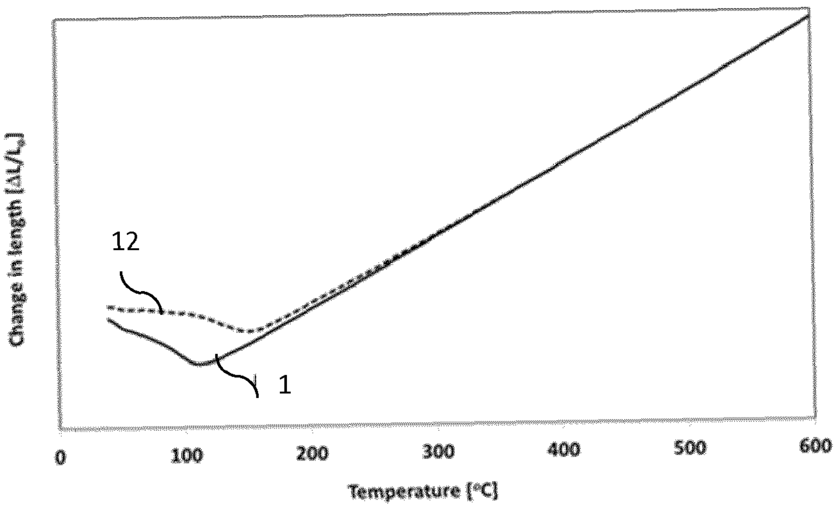

Change in length [ΔL/L0]
12
1
0
100
200
300
400
500
600
Temperature [°C]

Figure 6

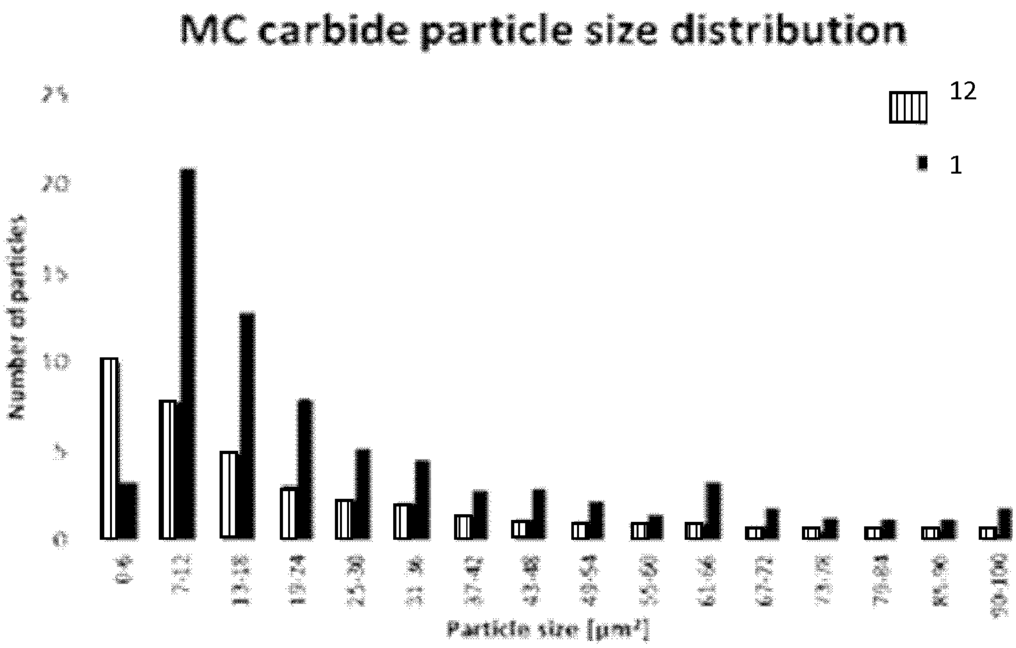

MC carbide particle size distribution
12
1
Number of particles
Particle size [µm²]

Figure 7

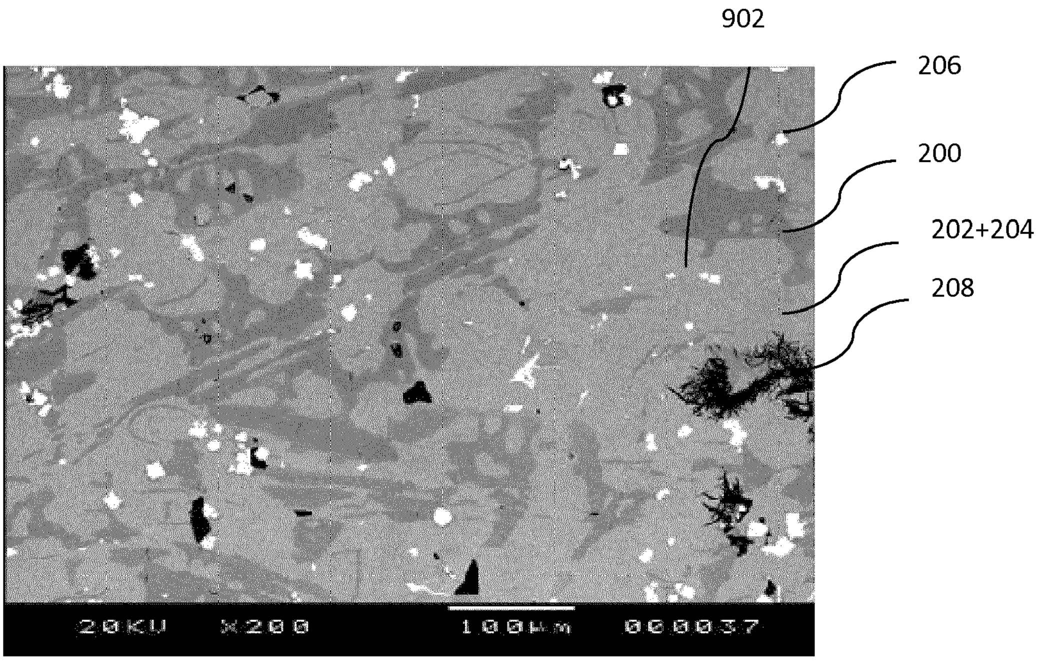


Figure 8

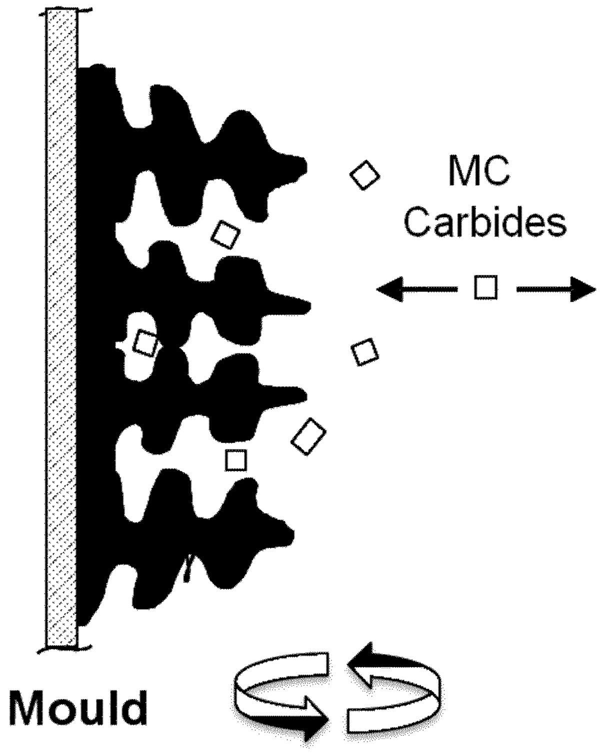


Figure 9

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EUROPEAN SEARCH REPORT

Application Number
EP 12 16 6893

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			C22C B21B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	30 November 2012	Badcock, Gordon

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 12 16 6893

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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