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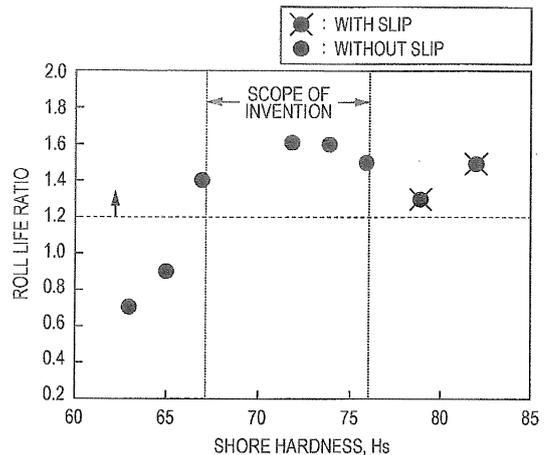
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(54) **CALIBER-CONTAINING CENTRIFUGALLY CAST ROLL FOR HOT ROLLING**

(57) Provided is a centrifugal cast caliber roll for a hot rolling mill having excellent wear resistance, excellent fatigue resistance, and excellent slip resistance.

The roll has a chemical composition containing, by mass%, C: 1.8% or more and 3.0% or less, Si: 0.2% or more and 1.0% or less, Mn: 0.2% or more and 1.5% or less, Cr: 5% or more and 9% or less, Mo: 4.0% or more and 7.0% or less, V: 4.0% or more and 7.0% or less, Nb: 0.5% or more and 2.0% or less, and the balance being Fe and inevitable impurities, in which the relationship $0.6 \leq (C - 0.24V - 0.13Nb) \leq 1.4$ (where, C, V, and Nb each denote the content (mass%) of the corresponding chemical element) is satisfied, and has a surface hardness of Hs 67 or higher and Hs 76 or lower in terms of shore hardness. With this, it is possible to obtain a caliber roll with which it is possible not only to inhibit wear and fatigue but also to prevent slip even in a harsh hot rolling environment in which a high rolling load is applied. In addition, there is an effect of improving the productivity of steel materials (such as a steel pipe), significantly improving the quality of products, and improving roll life.

FIG. 1



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Description

Technical Field

5 **[0001]** The present invention relates to a centrifugal cast roll for a hot rolling mill, in particular, to a roll having a caliber shape (caliber roll) with which slip is less likely to occur, or preferably to a rolling roll for a seamless steel pipe.

Background Art

10 **[0002]** A roll for a hot rolling mill significantly contributes to the progress of a rolling technique for a hot-rolled steel sheet as a result of the development of a high-performance high-speed steel roll that is developed in particular for rolling for a hot-rolled steel sheet and that is excellent in terms of wear resistance and fatigue resistance.

15 **[0003]** For example, Patent Literature 1 describes an outer layer material for a rolling roll. The outer layer material described in Patent Literature 1 has a chemical composition containing, by mass%, C: 1.5% to 3.5%, Si: 1.5% or less, Mn: 1.2% or less, Ni: 5.5% or less, Cr: 5.5% to 12.0%, Mo: 2.0% to 8.0%, V: 3.0% to 10.0%, and Nb: 0.5% to 7.0%, in which V, Nb, and C satisfy a particular relationship, and in which the condition that Nb/V is 0.2 to 0.8 is satisfied. Patent Literature 1 states, with this, it is possible to obtain an outer layer material for a rolling roll in which segregation or the like does not occur even if a centrifugal casting method is applied and which is excellent in terms of wear resistance and crack resistance.

20 **[0004]** In addition, Patent Literature 2 describes an outer layer material for a rolling roll. The outer layer material described in Patent Literature 2 has a chemical composition containing, by mass%, C: 1.5% to 3.5%, Si: 1.5% or less, Mn: 1.2% or less, Cr: 5.5% to 12.0%, Mo: 2.0% to 8.0%, V: 3.0% to 10.0%, and Nb: 0.5% to 7.0%, in which Nb, V, and C satisfy a particular relationship, and in which the condition that Nb/V is 0.2 to 0.8 is satisfied. Patent Literature 2 states, with this, it is possible to obtain an outer layer material for a rolling roll in which segregation or the like does not occur even if a centrifugal casting method is applied and which is excellent in terms of wear resistance and crack resistance, which significantly contributes to an increase in productivity of hot rolling.

25 **[0005]** In addition, Patent Literature 3 describes an outer layer material for a hot rolling roll. The outer layer material described in Patent Literature 3 has a chemical composition containing, by wt.%, C: 2.5% to 4.0%, Si: 1.5% or less, Mn: 1.2% or less, Cr: 6.0% to 20.0%, Mo: 2.0% to 12.0%, V: 3.0% to 10.0%, and Nb: 0.6% to 5.0%, in which C, V, Nb, and Cr are controlled so as to satisfy a particular relational expression. Patent Literature 3 states, with this, it is possible to obtain a roll for a hot rolling mill which is significantly excellent in terms of wear resistance, which is excellent in terms of surface deterioration resistance and roll banding resistance due to the low friction coefficient, and with which there is a significant decrease in the probability of failure when rolling is performed.

30 **[0006]** In addition, Patent Literature 4 describes a roll for a hot rolling mill. The roll for a hot rolling mill described in Patent Literature 4 has an outer layer having a chemical composition containing, by mass%, C: 2.4% to 2.9%, Si: 1% or less, Mn: 1% or less, Cr: 12% to 18%, Mo: 3% to 9%, V: 3% to 8%, and Nb: 0.5% to 4%, in which Mo/Cr is 0.27 or more and less than 0.7, and in which $(C + 0.2Cr)$ is 6.2 or less. According to the technique described in Patent Literature 4, forming of MC-type carbides and M_7C_3 -type carbides in appropriate amounts and strengthening of MC-type carbides and M_7C_3 -type carbides can be achieved, and since it is possible to obtain an outer layer without the segregation of carbides, it is possible to prevent surface defects on a rolled product.

35 **[0007]** Nowadays, since there is a growing tendency for oil wells and gas wells to be developed in deep locations or in a highly corrosive environment due to the exhaustion of, for example, crude oil, it is required that improvement of properties of seamless steel pipes, which are used for oil tubular goods or linepipes. Therefore, nowadays, there is an increase in the proportion of seamless steel pipes manufactured being composed of a material with less hot workability such as high-alloy steel or stainless steel to all of the seamless steel pipes manufactured. With such a change in material to be rolled, there is a problem in that, for example, cracking or surface deterioration of a roll due to wear and fatigue, and spalling of a roll due to fatigue frequently occur in a caliber roll for a hot rolling mill such as a mandrel mill roll and a plug mill roll, which are rolls for manufacturing seamless steel pipes.

40 **[0008]** In response to such problems, consideration is given to which a high-performance high-speed steel roll for manufacturing a hot-rolled steel sheet such as a roll according to Patent Literatures 1 to 4 is applied to a roll for a hot rolling mill having a caliber shape (caliber roll) such as a mandrel mill roll or a plug mill roll, which are rolls for manufacturing seamless steel pipes. However, in the case where a high-performance high-speed steel roll is used as a mandrel mill roll or a plug mill roll, there is a problem in that slip occurs.

45 **[0009]** Here, the term "slip" refers to a phenomenon in which the circumferential speed of a rolling roll and the traveling speed of the material to be rolled are different from each other across the entire contact surface of the material to be rolled and the rolling roll, then the difference in speed between the rolling roll and the material becomes to be large. There is a risk of a surface defect such as a flaw occurring in the material to be rolled or of a rolling mill operation being stopped in some cases depending on the degree of slip.

[0010] On the other hand, for example, Patent Literature 5 describes a caliber roll for a rolling mill. The caliber roll for a rolling mill described in Patent Literature 5 has a caliber part composed of a high-speed steel layer, in which compressive residual stress is provided to the caliber surface by performing quench hardening only on the caliber surface along the outline of the caliber so that the hardness of the caliber surface is Hs 65 or more and is higher than that of the innermost part by 10 or more in terms of Hs. In the case of the technique described in Patent Literature 5, the high-speed steel layer of the caliber part has a chemical composition containing, by wt.%, C: 0.5% to 2.6%, Si: 0.1% to 2.5%, Mn: 0.1% to 2.0%, Cr: 2% to 15%, Mo: 10% or less, W: 20% or less, and V and/or Nb: 15% or less, and, optionally, further containing Co: 10% or less and Ni: 2% or less. Patent Literature 5 states that, with this, it is possible to decrease specific roll consumption due to an increase in crack resistance.

[0011] In addition, Patent Literature 6 describes a mandrel mill rolling method. The technique described in Patent Literature 6 is a mandrel mill rolling method including using a cast iron roll, a cast steel roll, or a forged roll whose surface Shore hardness is Hs 60 or higher as a caliber roll and performing rolling without using a lubricant and with a rolling reduction of 50% or less at the caliber bottom of the caliber roll in the rolling stand to which the caliber roll is fitted. Patent Literature 6 states that, with this, it is possible to prevent slip or sticking as much as possible when rolling is performed.

Citation List

Patent Literature

[0012]

PTL 1: Japanese Unexamined Patent Application Publication No. 4-365836

PTL 2: Japanese Unexamined Patent Application Publication No. 5-1350

PTL 3: Japanese Unexamined Patent Application Publication No. 8-73977

PTL 4: Japanese Unexamined Patent Application Publication No. 10-183289

PTL 5: Japanese Unexamined Patent Application Publication No. 7-179945

PTL 6: Japanese Unexamined Patent Application Publication No. 2000-94014

Summary of Invention

Technical Problem

[0013] However, in the case of the technique described in Patent Literature 5, there is a problem in that there is still a case where slip frequently occurs and in that roll life is shorter than that required for a roll for hot rolling a seamless steel pipe. In addition, in the case where rolling for a high-alloy seamless steel pipe is performed by using a cast iron roll, a cast steel roll, or a forged roll, which is used in the technique described in Patent Literature 6, there is a problem in that, since roll life is short, there is a decrease in productivity.

[0014] An objective of the present invention is, by advantageously solving the problems with the conventional techniques described above, to provide a centrifugal cast caliber roll for a hot rolling mill (also referred to as caliber roll for a hot rolling mill, in the present description) having excellent wear resistance, excellent fatigue resistance, and excellent slip resistance. Solution to Problem

[0015] The present inventors, in order to achieve the object described above, first diligently conducted investigations regarding the reasons why slip occurs in a high-speed steel caliber roll, and, as a result, presumed that the slip of a high-speed steel caliber roll is caused by the caliber shape and hardness of the roll. That is, for example, on the surface of a caliber whose cross section has a part having a concave circular shape as is the case with a mandrel mill roll for rolling a seamless steel pipe, there are a position (neutral point) at which the circumferential speed of the roll surface is equal to the traveling speed of a material (steel pipe) to be rolled and positions other than the neutral point at which the circumferential speed of the roll surface is different from the traveling speed of the material (steel pipe) to be rolled when rolling is performed. In the case of such a roll, it is considered that, in the case where the hardness of the roll is high, since the relative speed at a portion in which the roll and the material (steel pipe) to be rolled are in contact with each other changes due to the slide of the material (steel pipe) to be rolled, the position of the neutral point tends to change, which results in slip occurring. Therefore, it was found that it was necessary to appropriately control roll hardness in order to prevent slip from occurring in a caliber roll.

[0016] First, the results of experiments which were conducted by the present inventors and which the present invention is based on will be described.

[0017] By preparing molten metal having a chemical composition containing, by mass%, 2.5% of C, 0.5% of Si, 0.4% of Mn, 0.016% of P, 0.009% of S, 6.1% of Cr, 5.3% of Mo, 5.9% of V, 0.8% of Nb, and the balance being Fe and inevitable impurities by using an induction furnace, a single-layer sleeve roll having a cylindrical shape (having an outer diameter

of 575 mm ϕ , an inner diameter of 255 mm ϕ , and a barrel length of 2.0 m) was obtained by using a centrifugal casting method (with a centrifugal force of 195 G). The obtained sleeve roll was subjected to softening annealing and then cut into plural pieces (having a length of about 350 mm). By providing a desired caliber to these sleeve rolls by performing crude processing including machining, by heating the processed sleeve rolls to a temperature of 950°C to 1100°C to perform quenching, and by performing a tempering treatment including heating the quenched sleeve rolls to a temperature of 430°C to 600°C plural times, sleeve rolls each having a different hardness of Hs 63 to Hs 82 were obtained.

[0018] Subsequently, by performing finish processing including grinding, polishing, and so forth on the obtained sleeve rolls, test rolls (having a length of 305 mm) having the caliber shape (having a caliber bottom diameter of 81 mm) illustrated in Fig. 2 were obtained. By setting these test rolls to a mandrel mill stand (stand #2) in a seamless steel pipe manufacturing line (172 passes), test rolling was performed on 1000 pipes or more for each of the sleeve rolls in a rolling cycle in which 13%-Cr-steel pipe was mainly rolled in order to investigate whether slip occurred or not and the amount of consumption of the test rolls.

[0019] Here, the amount of consumption of the rolls was evaluated on the basis of the amount of consumption of standard rolls obtained under a standard condition in which the test rolling described above was performed on a sleeve roll having a chemical composition containing, by mass%, 2.2% of C, 0.3% of Si, 0.3% of Mn, 6.0% of Cr, 2.5% of Mo, 5.0% of V, 1.5% of Nb, and the balance being Fe and inevitable impurities, a Shore hardness of Hs 72, and the same caliber shape as that of the test rolls described above.

[0020] By calculating {amount of consumption of standard roll (mm)}/{amount of consumption of test roll (mm)} from the obtained results, the calculated result was defined as "roll life ratio". A roll life ratio larger than 1 indicates a longer life than that of the standard roll, and, in the present invention, a case where the roll life ratio is 1.1 or more is judged as a case of good roll life. Here, the amount of consumption is also referred to as "amount of decrease in weight due to wear".

[0021] In addition, a case where the material was not gripped by the rolls or where the material did not travel forward even though gripped by the rolls was judged as a case of slip.

[0022] The obtained results are illustrated in Fig. 1.

[0023] As Fig. 1 indicates, even in the case of a high-speed steel roll, slip did not occur in the case of a test roll having a Shore hardness of Hs 76 or lower. On the other hand, in the case of a test roll having a Shore hardness of higher than Hs 76, slip occurred and rolling operation was not completed normally. From such results, it is clarified that it is possible to prevent slip from occurring even in the case of a high-speed steel caliber roll by providing a specified chemical composition to the roll so as to control the shore hardness of Hs 76 or lower.

[0024] In addition, while there is a decrease in roll life ratio to 1.0 or less in the case of a test roll having a Shore hardness of lower than Hs 67, there is an increase in roll life ratio to a value higher than 1.2, that is, there is an increase in roll life, in the case of a test roll having a Shore hardness of Hs 67 or higher. From such results, it was found that, by providing a specified chemical composition to a high-speed steel caliber roll so as to control the Shore hardness of Hs 67 or higher and Hs 76 or lower, roll slip does not occur, it is possible to expect an increase in roll life ratio, and it is possible to obtain a very high-performance caliber roll for a hot rolling mill for manufacturing a seamless steel pipe.

[0025] In addition, the present inventors, in order to further improve roll properties, in particular, in order to improve fatigue resistance, conducted investigations regarding the influence of alloy chemical elements on fatigue resistance when hot rolling is performed.

[0026] By preparing molten metal having different chemical compositions within the range of the composition containing, by mass%, C: 1.7% to 3.3%, Si: 0.2% to 1.6%, Mn: 0.3% to 1.3%, Cr: 4.2% to 9.6%, Mo: 3.8% to 7.7%, V: 4.2% to 6.8%, Nb: 0.5% to 2.4%, and the balance being Fe and inevitable impurities by using a high-frequency induction furnace, the molten metal were cast into ring roll materials (having an outer diameter of 250 mm ϕ and a width of 60 mm) by using a centrifugal casting method. Here, the casting temperature was 1470°C to 1540°C, and the centrifugal force was 160 G in multiples of gravity. After casting had been performed, hardness was controlled to be Hs 67 to Hs 76 by performing a quenching treatment and a tempering treatment. Here, fatigue resistance was evaluated on the basis of a standard condition, where the standard condition refers to a case of a centrifugal cast high-speed steel roll outer layer material having a chemical composition containing, by mass%, 2% of C, 0.3% of Si, 0.3% of Mn, 6% of Cr, 2.5% of Mo, 5% of V, 1.5% of Nb, and the balance being Fe and inevitable impurities and a hardness of Hs 72.

[0027] By taking a fatigue test piece having the shape illustrated in Fig. 5(a) (having an outer diameter of 60 mm ϕ and a width of 10 mm) from each of these materials, and by machining notches having the shape and dimensions illustrated in Fig. 5(b) (having a depth t of 1.3 mm and a length L in the circumferential direction of 1.0 mm) at two positions on the outer circumferential surface of the test piece by using a wire electric discharge machining method with a wire having a diameter of 0.2 mm ϕ , a hot rolling contact fatigue test was performed on the test piece. In addition, the edges of the rolling contact surface of the fatigue test piece had chamfered corners having a width of 1.0 mm. Hereinafter, in the case where chamfered corners are provided to the edges of the rolling contact surface of a test piece, the chamfered corners have the same width as that described above.

[0028] A hot rolling contact fatigue test was, as illustrated in Fig. 4, performed by using a slip-rolling-type method between two discs, which were the test piece and counter material. That is, while the test piece (fatigue test piece) was

cooled with water and rotated at a rotational speed of 700 rpm, the counter piece (composed of S45C and having an outer diameter of 190 mmφ, a width of 10 mm, and chamfered corners) was heated at a temperature of 830°C, pressed onto the rotating test piece with a contact load of 980 N, and rotated with a slip ratio of 10%. The test piece was rotated until the two notches machined in the fatigue test piece broke, and the respective rotation numbers until the notches broke were counted. The average of the two rotation numbers was defined as a breaking rotation number of the test piece. Subsequently, by using the breaking rotation number of the fatigue test piece taken from the material of the standard condition described above as a standard value, and by calculating the ratio of the breaking rotation number of each of the ring roll materials to the standard value, that is, (breaking rotation number of ring roll material)/(breaking rotation number of fatigue test piece of standard condition), the calculated ratio was defined as a fatigue resistance index. Here, a case where the fatigue resistance index was 1.1 or more was judged as a case of "excellent fatigue resistance". Here, the present inventors have confirmed that, by performing the hot rolling contact fatigue test using the notched fatigue test piece described above, it is possible to accurately simulate the generation and propagation of a fatigue crack in a roll for a hot rolling mill, and it is possible to easily evaluate the fatigue resistance of a roll for a hot rolling mill.

[0029] As Fig. 3 indicates, it is clarified that, in the case where the value of $(C - 0.24V - 0.13Nb)$ is out of the range of 0.6 or more and 1.4 or less, there is a decrease in the fatigue resistance of a roll.

[0030] The present invention has been completed on the basis of the knowledge described above and additional investigations. That is, the subjective matter of the present invention is as follows.

[0031]

(1) A centrifugal cast caliber roll for a hot rolling mill, the roll having a chemical composition containing, by mass%, C: 1.8% or more and 3.0% or less, Si: 0.2% or more and 1.0% or less, Mn: 0.2% or more and 1.5% or less, Cr: 5% or more and 9% or less, Mo: 4.0% or more and 7.0% or less, V: 4.0% or more and 7.0% or less, Nb: 0.5% or more and 2.0% or less, and the balance being Fe and inevitable impurities, in which relational expression (1) below is satisfied, and a surface hardness of Hs 67 or higher and Hs 76 or lower in terms of Shore hardness.

$$0.6 \leq (C - 0.24V - 0.13Nb) \leq 1.4 \quad \dots (1)$$

(Here, C, V, and Nb each denote the content (mass%) of the corresponding chemical element)

(2) The centrifugal cast caliber roll for a hot rolling mill according to item (1), the roll being a rolling roll for a seamless steel pipe.

Advantageous Effects of Invention

[0032] According to the present invention, it is possible to provide a caliber roll for a hot rolling mill capable of preventing slip, which has significantly improved wear resistance and fatigue resistance, or preferably which is used for manufacturing a seamless steel pipe. In addition, it is possible to manufacture the caliber roll for a hot rolling mill according to the present invention at low cost by using a centrifugal casting method. As described above, the present invention has a significant effect on the industry.

[0033] In addition, by using the caliber roll for a hot rolling mill according to the present invention, since it is possible not only to inhibit wear and fatigue but also to prevent slip even in a harsh hot rolling environment in which a high rolling load is applied, there is a large effect of improving the productivity of steel materials (such as a steel pipe), significantly improving the quality of products, and further improving roll life. Here, examples of an application in a harsh hot rolling environment in which a high rolling load is applied include hot rolling for manufacturing seamless steel pipes such as oil tubular goods and linepipes.

Brief Description of Drawings

[0034]

[Fig. 1] Fig. 1 is a graph illustrating the influence of roll hardness (Shore hardness Hs) on roll life ratio and slip.

[Fig. 2] Fig. 2 is a diagram schematically illustrating the shape and dimensions of a sleeve roll used as a test roll.

[Fig. 3] Fig. 3 is a graph illustrating the influence of $(C - 0.24V - 0.13Nb)$ on fatigue resistance index.

[Fig. 4] Fig. 4 is a diagram schematically illustrating the skeleton framework of a testing machine used for a wear test and a hot rolling contact fatigue test.

[Fig. 5] Fig. 5 is a diagram schematically illustrating the shape of a hot rolling contact fatigue test piece (fatigue test piece) and the shape and dimensions of notches formed on the outer circumferential surface of the test piece.

Description of Embodiments

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[0035] First, reasons for the limitations on the chemical composition of the centrifugal cast caliber roll for a hot rolling mill according to the present invention will be described. Hereinafter, mass% used when describing a chemical composition shall be simply referred to as %.

10 C: 1.8% or more and 3.0% or less

[0036] C increases hardness as a result of forming a solid solution in the matrix and carbides and influences the wear resistance and fatigue resistance of a roll as a result of forming hard carbides. In the case where the C content is less than 1.8%, there is deterioration in wear resistance is appeared due to a decrease in the amount of hard carbides. On the other hand, in the case where the C content is more than 3.0%, there is deterioration in fatigue resistance and wear resistance due to embrittlement caused by coarsening of carbides. Therefore, the C content is limited to be 1.8% or more and 3.0% or less.

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Si: 0.2% or more and 1.0% or less

[0037] Si is a chemical element which functions as a deoxidizing agent and which is effective for improving the castability of molten iron and steel, and it is necessary that the Si content be 0.2% or more in order to obtain such effects. On the other hand, in the case where the Si content is more than 1.0%, since the effects become saturated, it is not possible to expect an increase in the effects corresponding to an increase in the Si content, and it is difficult to control to achieve the desired hardness due to an increase in the amount of retained austenite. Therefore, the Si content is limited to be 0.2% or more and 1.0% or less.

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Mn: 0.2% or more and 1.5% or less

[0038] Mn is a chemical element which is effective for negating the negative effect of S by fixing S in the form of MnS and which is effective for improving hardenability by forming a solid solution in the matrix. Although it is necessary that the Mn content be 0.2% or more in order to obtain such effects, the effects become saturated in the case where the Mn content is more than 1.0%, and it is not possible to expect an increase in the effects corresponding to the cost for increasing the Mn content in the case where the Mn content is more than 1.5%. Therefore, the Mn content is limited to be 0.2% or more and 1.5% or less, or preferably 0.2% or more and 1.0% or less.

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Cr: 5% or more and 9% or less

[0039] Cr is a chemical element which is effective for improving wear resistance by combining with C to form mainly eutectic carbides and which is effective for stabilizing rolling by decreasing the frictional force between a material to be rolled and the roll when rolling is performed. In order to obtain such effects, it is necessary that the Cr content be 5% or more. On the other hand, in the case where the Cr content is more than 9%, slip or sticking occurs. Therefore, the Cr content is limited to be 5% or more and 9% or less.

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45 Mo: 4.0% or more and 7.0% or less

[0040] Mo has an important function of improving the fatigue resistance and wear resistance of a roll through solid solution strengthening as a result of forming a solid solution in the matrix and carbides. In order to obtain such an effect, it is necessary that the Mo content be 4.0% or more. On the other hand, in the case where the Mo content is more than 7.0%, there is deterioration in fatigue resistance due to the formation of hard and brittle free carbides mainly containing Mo. Therefore, the Mo content is limited to be 4.0% or more and 7.0% or less, or preferably 4.3% or more and 6.8% or less.

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V: 4.0% or more and 7.0% or less

[0041] V is a chemical element which is important in the present invention for achieving satisfactory wear resistance and fatigue resistance at the same time. V is a chemical element which improves wear resistance by forming very hard carbides (MC-type carbides) and which significantly improves the fatigue resistance of a roll as a result of having an effective function of dividing eutectic carbides in order to allow the eutectic carbides to dispersedly crystallize. Such

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effects become marked in the case where the V content is 4.0% or more. On the other hand, in the case where the V content is more than 7.0%, since there is coarsening of MC-type carbides, and since the centrifugal casting segregation of MC-type carbides is promoted, various properties of a roll become unstable. Therefore, the V content is limited to be 4.0% or more and 7.0% or less, or preferably 5.5% or more and 6.8% or less.

Nb: 0.5% or more and 2.0% or less

[0042] Nb is a chemical element which improves the wear resistance and fatigue resistance of a roll by strengthening MC-type carbides as a result of forming a solid solution in the MC-type carbides. In addition, Nb is a chemical element which is effective for improving the fatigue resistance of a roll by inhibiting eutectic carbides from fracturing as a result of promoting the division of eutectic carbides. Also, Nb has a function of inhibiting the segregation of MC-type carbides when centrifugal casting is performed. Such effects become marked in the case where the Nb content is 0.5% or more. On the other hand, in the case where the Nb content is more than 2.0%, since the growth of MC-type carbides in molten iron and steel is excessively promoted, the segregation of carbides is promoted when centrifugal casting is performed.

Therefore, the Nb content is limited to be 0.5% or more and 2.0% or less, or preferably 0.6% or more and 1.3% or less. **[0043]** In the present invention, the contents of C, V, and Nb are controlled to be within the ranges described above so that relational expression (1) below is satisfied.

$$0.6 \leq (C - 0.24V - 0.13Nb) \leq 1.4 \quad \dots (1)$$

(Here, C, V, and Nb each denote the content (mass%) of the corresponding chemical element)

[0044] The expression $(0.24V + 0.13Nb)$ indicates the amount of C which is expended in the formation of MC-type carbides. $(C - 0.24V - 0.13Nb)$ is also referred to as "effective carbon content" and indicates the amount of C (mass%) which forms a solid solution in the matrix or eutectic carbides. Therefore, this effective C content influences the wear resistance and fatigue resistance of a roll and frictional force between a material to be rolled and a roll as a result of influencing the hardness of the matrix and the amount of eutectic carbides. In particular, in order to achieve excellent fatigue resistance, it is necessary that the effective C content (mass%) be limited to 0.6 or more and 1.4 or less. In the case where the effective C content (mass%) is out of the range of 0.6 or more and 1.4 or less, as Fig. 3 indicates, there is a decrease in the fatigue resistance of a roll. It is more preferable that the effective C content (mass%) be 0.7% or more and 1.3% or less. With this, it is possible to further decrease scatter in fatigue resistance.

[0045] The remainder other than the constituent chemical elements described above is Fe and inevitable impurities.

[0046] Examples of the inevitable impurities include P: 0.05% or less, S: 0.05% or less, N: 0.06% or less, and B: 0.02% or less. Since P deteriorates the properties of iron and steel as a result of being segregated at grain boundaries, it is preferable that the P content be as small as possible in the present invention. It is acceptable that the P content be 0.05% or less in the present invention. In addition, since S deteriorates the properties of iron and steel as a result of existing in the form of sulfide-based inclusions, it is preferable that the S content be as small as possible in the present invention. It is acceptable that the S content be 0.05% or less in the present invention. In addition, N is usually mixed into iron and steel in an amount of about 0.06% or less. Within such a range of N content, there is no influence on the effect of the present invention. In addition, B is an impurity chemical element which is mixed into iron and steel from scrap, which is a raw material to be melted, casting flux, and so forth. It is preferable that the B content be as small as possible in the present invention. It is acceptable that the B content be 0.02% or less in the present invention, because there is no negative influence on the effect of the present invention.

[0047] Hereafter, the reasons for the limitations on the hardness of the centrifugal cast caliber roll for a hot rolling mill according to the present invention will be described.

[0048] The centrifugal cast caliber roll for a hot rolling mill according to the present invention has the chemical composition described above, a caliber surface hardness of Hs 67 or higher and Hs 76 or lower in terms of Shore hardness. In the case of a rolling roll for a hot-rolled steel sheet, the hardness is generally controlled to be about Hs 79 or more. In the case of a caliber roll for a hot rolling mill such as a roll for manufacturing a seamless steel pipe, for which the present invention is intended, it is difficult to stably perform rolling due to slip occurring when rolling is performed in the case where the hardness is higher than Hs 76. On the other hand, in the case where the hardness is lower than Hs 67, there is a decrease in wear resistance and fatigue resistance, and surface deterioration may occur. Therefore, in the case of the centrifugal cast caliber roll for a hot rolling mill according to the present invention, the caliber surface hardness is limited to be Hs 67 or higher and Hs 76 or lower in terms of Shore hardness.

[0049] Hereafter, a preferable method for manufacturing the centrifugal cast caliber roll for a hot rolling mill according to the present invention will be described.

[0050] It is preferable that molten metal having the chemical composition described above be prepared, poured into

a mold, and then cast. There is no particular limitation on what method is applied for preparing molten metal, and any of ordinary melting methods such as one in which a high-frequency induction furnace is used may be applied. Here, in the present invention, casting is performed by using a centrifugal casting method, which is inexpensive and operated at low energy costs. When casting is performed, it is preferable to use a mold (rotary mold) whose inner surface is covered with a refractory having a thickness of 0.5 mm to 6 mm composed mainly of zircon and the like.

[0051] Although it is preferable that the centrifugal cast caliber roll for a hot rolling mill according to the present invention be a sleeve-type roll having a single layer, the roll may be composed of plural layers. In the case where the roll is composed of plural layers, it is preferable that the roll be an integrated roll which is composed of an integrated combination of an outer layer and an inner layer and which is manufactured by pouring molten metal having the chemical composition of the inner layer during the solidification of the outer layer or after the solidification of the outer layer. In addition, since spalling tends to occur in a cast product (roll) in the case where the molten metal is cast into a caliber shape mold, it is not necessary that the mold have a caliber shape. It is preferable that, for example, a cylindrical shape be formed with no caliber shape being formed in a casting process and that a caliber shape be formed by performing forging and/or, for example, machining after the casting process.

[0052] Here, it is preferable that an inner layer be composed of, for example, spheroidal graphite cast iron, vermicular graphite cast iron (VC cast iron), hypereutectoid steel, adamite steel, or spheroidal graphite steel, which is excellent in terms of casting capability and mechanical properties. In addition, since a part of the outer layer material is melted for integration, embrittlement of the inner layer may occur due to alloy chemical elements (carbide-forming chemical elements) such as Cr and V contained in the outer layer material mixing into the inner layer, which requires attention.

[0053] The roll provided with a caliber is subsequently subjected to a quenching treatment and a tempering treatment in order to obtain a caliber roll having a caliber surface hardness within the range described above. Here, it is preferable that a quenching treatment be performed by charging the roll into a heat treatment furnace, by heating the roll to a temperature of 950°C to 1100°C, and by then cooling the roll with air. In addition, it is preferable that a tempering treatment be performed by heating the roll to a temperature of 430°C to 600°C and by then cooling the roll.

[0054] Hereafter, the present invention will be described more in detail on the basis of examples.

EXAMPLES

(Example 1)

[0055] Molten metals having the chemical compositions given in Table 1 were prepared by using a high-frequency induction furnace, and then, ring roll materials (having an outer diameter of 250 mm ϕ , an inner diameter of 130 mm ϕ , and a length of 60 mm) were obtained by casting using a centrifugal casting method. Here, the casting temperature was 1470°C to 1540°C, and the centrifugal force was 160 G in multiples of gravity. After casting had been performed, by performing a quenching treatment and a tempering treatment, the hardness was controlled.

[0056] Here, the hardness was determined at five positions in the vicinity of the surface of the ring roll material by using a Shore hardness meter, and the average of the five determined values was defined as the average hardness of the corresponding roll material.

[0057] A fatigue test piece and a wear test piece were taken from the obtained ring roll material.

[0058] The fatigue test piece had the shape illustrated in Fig. 5(a) (having an outer diameter of 60 mm ϕ , an inner diameter of 25 mm ϕ , and a width of 10 mm), and notches having the dimensions and the shape illustrated in Fig. 5(b) (having a depth t of 1.3 mm and a length L in the circumferential direction of 1.0 mm) were formed at two positions in the outer circumferential surface of the fatigue test piece by using a wire electric discharge machining method with a wire having a diameter of 0.2 mm ϕ . In addition, the edges of the rolling contact surface of the fatigue test piece had chamfered corners.

[0059] A hot rolling contact fatigue test was performed on the fatigue test piece described above in order to evaluate fatigue resistance.

[0060] A hot rolling contact fatigue test was, as illustrated in Fig. 4, performed by using a slip-rolling-type method between two discs, which were the test piece and a counter material. That is, while the test piece (fatigue test piece) was cooled with water and rotated at a rotational speed of 700 rpm, the counter piece (composed of S45C and having an outer diameter of 190 mm ϕ , a width of 10 mm, and chamfered corners) was heated at a temperature of 830°C by using a high-frequency induction heating coil, pressed onto the rotating test piece with a contact load of 980 N, and rotated with a slip ratio of 10%. By rotating the test piece until the two notches machined in the fatigue test piece broke, and by counting the respective rotation numbers until the notches broke, the average of the two rotation numbers was defined as a breaking rotation number. Subsequently, by using the breaking rotation number of test material No. 21, that is, the comparative example (standard) given in Table 2 as a standard value, and by calculating the ratio of the breaking rotation number of each of the ring roll materials to the standard value, that is, (breaking rotation number of ring roll material)/(breaking rotation number of test material No. 21, that is, comparative example (standard)), the cal-

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culated ratio was defined as a fatigue resistance index and used as an index of fatigue resistance. Here, a case where the fatigue resistance index was 1.1 or more was judged as a case of "excellent fatigue resistance".

[0061] The wear test piece had an outer diameter of 60 mm ϕ , an inner diameter of 25 mm ϕ , and a width of 10 mm. In addition, the edges of the rolling contact surface of the wear test piece had chamfered corners. A wear test was performed on the wear test piece described above in order to evaluate wear resistance.

[0062] A wear test was, as illustrated in Fig. 4, performed by using a slip-rolling-type method between two discs, which were the test piece and a counter material. That is, while the test piece (wear test piece) was cooled with water and rotated at a rotational speed of 700 rpm, the counter piece (composed of S45C and having an outer diameter of 190 mm ϕ , a width of 15 mm, and chamfered corners) was heated at a temperature of 830°C, pressed onto the rotating test piece with a contact load of 980 N, and rotated with a slip ratio of 10% until the cumulative rotation number was 200000. After the wear test had been performed, the amount of decrease in weight due to wear of the wear test piece was determined.

[0063] Subsequently, by using the amount of decrease in weight due to wear of test material No. 21, that is, the comparative example (standard) given in Table 2 as a standard value, and by calculating the ratio of the amount of decrease in weight due to wear of each of the test materials to the standard value, that is, (amount of decrease in weight due to wear of test material)/(amount of decrease in weight due to wear of test material No. 21, that is, comparative example (standard)), the calculated ratio was defined as a wear resistance index and used to evaluate wear resistance. Here, a case where the wear resistance index was 1.1 or more was judged as a case of "excellent wear resistance".

[0064] The obtained results are given in Table 2.

[Table 1]

Test Molten Metal	Chemical Composition (mass%)													Relational Expression (1)*		Note
	C	Si	Mn	Cr	Mo	V	Nb	Impurity				Effective C Content (mass%)	Satisfied or not			
								P	S	N	B					
A	1.9	0.8	0.9	7.8	5.3	4.8	0.8	0.025	0.008	0.025	0.003	0.6	○	Conforming Example		
B	2.2	0.5	0.4	6.4	5.6	6.0	1.1	0.024	0.011	0.036	0.009	0.6	○	Conforming Example		
<u>C</u>	2.0	0.4	0.7	6.3	4.2	5.6	1.0	0.008	0.012	0.041	0.007	<u>0.5</u>	×	Comparative Example		
D	2.4	0.5	0.6	6.2	5.4	6.0	0.8	0.017	0.013	0.034	0.006	0.9	○	Conforming Example		
E	2.6	0.4	0.6	6.2	5.3	5.9	0.8	0.014	0.011	0.039	0.009	1.1	○	Conforming Example		
F	2.9	0.5	0.5	6.1	4.2	6.1	0.6	0.009	0.014	0.024	0.003	1.4	○	Conforming Example		
G	<u>1.7</u>	0.5	0.5	6.2	5.1	5.6	0.7	0.025	0.010	0.026	0.002	<u>0.3</u>	×	Comparative Example		
H	<u>3.1</u>	0.4	0.5	7.2	4.6	6.1	1.0	0.018	0.009	0.033	0.004	<u>1.5</u>	×	Comparative Example		
I	2.2	0.3	0.4	6.1	5.4	6.4	1.4	0.024	0.013	0.045	0.001	<u>0.5</u>	×	Comparative Example		
J	<u>3.3</u>	0.6	0.5	5.2	4.3	6.2	0.9	0.006	0.004	0.037	-	<u>1.7</u>	×	Comparative Example		
K	2.4	0.2	0.3	9.1	6.8	6.8	0.8	0.016	0.009	0.038	-	0.7	○	Conforming Example		
L	2.4	0.4	0.5	4.8	5.8	5.6	1.8	0.022	0.014	0.016	-	0.8	○	Conforming Example		
M	2.5	0.2	1.3	5.7	4.3	6.0	0.9	0.018	0.012	0.024	0.016	0.9	○	Conforming Example		
N	2.5	0.5	0.4	5.8	5.2	5.9	0.8	0.018	0.010	0.029	0.008	1.0	○	Conforming Example		
<u>O</u>	2.6	<u>1.6</u>	0.8	<u>4.2</u>	3.8	4.3	0.9	0.022	0.006	0.036	0.007	<u>1.5</u>	×	Comparative Example		
P	2.6	0.4	0.4	5.6	4.9	6.1	1.2	0.023	0.012	0.042	-	1.0	○	Conforming Example		
Q	2.0	0.3	0.5	6.8	6.2	4.4	2.0	0.024	0.007	0.038	0.007	0.6	○	Conforming Example		
<u>R</u>	<u>3.3</u>	0.5	0.5	<u>9.6</u>	5.4	5.2	2.4	0.015	0.016	0.028	0.003	<u>1.7</u>	×	Comparative Example		
S	1.8	0.5	0.4	7.2	6.7	4.2	0.9	0.017	0.015	0.028	0.002	0.7	○	Conforming Example		
<u>T</u>	2.4	0.5	0.5	5.4	<u>7.7</u>	5.2	0.5	0.025	0.008	0.028	0.003	1.1	○	Comparative Example		
<u>Y</u>	2.2	0.3	0.3	6.0	<u>2.5</u>	5.0	1.5	0.018	0.011	0.032	0.048	0.8	○	Comparative Example		

*: $0.6 \leq (C - 0.24V - 0.13Nb) \leq 1.4 \dots(1)$

Effective C content: C - 0.24V - 0.13Nb

An underlined portion indicates an item out of the range according to the present invention.

[Table 2]

Test Material No.	Molten Metal No.	Hardness Hs	Test Result		Note
			Wear Resistance	Fatigue Resistance	
1	A	67	1.1	1.2	Example
2	B	73	1.2	1.2	Example
<u>3</u>	<u>C</u>	<u>65</u>	0.7	0.7	Comparative Example
4	D	68	1.5	1.5	Example
5	E	73	1.6	1.6	Example
6	F	76	1.2	1.3	Example
<u>7</u>	<u>G</u>	<u>64</u>	0.8	0.4	Comparative Example
<u>8</u>	<u>H</u>	78	0.8	0.6	Comparative Example
9	<u>I</u>	71	0.7	0.8	Comparative Example
<u>10</u>	<u>J</u>	69	0.6	0.4	Comparative Example
11	K	73	1.6	1.6	Example
12	L	73	1.3	1.4	Example
13	M	75	1.3	1.3	Example
14	N	67	1.4	1.5	Example
<u>15</u>	<u>O</u>	77	0.8	0.6	Comparative Example
16	P	69	1.4	1.4	Example
17	Q	75	1.2	1.3	Example
<u>18</u>	<u>R</u>	71	1.1	0.6	Comparative Example
19	S	74	1.2	1.2	Example
<u>20</u>	<u>T</u>	72	1.1	0.7	Comparative Example
<u>21</u>	<u>Y</u>	72	1.0 (Standard)	1.0 (Standard)	Comparative Example (Standard)

An underlined portion indicates an item out of the range according to the present invention.

[0065] In the case of any of the examples of the present invention, although Shore hardness was within a range of Hs 67 or higher and Hs 76 or lower, which was lower than the hardness of the outer layer material of an ordinary roll for rolling a steel sheet, that is, Hs 81, there was no tendency for wear resistance or fatigue resistance to decrease with decreasing hardness in this range of hardness. With reference to the chemical compositions of molten metal given in Table 1, and on the basis of a comparison between the examples of the present invention and the comparative examples given in Table 2, it is considered that conditions regarding chemical composition such as effective C content has a rather large influence on wear resistance and fatigue resistance.

(Example 2)

[0066] Molten metal having the same chemical composition as that of test molten metal N (having an effective C content (C - 0.24V - 0.13Nb) of 0.98) given in Table 1 was cast into a single-layer sleeve roll having a circular cylindrical shape (having an outer diameter of 575 mm ϕ , an inner diameter of 255 mm ϕ , and a length of 2.0 m) by using a centrifugal casting method (with a centrifugal force of 195 G). The obtained sleeve roll was subjected to soft annealing and cut into plural pieces (having a length of about 350 mm). By providing a caliber having a desired shape to these sleeve rolls by performing crude processing, by heating the machined sleeve rolls to a temperature of 950°C to 1100°C in order to perform quenching, and by performing a tempering treatment including heating the quenched sleeve rolls to a temperature of 430°C to 600°C plural times, hardness was controlled.

[0067] Subsequently, by performing finish processing on the obtained sleeve rolls, test rolls (having a length of 305 mm) having the caliber shape (having a caliber bottom diameter of 81 mm) illustrated in Fig. 2 were obtained. By fitting these test rolls to a mandrel mill stand (stand #2) in a seamless steel pipe manufacturing line (172 passes), test rolling was performed on 1000 pipes or more for each of the sleeve rolls in a rolling cycle in which a 13%-Cr-steel pipe was mainly rolled in order to investigate whether or not slip occurred.

[0068] The obtained results are given in Table 3.

[Table 3]

Test Roll No.	Hardness Hs	Occurrence of Slip	Note
R1	72	Not occurred	Example
R2	74	Not occurred	Example
R3	77	Occurred	Comparative Example
R4	67	Not occurred	Example
R5	<u>63</u>	Not occurred (Surface Deterioration)	Comparative Example
R6	<u>65</u>	Not occurred (Surface Deterioration)	Comparative Example
R7	<u>79</u>	Occurred	Comparative Example
R8	<u>82</u>	Occurred	Comparative Example

An underlined portion indicates an item out of the range according to the present invention.

[0069] In the case of any of the rolls having the high-speed steel chemical composition within the range according to the present invention and a hardness of Hs 67 or higher and Hs 76 or lower in terms of Shore hardness, slip did not occur when used for hot-rolling seamless steel pipes. Surface deterioration of a roll occurred in the case of a hardness of lower than Hs 67, which is out of the range described above, and slip occurred in the case of a hardness of higher than Hs 76. It is clarified that a roll having the chemical composition within the range according to the present invention and a surface hardness of Hs 67 or higher and Hs 76 or lower in terms of Shore hardness is a roll with which it is possible to prevent surface deterioration and slip.

[0070] As described above, a caliber roll having the chemical composition and hardness within the ranges according to the present invention is a roll with which slip does not occur when hot rolling is performed, which is excellent in terms of wear resistance and fatigue resistance, and which is effectively used for rolling a seamless steel pipe.

Claims

1. A centrifugal cast caliber roll for a hot rolling mill, the roll having a chemical composition containing, by mass%, C: 1.8% or more and 3.0% or less, Si: 0.2% or more and 1.0% or less, Mn: 0.2% or more and 1.5% or less, Cr: 5% or more and 9% or less, Mo: 4.0% or more and 7.0% or less, V: 4.0% or more and 7.0% or less, Nb: 0.5% or more and 2.0% or less, and the balance being Fe and inevitable impurities, in which relational expression (1) below is satisfied, and a surface hardness of Hs 67 or higher and Hs 76 or lower in terms of Shore hardness:

$$0.6 \leq (C - 0.24V - 0.13Nb) \leq 1.4 \quad \dots (1),$$

where, C, V, and Nb each denote the content (mass%) of the corresponding chemical element.

2. The centrifugal cast caliber roll for a hot rolling mill according to Claim 1, the roll being a rolling roll for a seamless steel pipe.

FIG. 1

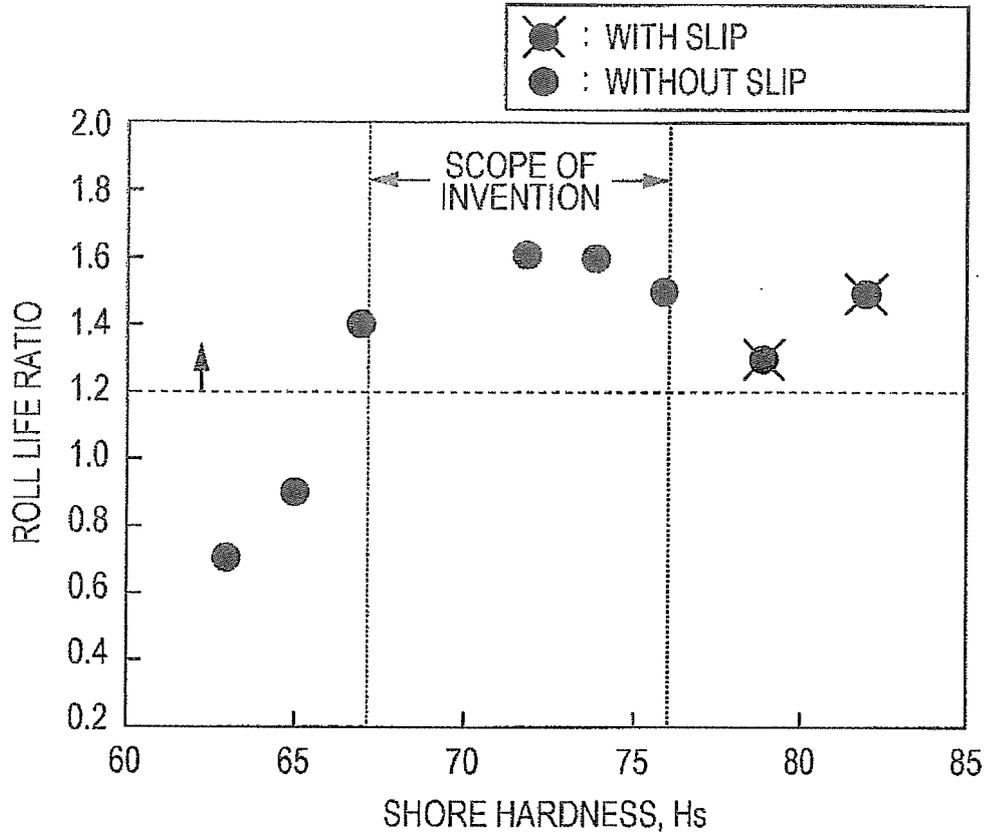


FIG. 2

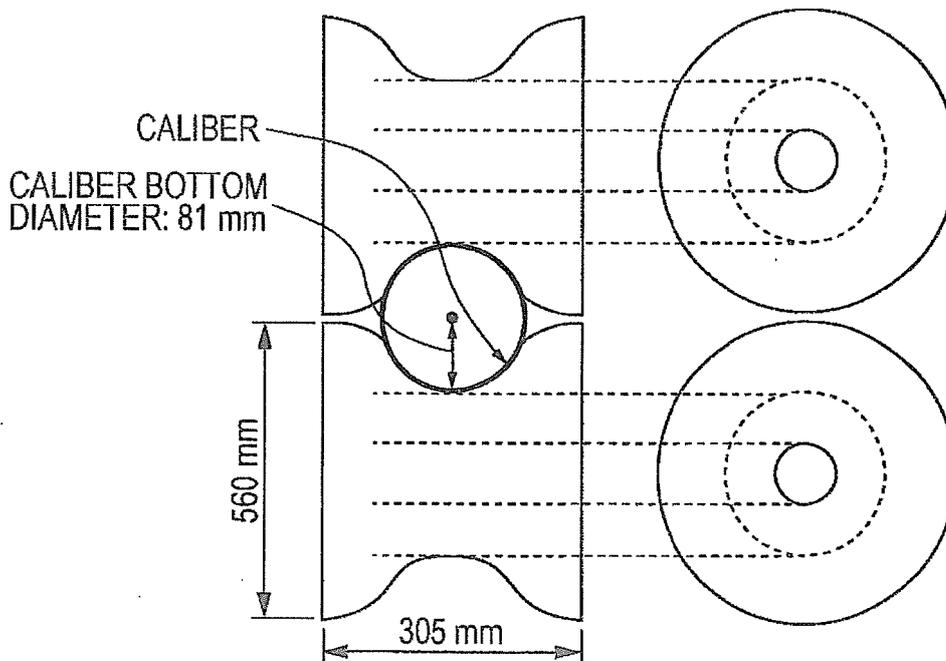


FIG. 3

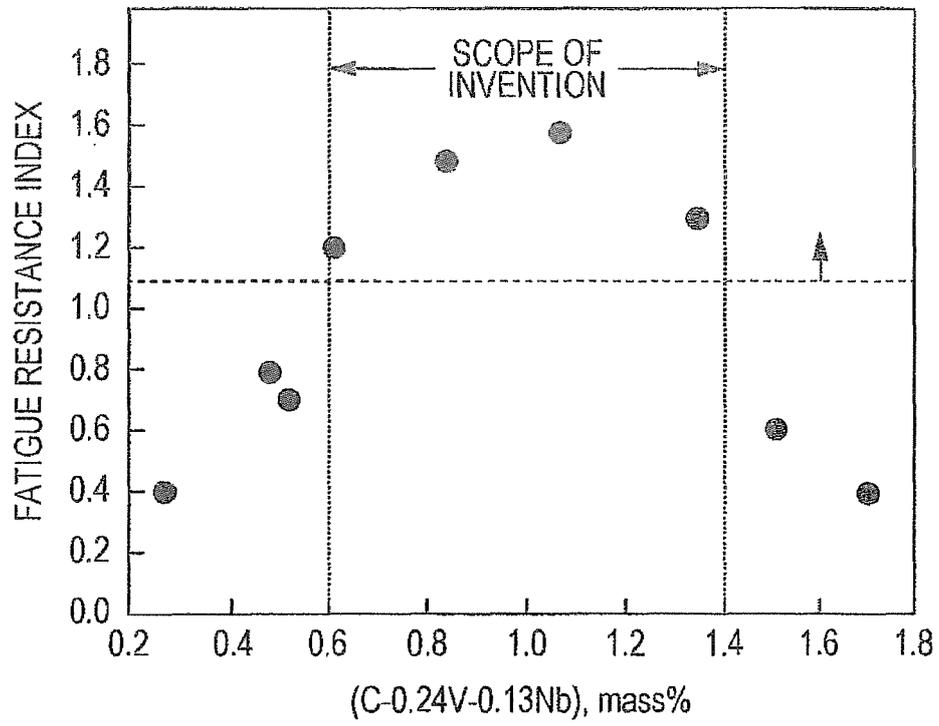


FIG. 4

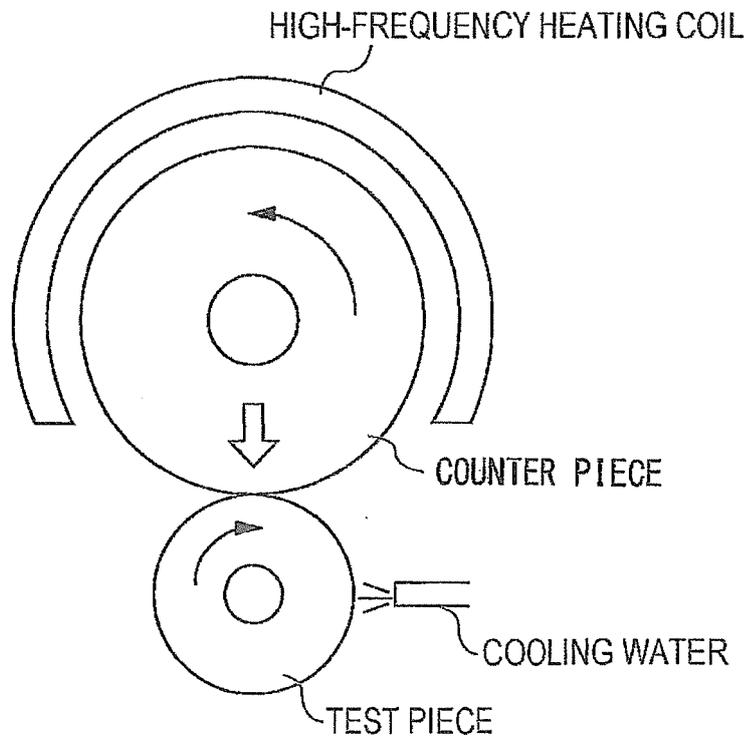
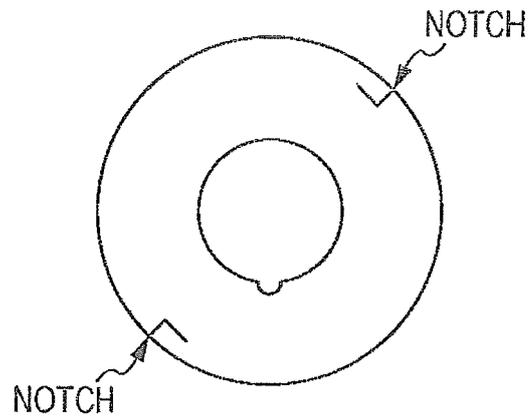
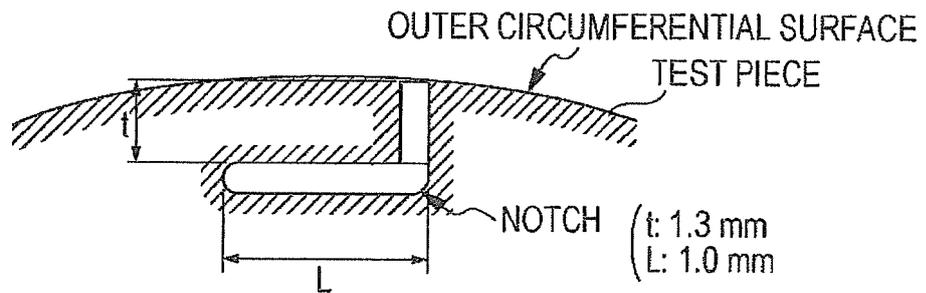


FIG. 5

(a)



(b)



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/003239

A. CLASSIFICATION OF SUBJECT MATTER

B21B27/00(2006.01)i, B22D13/02(2006.01)i, C21D5/00(2006.01)n, C22C37/00(2006.01)n

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B21B27/00-B21B27/02, C22C37/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2015
Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2002-129275 A (Kawasaki Steel Corp.), 09 May 2002 (09.05.2002), paragraphs [0057] to [0077]; fig. 1 (Family: none)	1-2
A	JP 2000-94014 A (Sumitomo Metal Industries, Ltd.), 04 April 2000 (04.04.2000), entire text; fig. 1 (Family: none)	1-2

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search
27 August 2015 (27.08.15)

Date of mailing of the international search report
08 September 2015 (08.09.15)

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- JP 7179945 A [0012]
- JP 2000094014 A [0012]