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(54) **ROLL OUTER LAYER MATERIAL FOR HOT ROLLING AND COMPOSITE ROLL FOR HOT ROLLING**

(57) An object is to provide an outer layer material of a hot rolling mill roll and a composite roll for hot rolling that have decreased pit defects on a roll surface and excellent resistance to surface roughening while ensuring wear resistance.

An outer layer material of a hot rolling mill roll, has a composition containing, in mass%, C: 2.0 to 3.0%, Si: 0.2 to 1.0%, Mn: 0.2 to 1.0%, Cr: 4.0 to 7.0%, Mo: 3.0 to 6.5%, V: 5.0 to 7.5%, Nb: 0.5 to 3.0%, Ni: 0.05 to 3.0%, Co: 0.2 to 5.0%, and W: 0.5 to 5.0%, with the balance being Fe and incidental impurities, and the contents of C, Cr, Mo, V, Nb, Ni, and W satisfying the following expression (1); has 85% or more of a matrix microstructure being a tempered martensite and/or a bainite microstructure; and has a minor axis of tempered martensite or bainite of 0.5 to 3.0 μm;

$$0.05 \le (\%C - \%V \times 0.177 - \%Nb \times 0.129 - \%Cr \times 0.099 - \%Mo \times 0.063 - \%W \times 0.033) + (\%Ni) \le 4.0 \quad (1)$$ (1)

where %C, %V, %Nb, %Cr, %Mo, %W, and %Ni each represent the respective content of each respective element (mass%).

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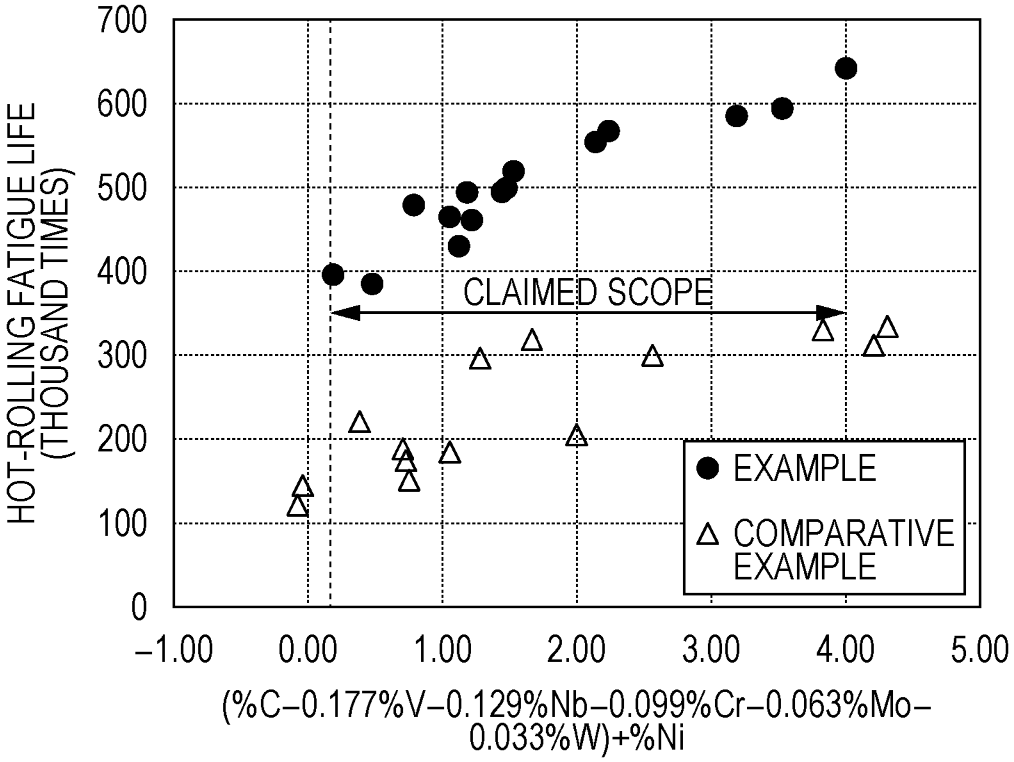
FIG. 3


HOT-ROLLING FATIGUE LIFE
(THOUSAND TIMES)
700
600
500
400
300
200
100
0
CLAIMED SCOPE
EXAMPLE
COMPARATIVE
EXAMPLE
−1.00
0.00
1.00
2.00
3.00
4.00
5.00
(%C−0.177%V−0.129%Nb−0.099%Cr−0.063%Mo−
0.033%W)+%Ni

Description

Technical Field

[0001] The present invention concerns a composite roll for hot rolling and relates especially to an outer layer material of a hot rolling mill roll and a composite roll for hot rolling that are suitable for a hot finishing mill for steel sheets.

Background Art

[0002] The environment in which rolls are used has become increasingly severe in recent years as hot rolling technology of steel sheets advances. In addition, production of steel sheets that are subjected to high loads, such as high-strength steel sheets and thin products, has been increasing. Accordingly, work rolls for rolling mills have become susceptible to frequent surface roughening and chipping defects due to fatigue on the rolling surfaces, and demand for further resistance to surface roughening and chipping has thus been growing. High-speed steel rolls having enhanced wear resistance due to V being incorporated in an amount of several % to form a large amount of hard carbides are widely used today in hot rolling.

[0003] As an outer layer material of such a high-speed steel roll, Patent Literature 1, for example, proposes an outer layer material of a rolling mill roll containing C: 1.5 to 3.5%, 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%, where Nb and V are contained such that the contents of Nb, V, and C satisfy a specific relationship and that a ratio of Nb to V falls within a specific range. As a result, an outer layer material of a rolling mill roll having excellent wear resistance and crack resistance is provided due to suppressed segregation of hard carbides in the outer layer material even when a centrifugal casting method is employed. Moreover, Patent Literature 2 proposes an outer layer material of a rolling mill roll containing C: 1.5 to 3.5%, 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%, where Nb and V are contained such that the contents of Nb, V, and C satisfy a specific relationship and that a ratio of Nb to V falls within a specific range. As a result, even when a centrifugal casting method is employed, segregation of hard carbides in the outer layer material is suppressed, and wear resistance and crack resistance are enhanced, thereby contributing largely to increased productivity in hot rolling.

[0004] Meanwhile, to enhance quality and productivity of hot-rolled products, the environment in which hot rolling mill rolls are used has become increasingly severe and the amount of continuously rolled steel sheets has been increasing. Moreover, there are stricter requirements for the surface quality of hot-rolled products. Accordingly, decreasing fatigue damage on a roll surface, such as surface roughening, rather than wear has become an enormous challenge. To tackle such a challenge, Patent Literature 3 proposes a centrifugally cast composite roll having excellent fatigue resistance of a roll surface layer in a hot rolling environment by adjusting the contents of C, Mo, V, and Nb in the composition containing C: 2.2 to 2.6%, Cr: 5.0 to 8.0%, Mo: 4.4 to 6.0%, V: 5.3 to 7.0%, and Nb 0.6 to 1.3% so that Mo + V and C - 0.24V - 0.13Nb fall within specific ranges. Moreover, Patent Literature 4 proposes an outer layer material of a rolling mill roll containing C: 1.3 to 2.2%, Si: 0.3 to 1.2%, Mn: 0.1 to 1.5%, Cr: 2.0 to 9.0%, Mo: 9.0% or less, V: 4.0 to 15.0%, and one or two or more of W: 20.0% or less, Ni: 5.0% or less, and Co: 10.0% or less, with the balance substantially being Fe and incidental impurities, where a size of a carbide dispersed in a microstructure falls within a specific range. Patent Literature 4 can decrease pit defects by lowering the amount of eutectic carbides that tend to be formed as coarse carbides.

Citation List

Patent Literature

[0005]

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. 2009-221573
PTL 4: Japanese Patent No. 3962838

Summary of Invention

Technical Problem

[0006] Recent rolling technology has been making progress at a remarkable rate for further improving the quality and grade of rolled steel sheets. At the same time, lower costs for rolling are highly demanded. The environment in which rolls are used has thus become increasingly severe. Accordingly, conventional designing of roll materials by focusing on carbides alone occasionally leads to a case in which formation of pit defects cannot be decreased.

[0007] The present invention has been made in view of the above, and an object of the present invention is to provide an outer layer material of a hot rolling mill roll and a composite roll for hot rolling that have decreased pit defects on a roll surface and excellent resistance to surface roughening while ensuring wear resistance.

Solution to Problem

[0008] The present inventors closely investigated the sites where pit defects on the surface of a hot rolling mill roll arise. As a result, it was revealed that pit defects are pit-like chips resulting from propagation of cracks that originate from eutectic carbides (primarily, M_2C-, M_6C-, M_7C_3-, and $M_{23}C_6$-type carbides). In addition to conventionally focusing on the type and size of the carbides, the present inventors considered that lowering the propagation rate of cracks in a matrix microstructure is effective for decreasing pit defects, thereby completing the present invention. In other words, as a result of studies on various factors that affect resistance to hot-rolling fatigue and the size of a matrix microstructure of an outer layer material of a roll, the present inventors newly found that fatigue resistance during hot rolling is remarkably enhanced by adjusting the component range of each element and by adjusting the content of each element so that each element satisfies a specific relationship. In addition, it was found that fatigue resistance during hot rolling is further remarkably enhanced by controlling the size of a matrix microstructure.

[0009] First, the experimental results that underlie the present studies will be described. Molten metal, in a high-frequency induction furnace, having a composition that varies within the following ranges containing, in mass%, Si: 0.1 to 1.5%, Mn: 0.1 to 1.5%, C: 1.6 to 3.5%, Cr: 3.5 to 9.0%, Mo: 2.1 to 7.0%, V: 4.1 to 8.5%, Nb: 0.3 to 4.6%, Ni: 0.02 to 3.6%, Co: 0.3 to 8.0%, and W: 0.2 to 8.0%, with the balance being Fe and incidental impurities, was cast, by a centrifugal casting method, into a ring roll material (outer diameter: 250 mmϕ, width: 65 mm, thickness 55 mm) that corresponds to an outer layer material of a roll. A pouring temperature was set to 1,450°C to 1,530°C, and a centrifugal force in the circumferential portion of the ring roll material was set to 180G as a gravity multiple. The hardness HS of 78 to 86 was achieved by performing quenching and tempering after casting. Quenching was performed by heating to a heating temperature of 1,070°C and air cooling. Tempering was performed at a temperature of 530°C to 570°C twice or three times depending on the components such that the amount of retained austenite in volume% became less than 10%.

[0010] A specimen for a hot-rolling fatigue test (outer diameter 60 mmϕ, thickness 10 mm) was taken from the obtained ring roll material and subjected to a hot-rolling fatigue test that disclosed in Japanese Unexamined Patent Application Publication No. 2010-101752 to achieve reproducible assessment of fatigue resistance of a work roll for hot rolling in an actual machine. A notch (depth t: 1.2 mm, length in circumferential direction L: 0.8 mm) as illustrated in Fig. 1 was introduced into two sites on the outer surface of the fatigue specimen by discharge machining (wire-cut) using a 0.2 mmϕ wire. The ends on the rolling surface of the fatigue specimen were chamfered at 1.2C.

[0011] The hot-rolling fatigue test was performed in a two-disk rolling-sliding mode between the specimen having notches (specimen for hot-rolling fatigue test) and a heated loading piece as illustrated in Fig. 1. Specifically, as illustrated in Fig. 1, the specimen 1 (specimen for hot-rolling fatigue test) was rotated at 700 rpm and simultaneously cooled with cooling water 2 while the loading piece 4 (material: S45C, outer diameter: 190 mmϕ, width: 15 mm) heated to 800°C by a high-frequency induction heating coil 3 was pressed against the rotating specimen 1 under a load of 980 N and rolled at a slip rate of 9%. The specimen for a hot-rolling fatigue test 1 was rotated until breaking at two notches 5 introduced thereinto, the number of rolling rotations until breakage at each notch was counted, and the average was regarded as hot-rolling fatigue life. A hot-rolling fatigue life exceeding 350,000 times was evaluated as a remarkably excellent hot-rolling fatigue life.

[0012] Moreover, microstructure observation of the obtained ring roll material was performed. Microstructure observation was performed with an optical microscope after taking a 10 × 10 × 5 mm specimen (5 mm in ring thickness direction) for microstructure observation at any position 10 mm inside the outer surface of the ring roll material, mirror-polishing the 10 × 10 mm surface, and etching with Nital (5 volume% nitric acid + ethanol) for about 10 seconds.

[0013] Further, to measure a minor axis (short-axis length) of tempered martensite or bainite, EBSD measurement was performed after taking a specimen for measurement (5 mm × 10 mm × 5 mm) at any position 10 mm inside the outer surface of the obtained ring roll material and mirror-polishing the 5 mm × 10 mm surface. The measurement of a minor axis was performed by electron backscatter diffraction (EBSD) in a region of 10,000 μm^2 or more at an accelerating voltage of 15 kV and a step size of 0.1 μm. Boundary lines were drawn at sites with misorientation of 15° or more from neighboring measurement points, minor axes of 20 crystals with a major axis of 5 μm or more were measured on the measurement surface by regarding a region surrounded by the boundary lines as one crystal as illustrated in Fig. 12, and the average value was calculated.

[0014] Regarding the obtained results, a relationship between hot-rolling fatigue life and (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) is shown in Fig. 3, and a relationship between hot-rolling fatigue life and the minor axis of tempered martensite or bainite is shown in Fig. 4.

[0015] Fig. 3 reveals that the hot-rolling fatigue life is remarkably enhanced when the expression (%C - %V × 0.177

- %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) is 0.05 or more and 4.0 or less. Here, V, Cr, Mo, Nb, and W are elements that tend to form carbides, and the expression (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) represents the amount of carbon dissolved in a matrix. The expression (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) is thus the sum of the amount of carbon and the amount of Ni dissolved in the matrix. By adjusting this value within an appropriate range, an outer layer material of a roll having a slow propagation rate of cracks in the matrix and thus excellent hot-rolling fatigue life is obtained. Further, by satisfying the above-mentioned component range and by controlling the crystal size of tempered martensite or bainite in the matrix microstructure within the range shown in Fig. 4, it becomes possible to remarkably enhance hot-rolling fatigue life.

[0016] The present invention has been completed on the basis of the above findings and is summarized as follows.

[1] An outer layer material of a hot rolling mill roll, having a composition containing, in mass%, C: 2.0 to 3.0%, Si: 0.2 to 1.0%, Mn: 0.2 to 1.0%, Cr: 4.0 to 7.0%, Mo: 3.0 to 6.5%, V: 5.0 to 7.5%, Nb: 0.5 to 3.0%, Ni: 0.05 to 3.0%, Co: 0.2 to 5.0%, and W: 0.5 to 5.0%, with the balance being Fe and incidental impurities, and the contents of C, Cr, Mo, V, Nb, Ni, and W satisfying the following expression (1); having 85% or more of a matrix microstructure being a tempered martensite and/or a bainite microstructure; and having a minor axis of tempered martensite or bainite of 0.5 to 3.0 μm; 0.05 ≤ (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) ≤ 4.0 (1) where %C, %V, %Nb, %Cr, %Mo, %W, and %Ni each represent the respective content of each respective element (mass%).

[2] A composite roll for hot rolling, including an outer layer and an inner layer which are integrally fused, where the outer layer is formed from the outer layer material of a hot rolling mill roll according to [1]. Advantageous Effects of Invention

[0017] According to the present invention, it becomes possible to manufacture an outer layer material of a hot rolling mill roll and a composite roll for hot rolling that have a remarkably lowered propagation rate of cracks. As a result, there are also advantages that surface damage due to hot rolling, such as surface roughening and chipping, can be decreased, thereby extending a continuous rolling distance and enhancing roll life.

Brief Description of Drawings

[0018]

Fig. 1 schematically illustrates the configuration of a testing machine used in a hot-rolling fatigue test, a specimen for a hot-rolling fatigue test (fatigue specimen), and the shape and size of a notch introduced into the outer surface of the specimen for a hot-rolling fatigue test (fatigue specimen).

Fig. 2 shows a measured result obtained by EBSD of an outer layer material of a hot rolling mill roll according to an embodiment of the present invention.

Fig. 3 shows a relationship between hot-rolling fatigue life and (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) in a hot-rolling fatigue test.

Fig. 4 shows a relationship between hot-rolling fatigue life and the minor axis of tempered martensite or bainite in the hot-rolling fatigue test.

Description of Embodiments

[0019] An outer layer material of a hot rolling mill roll of the present invention is manufactured by a casting method, such as a publicly known centrifugal casting method or the continuous pouring process for cladding, and applied to an outer layer material of a composite roll for hot rolling, which is suitable for hot finish rolling, although the outer layer material may be used as a ring roll or a sleeve roll without additional material. Meanwhile, a composite roll for hot rolling of the present invention is composed of an outer layer and an inner layer that is integrally fused. Here, an intermediate layer may be provided between the outer layer and the inner layer. In other words, in place of an inner layer that is integrally fused with an outer layer, an inner layer may be integrally fused with an intermediate layer that has been integrally fused with an outer layer. In the present invention, the composition of each inner layer or intermediate layer is not particularly limited, and the inner layer is preferably spheroidal graphite cast iron (ductile cast iron) or forged steel, while the intermediate layer is preferably high-carbon material containing C: 1.5 to 3.0 mass%.

[0020] First, the reasons for limiting the composition of an outer layer (outer layer material) of a composite roll for hot rolling of the present invention will be described. Hereinafter, mass% is simply denoted by % unless otherwise stated.

C: 2.0 to 3.0%

[0021] C acts to increase the hardness of a matrix through dissolution and to enhance wear resistance of an outer layer material of a roll through formation of hard carbides by bonding with carbide-forming elements. The amount of eutectic carbides varies according to C content. Eutectic carbides affect characteristics of rolling applications. When C content is less than 2.0%, an insufficient amount of eutectic carbides increases frictional force during rolling and destabilizes rolling, while a low amount of C dissolved in a matrix microstructure lowers hot-rolling fatigue resistance. Meanwhile, when the content exceeds 3.0%, carbides coarsen and the amount of eutectic carbides increases excessively, and consequently, an outer layer material of a roll is hardened and embrittled, which promotes generation and growth of fatigue cracks, thereby decreasing fatigue resistance. Accordingly, C is limited to the range of 2.0 to 3.0% and is preferably 2.1 to 2.8%.

Si: 0.2 to 1.0%

[0022] Si is an element that acts as a deoxidizing agent and enhances casting properties of molten metal. To obtain such effects, a content of 0.2% or more is required. Meanwhile, when a content exceeds 1.0%, the effects level off, effects commensurate with the content cannot be expected, economical disadvantages thus result, and worse still a matrix microstructure is embrittled in some cases. Accordingly, Si is limited to 0.2 to 1.0% and is preferably 0.3 to 0.7%.

Mn: 0.2 to 1.0%

[0023] Mn is an element that acts to fix S as MnS to suppress the effect of S and effectively enhances hardenability through partial dissolution in a matrix microstructure. To obtain such effects, a content of 0.2% or more is required. Meanwhile, when a content exceeds 1.0%, the effects level off, effects commensurate with the content thus cannot be expected, and worse still the material is embrittled in some cases. Accordingly, Mn is limited to 0.2 to 1.0% and is preferably 0.3 to 0.8%.

Cr: 4.0 to 7.0%

[0024] Cr is an element that acts to enhance wear resistance primarily through formation of eutectic carbides by bonding with C and to stabilize rolling by lowering the frictional force with steel sheets during rolling and decreasing surface damage to rolls. To obtain such effects, a content of 4.0% or more is required. Meanwhile, when a content exceeds 7.0%, fatigue resistance is reduced due to increased coarse eutectic carbides. Accordingly, Cr is limited to the range of 4.0 to 7.0% and is preferably 4.3 to 6.5%.

Mo: 3.0 to 6.5%

[0025] Mo is an element that forms hard carbides by bonding with C to enhance wear resistance. Moreover, Mo dissolves in hard MC-type carbides composed of bonded V, Nb, and C to strengthen the carbides and dissolves in eutectic carbides to increase fracture resistance of the carbides. Through such actions, Mo enhances wear resistance and fatigue resistance of an outer layer material of a roll. To obtain such effects, a content of 3.0% or more is required. Meanwhile, when a content exceeds 6.5%, Mo-based brittle carbides are formed, thereby lowering hot-rolling fatigue resistance and lowering fatigue resistance. Accordingly, Mo is limited to the range of 3.0 to 6.5% and is preferably 3.5 to 6.0%.

V: 5.0 to 7.5%

[0026] V is an important element in the present invention to impart both wear resistance and fatigue resistance of rolls. V is an element that enhances wear resistance through formation of extremely hard carbides (MC-type carbides) and remarkably enhances fatigue resistance as an outer layer material of a roll by effectively acting to enable divided and dispersed precipitation of eutectic carbides, thereby enhancing hot-rolling fatigue resistance. Such effects become evident at a content of 5.0% or more. Meanwhile, a content exceeding 7.5% coarsens MC-type carbides and thus destabilizes various characteristics of rolling mill rolls. Accordingly, V is limited to the range of 5.0 to 7.5% and is preferably 5.2 to 7.0%.

Nb: 0.5 to 3.0%

[0027] Nb enhances wear resistance, especially fatigue resistance by acting to strengthen MC-type carbides through dissolution therein and to thus increase fracture resistance of MC-type carbides. Dissolution of Nb and Mo together in carbides remarkably enhances wear resistance and fatigue resistance. In addition, Nb is an element that acts to suppress fracture of eutectic carbides through promoted division of eutectic carbides and enhances fatigue resistance of an outer layer material of a roll. Further, Nb also acts to suppress segregation of MC-type carbides during centrifugal casting. Such effects become evident at a content of 0.5% or more. Meanwhile, when a content exceeds 3.0%, growth of MC-type carbides in molten metal is promoted, thereby impairing hot-rolling fatigue resistance. Accordingly, Nb is limited to the range of 0.5 to 3.0% and is preferably 0.8 to 1.5%.

Ni: 0.05 to 3.0%

[0028] Ni is an element that lowers the transformation temperature of austenite during heat treatment through dissolution in a matrix and enhances hardenability of the matrix. To obtain such effects, a content of 0.05% or more is required. Meanwhile, when a content exceeds 3.0%, the transformation temperature of austenite becomes excessively low and hardenability is enhanced, thereby causing austenite to be readily retained after heat treatment. Such retained austenite lowers hot-rolling fatigue resistance through generation of cracks during hot rolling, for example. Accordingly, Ni is limited to the range of 0.05 to 3.0%. Due to ease of operation, i.e., possible refining of the crystal size of a matrix microstructure even at a slow cooling rate during heat treatment, the content is preferably 0.2 to 3.0%.

Co: 0.2 to 5.0%

[0029] Co is an element that acts to strengthen a matrix especially at a high temperature through dissolution in the matrix and to enhance fatigue resistance. To obtain such effects, a content of 0.2% or more is required. Meanwhile, when a content exceeds 5.0%, the effects level off, effects commensurate with the content cannot be expected, and economical disadvantages thus result. Accordingly, Co is limited to the range of 0.2 to 5.0% and is preferably 0.5 to 3.0%.

W: 0.5 to 5.0%

[0030] W is an element that acts to strengthen a matrix especially at a high temperature through dissolution in the matrix and to enhance fatigue resistance. W also enhances wear resistance through formation of M_2C- or M_6C-type carbides. To obtain such effects, a content of 0.5% or more is required. Meanwhile, when a content exceeds 5.0%, not only do the effects level off, but also hot-rolling fatigue resistance is reduced through the formation of coarse M_2Cor M_6C-type carbides. Accordingly, W is limited to the range of 0.5 to 5.0% and is preferably 1.0 to 3.5%.

[0031] In the present invention, C, Cr, Mo, V, Nb, Ni, and W are contained in the above-mentioned ranges and are also contained, through adjustment, so as to satisfy the following expression (1):

$$0.05 \le (\%C - \%V \times 0.177 - \%Nb \times 0.129 - \%Cr \times 0.099 - \%Mo \times 0.063 - \%W \times 0.033) + (\%Ni) \le 4.0 \quad (1)$$

where %C, %V, %Nb, %Cr, %Mo, %W, and %Ni each represent the respective content of each respective element (mass%).

[0032] By adjusting (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) to satisfy the above expression (1), the number of rolling until breakage occurs is remarkably increased, and hot-rolling fatigue resistance is thus remarkably enhanced. The expression (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) is an important factor to become a driving force for improved hot-rolling fatigue resistance, and hot-rolling fatigue resistance deteriorates outside the scope of the above expression (1). Here, V, Cr, Mo, Nb, and W are elements that tend to form carbides, and the expression (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) represents the amount of carbon dissolved in a matrix. The expression (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) is thus the sum of the amount of carbon and Ni dissolved in the matrix. By adjusting this value within an appropriate range, an outer layer material of a roll having a slow propagation rate of cracks in the matrix and thus excellent hot-rolling fatigue life is obtained. Therefore, in the present invention, (%C - %V × 0.177 - %Nb × 0.129 - %Cr × 0.099 - %Mo × 0.063 - %W × 0.033) + (%Ni) is adjusted to satisfy the above expression (1) .

[0033] The balance other than the components described above is Fe and incidental impurities.

[0034] Further, in the present invention, preferably 85% or more of a matrix microstructure is a tempered martensite and a bainite microstructure, and a minor axis of tempered martensite or bainite is 0.5 to 3.0 μm. When the fraction of a retained austenite and/or a pearlite microstructure is high, hot-rolling fatigue resistance lowers. Accordingly, a tempered martensite and/or a bainite microstructure is preferably contained in 85% or more of the matrix microstructure and more preferably contained in 90% or more in view of hot-rolling fatigue resistance. The balance includes retained austenite and/or pearlite. To achieve 85% or more of tempered martensite and/or bainite in the matrix microstructure, the number of cooling steps repeated after heating to and retaining at 500°C to 570°C may be controlled.

[0035] In a component system in which a minor axis of tempered martensite or bainite is less than 0.5 μm, it becomes difficult to decrease the amount of retained austenite even by repeated tempering due to excessively lowered transformation temperature, and hot-rolling fatigue resistance lowers due to possible crack generation during hot rolling caused by retained austenite. Meanwhile, when a minor axis of tempered martensite or bainite exceeds 3.0 μm, a propagation rate of cracks in the matrix microstructure is fast, and hot-rolling fatigue resistance thus lowers. Accordingly, a minor axis of tempered martensite or bainite is preferably limited to the range of 0.5 to 3.0 μm and preferably to the range of 0.5 to 2.0 μm in view of hot-rolling fatigue resistance. To achieve such a minor axis, components and a cooling rate may be controlled such that the transformation temperature of the matrix falls within the range of 200°C to 400°C.

[0036] Next, a preferable method of manufacturing a composite roll for hot rolling of the present invention will be described.

[0037] In the present invention, an outer layer material is preferably manufactured by a casting method, such as a publicly known centrifugal casting method or the continuous pouring process for cladding. The present invention is obviously not limited to these methods.

[0038] When an outer layer material of a roll is cast by a centrifugal casting method, molten metal having the above-described composition for an outer layer material of a roll is first poured into a rotating mold whose inner surface is covered with 1 to 5 mm-thick refractory containing zircon and the like as a main material to achieve a predetermined thickness and then centrifugally cast. Here, the number of rotations of the mold is preferably set such that a gravity multiple applied to the outer surface of the roll falls within the range of 120 to 220G. When an intermediate layer is formed, molten metal having an intermediate layer composition is preferably poured into the rotating mold during solidification or after completing solidification of the outer layer material of a roll and then centrifugally cast. A composite roll is preferably formed by terminating rotation of the mold after the outer layer or the intermediate layer has been completely solidified, allowing the mold to stand, and then performing static casting of an inner layer material. Through this step, the inner surface side of the outer layer material of a roll is redissolved to fuse as one body the outer layer and the inner layer, or the outer layer and the intermediate layer, as well as the intermediate layer and the inner layer.

[0039] For the inner layer subjected to static casting, spheroidal graphite cast iron, compacted vermicular graphite cast iron (CV cast iron), and so forth having excellent casting properties and mechanical properties are preferably used. In a centrifugally cast roll, an outer layer and an inner layer are integrally fused, and consequently, about 1 to 8 % components of the outer layer material are incorporated into the inner layer. Incorporation of carbide-forming elements, such as Cr and V, contained in the outer layer material into the inner layer embrittles the inner layer. Accordingly, the ratio of incorporation of outer layer components into an inner layer is preferably limited to less than 6%.

[0040] When an intermediate layer is formed, graphitized steel, high-carbon steel, hypoeutectic cast iron, or the like is preferably used as an intermediate layer material. The intermediate layer and the outer layer are similarly fused as one body, and outer layer components in the range of 10 to 95% are incorporated into the intermediate layer. From a viewpoint of decreasing the amount of outer layer components incorporated into an inner layer, it is essential to decrease the amount of outer layer components incorporated into the intermediate layer as much as possible.

[0041] A composite roll for hot rolling of the present invention is preferably heat-treated after casting. In heat treatment, a step of heating to 950°C to 1,100°C and air cooling or air blast cooling, and further, a step of cooling after heating to and retaining at 500°C to 570°C twice or more are preferably performed. On such an occasion, it becomes possible to achieve the above-mentioned suitable minor-axis size by adjusting a cooling rate in accordance with components so that the transformation temperature falls within the range of 200°C to 400°C. Here, depending on the number of the cooling step repeated after heating to and retaining at 500°C to 570°C, the amount of tempered martensite and/or bainite in a matrix microstructure varies. Accordingly, the number of the step repeated may be set such that 85% or more of a matrix microstructure becomes tempered martensite and/or bainite.

[0042] The hardness of a composite roll for hot rolling of the present invention is preferably 79 to 88HS (Shore hardness) and more preferably 80 to 86HS. Wear resistance deteriorates when the hardness is lower than 80HS, whereas it becomes difficult to remove, by grinding, cracks formed on the surface of a hot rolling mill roll during hot rolling when the hardness exceeds 86HS. To ensure the above hardness in a stable manner, it is preferable to adjust a heat treatment temperature and a heat treatment time after casting.

EXAMPLES

[0043] Molten metal, in a high-frequency induction furnace, having the composition for an outer layer material of a roll shown in Table 1 was formed into ring test materials (ring rolls; outer diameter: 250 mmϕ, width 65 mm, thickness 55 mm) by centrifugal casting. The pouring temperature was set to 1,450°C to 1,530°C, and the centrifugal force in the circumferential portion of the respective ring roll materials was set to 180G as a gravity multiple. After casting, each ring test material was quenched by reheating to a reheating temperature of 1,070°C followed by air-cooling and tempered at a temperature of 530°C to 570°C twice or three times depending on components to adjust the amount of retained austenite, in volume%, to less than 10% and the hardness to 78 to 86HS. A hardness specimen, a specimen for a hot-rolling fatigue test, and a specimen for EBSD measurement were taken from each obtained ring test material, and a hardness test, a hot-rolling fatigue test, and a microstructure observation test were performed.

[Table 1]

(mass%)

No.	C	Si	Mn	V	Cr	Mo	Ni	Nb	Co	W	Value of expression (1): (%C - 0.177%V - 0.129%Nb - 0.099%Cr - 0.063%Mo - 0.033%W) + %Ni	Scope of expression (1)	Note
1	2.0	0.2	0.3	6.0	5.0	4.5	0.50	1.0	0.5	2.0	0.46	Satisfied	Example
2	2.5	0.4	0.2	6.2	7.0	3.0	0.80	0.9	0.6	5.0	1.04	Satisfied	Example
3	3.0	0.6	0.5	5.8	5.0	4.2	0.70	3.0	0.8	2.0	1.46	Satisfied	Example
4	2.5	1.0	0.5	7.5	4.8	4.1	0.50	0.5	1.2	3.0	0.78	Satisfied	Example
5	2.3	0.5	1.0	6.1	4.0	6.5	1.00	1.5	0.5	0.5	1.20	Satisfied	Example
6	2.2	0.4	0.4	6.3	5.1	4.9	0.10	1.0	3.0	2.0	0.18	Satisfied	Example
7	2.4	0.4	0.4	5.0	4.7	4.5	0.50	0.9	0.8	1.3	1.11	Satisfied	Example
8	2.6	0.4	0.4	5.4	4.6	3.4	1.30	0.7	0.8	1.6	2.13	Satisfied	Example
9	2.7	0.6	0.3	5.9	4.5	4.6	2.50	1.3	0.7	2.0	3.19	Satisfied	Example
10	3.0	0.5	0.5	5.5	5.4	5.0	3.00	0.8	5.0	2.3	4.00	Satisfied	Example
11	2.1	0.5	0.6	5.2	6.8	4.3	1.30	0.6	0.7	0.8	1.43	Satisfied	Example
12	2.6	0.8	0.4	7.0	4.1	3.2	2.00	2.9	4.4	4.6	2.23	Satisfied	Example
13	2.3	0.2	0.9	6.4	4.3	6.1	1.60	2.4	3.8	4.0	1.52	Satisfied	Example
14	2.8	0.9	0.2	5.3	5.8	5.0	2.90	1.8	2.5	3.5	3.53	Satisfied	Example
15	2.7	0.3	0.5	7.3	4.6	4.6	0.80	1.6	1.9	2.6	1.17	Satisfied	Example
16	<u>1.8</u>	0.5	0.4	5.6	4.3	4.0	0.50	1.0	0.9	4.0	0.37	Satisfied	Comparative Example
17	<u>3.5</u>	0.4	0.4	6.0	4.3	4.4	1.00	1.3	0.5	<u>0.3</u>	2.56	Satisfied	Comparative Example
18	2.3	<u>0.1</u>	0.4	<u>8.3</u>	4.4	<u>2.1</u>	1.10	<u>0.3</u>	1.3	1.8	1.26	Satisfied	Comparative Example
19	2.3	0.5	1.0	<u>4.1</u>	4.8	3.5	<u>0.02</u>	1.0	1.4	2.4	0.69	Satisfied	Comparative Example

(continued)

(mass%)

No.	C	Si	Mn	V	Cr	Mo	Ni	Nb	Co	W	Value of expression (1): (%C - 0.177%V - 0.129%Nb - 0.099%Cr - 0.063%Mo - 0.033%W) + %Ni	Scope of expression (1)	Note
20	2.0	1.0	0.6	5.2	<u>3.5</u>	3.4	0.80	1.6	0.3	2.3	1.04	Satisfied	Comparative Example
21	2.6	0.6	0.6	5.5	<u>9.0</u>	<u>7.0</u>	0.70	1.7	2.6	1.9	0.71	Satisfied	Comparative Example
22	2.5	<u>1.2</u>	0.6	6.2	6.0	5.5	<u>3.60</u>	1.5	2.8	1.3	3.83	Satisfied	Comparative Example
23	2.4	0.7	<u>1.5</u>	6.0	5.6	5.0	0.90	<u>4.6</u>	4.6	1.1	0.74	Satisfied	Comparative Example
24	2.4	<u>1.5</u>	0.6	5.4	5.3	5.6	1.60	1.1	<u>8.0</u>	1.0	1.99	Satisfied	Comparative Example
25	2.4	0.6	0.6	<u>8.5</u>	5.0	5.7	1.80	1.4	2.2	<u>0.2</u>	1.65	Satisfied	Comparative Example
26	3.0	0.5	<u>1.3</u>	5.1	4.2	3.1	2.90	0.5	2.0	0.6	<u>4.30</u>	Unsatisfied	Comparative Example
27	2.1	0.5	0.6	5.8	5.0	3.9	0.20	2.8	0.6	<u>8.0</u>	<u>-0.09</u>	Unsatisfied	Comparative Example
28	2.3	0.5	0.6	6.2	6.6	6.0	0.20	2.1	3.3	4.6	<u>-0.05</u>	Unsatisfied	Comparative Example
29	2.8	0.5	<u>0.1</u>	5.1	4.2	3.1	3.00	0.5	1.1	0.6	<u>4.20</u>	Unsatisfied	Comparative Example

Underlined parts represent being outside the scope of the present invention.

[0044] Vickers hardness HV50 was measured according to JIS Z 2244 by using a Vickers hardness tester (test force: 50 kgf (490 N)) for the obtained hardness specimen and converted into Shore hardness HS by using a JIS conversion table. Here, the hardness was obtained by setting 10 measurement points and calculating the average after subtracting the maximum and minimum values.

[0045] A hot-rolling fatigue test method was as follows. A specimen for a hot-rolling fatigue test (outer diameter 60 mmϕ, thickness 10 mm, chamfered) was taken from each obtained ring test material. A notch (depth t: 1.2 mm, length in circumferential direction L: 0.8 mm) as illustrated in Fig. 1 was introduced into two sites (positions 180° apart) on the outer surface of the specimen for a hot-rolling fatigue test by discharge machining (wire-cut) using a 0.20 mmϕ wire. The hot-rolling fatigue test was performed in a two-disk rolling-sliding mode between the specimen and a loading material as illustrated in Fig. 1. The specimen 1 was rotated at 700 rpm and simultaneously cooled with cooling water 2 while the loading piece 4 (material: S45C, outer diameter: 190 mmϕ, width: 15 mm, C1-chamfered) heated to 800°C by a high-frequency induction heating coil 3 was brought into contact with the rotating test piece 1 under a load of 980 N and rolled at a slip rate of 9%. The specimen for a hot-rolling fatigue test 1 was rotated until breaking at two notches 5 introduced thereinto, the number of rolling rotations until breakage at each notch was counted, and the average was regarded as hot-rolling fatigue life. A hot-rolling fatigue life exceeding 350,000 times was evaluated as a remarkably excellent hot-rolling fatigue life.

[0046] Microstructure observation was performed with an optical microscope after taking a 10 × 10 × 5 mm specimen for microstructure observation (5 mm in ring thickness direction) at any position 10 mm inside the outer surface of the ring roll material, mirror-polishing the 10 × 10 mm surface, and etching with Nital (5 volume% nitric acid + ethanol) for about 10 seconds.

[0047] The minor axis (short-axis length) of tempered martensite or bainite was obtained by EBSD measurement after taking a specimen for EBSD measurement (5 mm × 10 mm × 5 mm) at any position 10 mm inside the outer surface of each obtained ring roll material and mirror-polishing the 5 mm × 10 mm surface. The EBSD measurement was performed in a region of 10,000 μm^2 or more at an accelerating voltage of 15 kV and a step size of 0.1 μm. For the obtained data, boundary lines were drawn at sites with misorientation of 15° or more from neighboring measurement points as illustrated in Fig. 2, the minor axis was measured for 20 crystals with a major axis of 10 μm or more on the measurement surface by regarding a region surrounded by the boundary lines as one crystal, and the average was calculated.

[0048] The obtained results are shown in Table 2.

[Table 2]

No.	Minor axis (μm)	Hardness (HS)	Hot-rolling fatigue life (thousand times)	Note
1	2.8	80	387	Example
2	2.4	82	467	Example
3	2.0	80	501	Example
4	2.5	78	481	Example
5	2.3	85	463	Example
6	2.9	86	398	Example
7	2.4	80	432	Example
8	1.7	81	556	Example
9	1.0	83	587	Example
10	0.5	79	643	Example
11	2.1	78	497	Example
12	1.4	80	569	Example
13	2.0	80	521	Example
14	0.7	83	596	Example
15	2.3	85	496	Example
16	2.8	86	223	Comparative Example
17	1.2	84	301	Comparative Example
18	2.2	82	298	Comparative Example

(continued)

No.	Minor axis (μm)	Hardness (HS)	Hot-rolling fatigue life (thousand times)	Note
19	2.7	80	190	Comparative Example
20	2.6	81	187	Comparative Example
21	2.9	81	176	Comparative Example
22	0.5	83	332	Comparative Example
23	2.8	84	153	Comparative Example
24	1.9	86	206	Comparative Example
25	0.6	80	321	Comparative Example
26	0.5	79	336	Comparative Example
27	3.6	78	123	Comparative Example
28	3.8	78	146	Comparative Example
29	0.5	80	314	Comparative Example

[0049] In the Examples, the hot-rolling fatigue life was remarkably enhanced, and an excellent hot-rolling fatigue life exceeding 350,000 times was exhibited. Moreover, as a result of microstructure observation, 85% or more of the matrix microstructure was confirmed to be tempered martensite and/or bainite in all the Examples.

[0050] According to the present invention, it becomes possible to manufacture a composite roll for hot rolling having a strikingly lowered propagation rate of cracks. As a result, surface damage due to hot rolling, such as surface roughening and chipping, can be suppressed, thereby effectively achieving an extended continuous rolling distance and enhanced roll life.

Reference Signs List

[0051]

1. Specimen (specimen for hot-rolling fatigue test)
2. Cooling water
3. High-frequency induction heating coil
4. Loading piece
5. Notch

Claims

1. An outer layer material of a hot rolling mill roll, having a composition containing, in mass%,
C: 2.0 to 3.0%,
Si: 0.2 to 1.0%,
Mn: 0.2 to 1.0%,
Cr: 4.0 to 7.0%,
Mo: 3.0 to 6.5%,
V: 5.0 to 7.5%,
Nb: 0.5 to 3.0%,
Ni: 0.05 to 3.0%,
Co: 0.2 to 5.0%, and
W: 0.5 to 5.0%,
with the balance being Fe and incidental impurities, and the contents of C, Cr, Mo, V, Nb, Ni, and W satisfying the following expression (1); having 85% or more of a matrix microstructure being a tempered martensite and/or a bainite microstructure; and having a minor axis of tempered martensite or bainite of 0.5 to 3.0 μm;

$$0.05 \leq (\%C - \%V \times 0.177 - \%Nb \times 0.129 - \%Cr \times 0.099 - \%Mo \times 0.063 - \%W \times 0.033) + (\%Ni) \leq 4.0 \quad (1)$$

wherein %C, %V, %Nb, %Cr, %Mo, %W, and %Ni each represent the respective content of each respective element (mass%).

2. A composite roll for hot rolling, comprising an outer layer and an inner layer which are integrally fused, wherein the outer layer is formed from the outer layer material of a hot rolling mill roll according to Claim 1.

FIG. 1

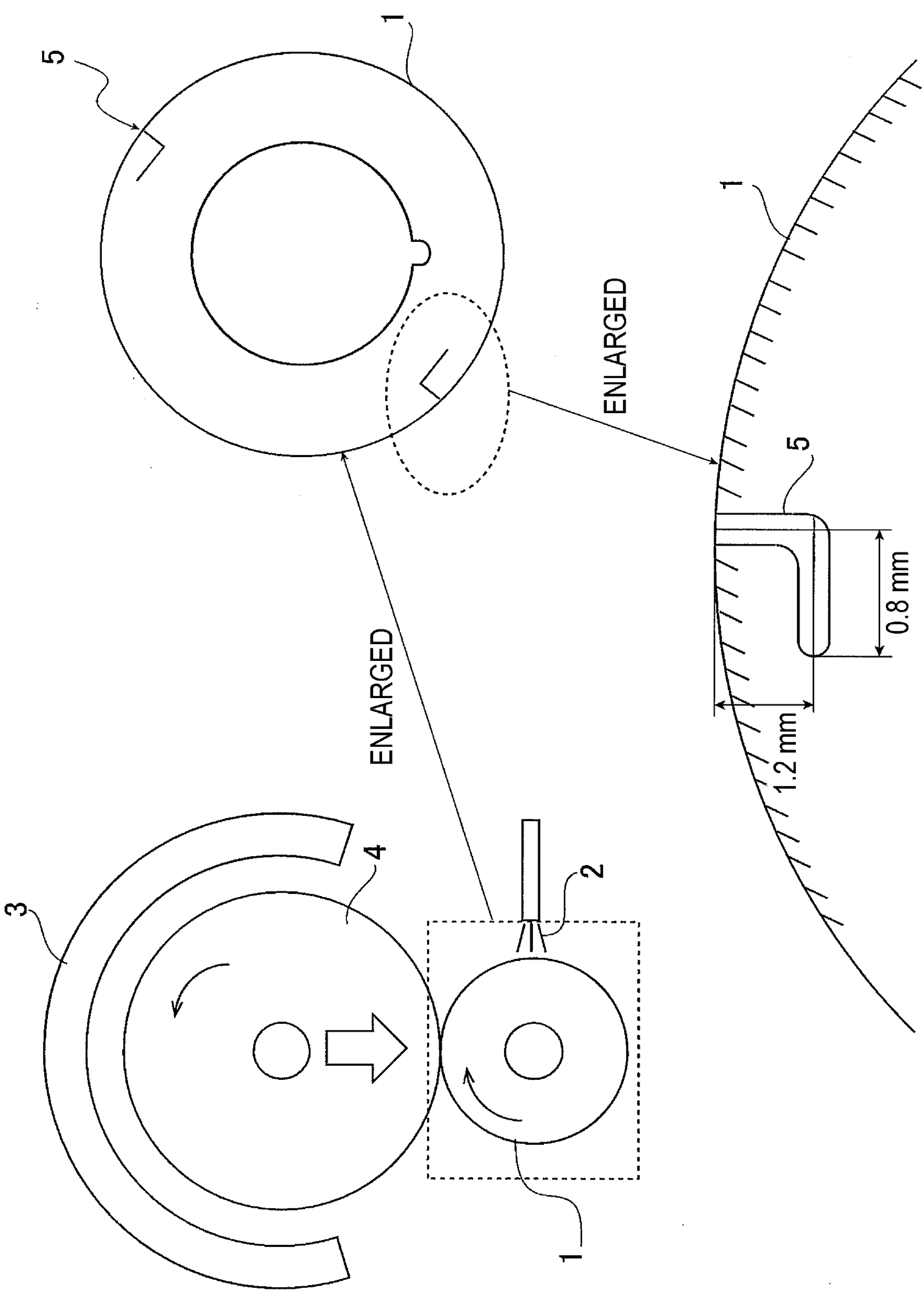


FIG. 2

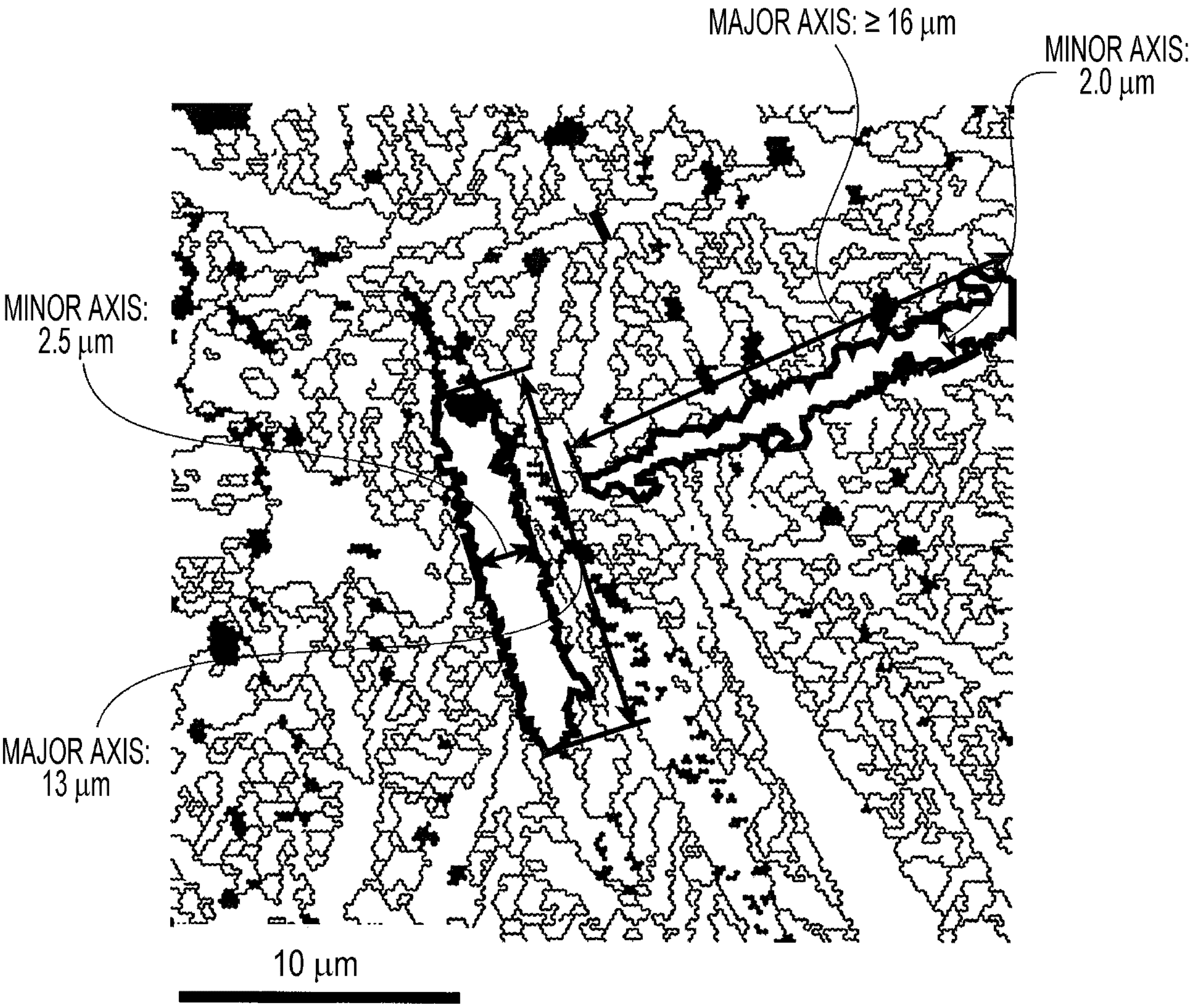

MAJOR AXIS: ≥ 16 μm
MINOR AXIS: 2.0 μm
MINOR AXIS: 2.5 μm
MAJOR AXIS: 13 μm
10 μm

FIG. 3

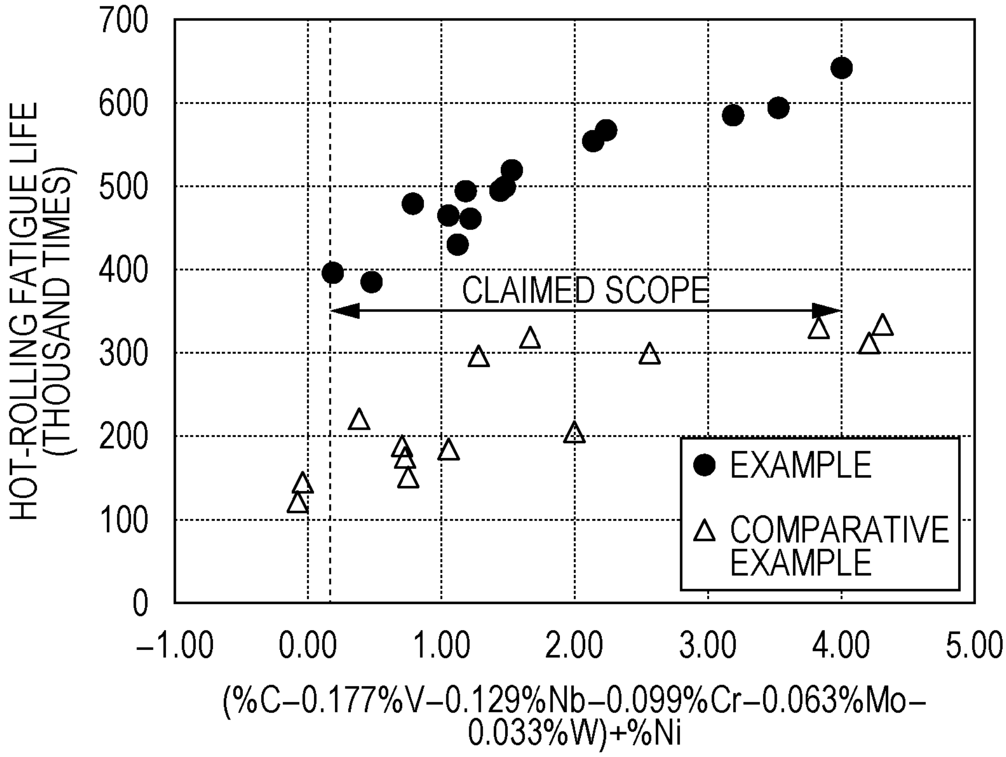
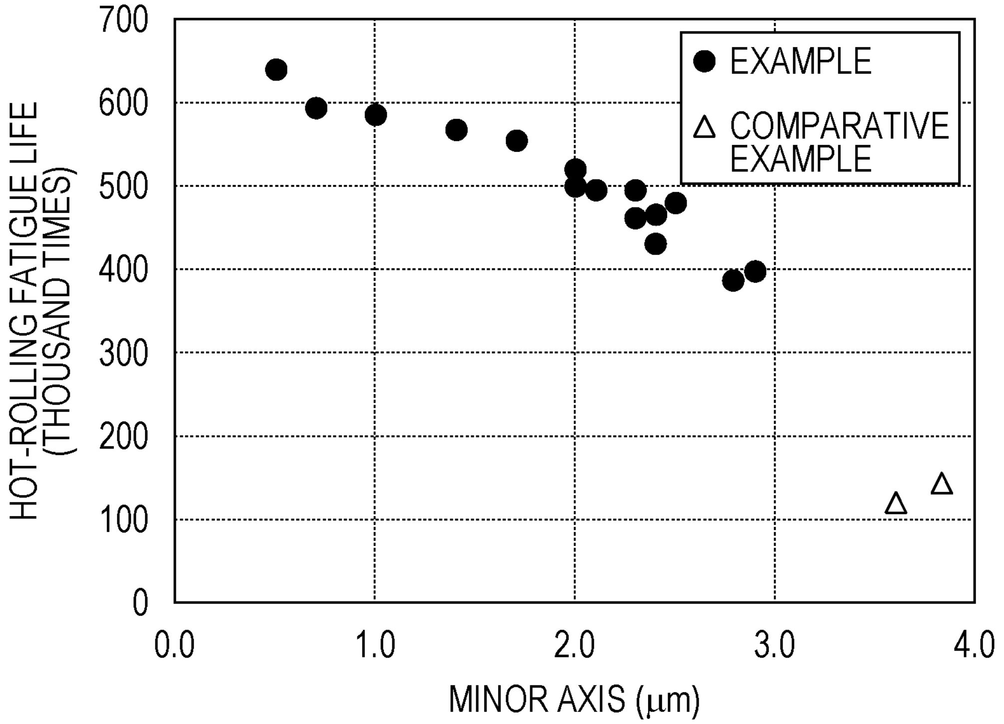

700
600
500
400
300
200
100
0
HOT-ROLLING FATIGUE LIFE (THOUSAND TIMES)
CLAIMED SCOPE
EXAMPLE
COMPARATIVE EXAMPLE
–1.00
0.00
1.00
2.00
3.00
4.00
5.00
(%C–0.177%V–0.129%Nb–0.099%Cr–0.063%Mo–0.033%W)+%Ni

FIG. 4


700
600
500
400
300
200
100
0
HOT-ROLLING FATIGUE LIFE (THOUSAND TIMES)
EXAMPLE
COMPARATIVE EXAMPLE
0.0
1.0
2.0
3.0
4.0
MINOR AXIS (μm)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/023663

A. CLASSIFICATION OF SUBJECT MATTER
B21B27/00(2006.01)i, *B22D13/02*(2006.01)i, *C21D5/00*(2006.01)n, *C21D9/38*(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, B22D13/02, C21D5/00, C21D9/38, 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	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2005-246391 A (Nippon Steel Corp.), 15 September 2005 (15.09.2005), claims; paragraphs [0011] to [0037] (Family: none)	1-2
A	JP 2015-193015 A (Hitachi Metals, Ltd.), 05 November 2015 (05.11.2015), claims; paragraphs [0020] to [0073] (Family: none)	1-2
A	JP 2000-109951 A (Kawasaki Steel Corp.), 18 April 2000 (18.04.2000), paragraphs [0027] to [0028] (Family: none)	1-2

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2017 (14.09.17)	26 September 2017 (26.09.17)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 5001350 A **[0005]**
- JP 2009221573 A **[0005]**
- JP 3962838 B **[0005]**
- JP 2010101752 A **[0010]**