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(54) **HIGH-STRENGTH HOT-ROLLED STEEL PLATE AND METHOD FOR MANUFACTURING HIGH-STRENGTH HOT-ROLLED STEEL PLATE**

(57) A high-strength hot-rolled steel sheet according to the present invention has a specific chemical composition and a steel microstructure including, as main phases, 80% to 100% of martensite and bainite in terms of total area fraction. An entire area fraction of the martensite in the bainite is 2% to 20%. Among the martensite in the bainite, an area fraction of martensite each having an orientation difference of 15° or more between a crystal

orientation of the martensite and a crystal orientation of at least one of bainite adjacent to the martensite is more than 50% relative to the whole martensite. When regions surrounded by boundaries between adjacent crystals having an orientation difference of 15° or more are defined as crystal grains, an average aspect ratio of the crystal grains present in a region extending from a surface of the steel sheet to a depth of 5 μm is 2.0 or less.

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Description

Technical Field

- 5 **[0001]** The present invention relates to a high-strength hot-rolled steel sheet suitable as a material for automotive parts and a method for manufacturing the high-strength hot-rolled steel sheet.

Background Art

- 10 **[0002]** From the viewpoint of improving crash safety and fuel economy of automobiles, there is a need to increase the strength of steel sheets used for automotive parts. On the other hand, in steel sheets having increased strength, cracking due to the lack of workability occurs significantly during pressing, and thus the pressing process and workability of the steel sheets need to be improved. Hot-rolled steel sheets having a TS of more than 980 MPa are required to have particularly high ductility in order to apply such steel sheets to parts with complicated shapes, such as a lower arm. In addition, such steel sheets are often formed into parts with complicated shapes through a plurality of steps and required to have formability for nonuniform deformation history. Bending and unbending are a working method that is particularly often used, and excellent bending-unbending workability is desired.

[0003] To address the needs, various hot-rolled steel sheets have been developed as described in, for example, Patent Literature 1 to Patent Literature 3.

- 20 **[0004]** Patent Literature 1 discloses a technique related to a Zn-Al-based plating-coated steel sheet having improve unbending resistance. The coated steel sheet has, on a surface of the steel sheet, a coated layer containing Al: 50 to 60 mass% with the balance being substantially Zn, and a coating film disposed as an upper layer of the coated layer, in which a cross-sectional hardness HM (HV) of the base metal and a cross-sectional hardness HP (HV) of the coated layer satisfy $HM > HP$ and $HP \geq 90$.

- 25 **[0005]** Patent Literature 2 describes a hot-rolled steel sheet having a microstructure that includes ferrite as a main phase and retained austenite as a second phase, in which retained austenite is contained in an amount of 5% by volume or more on average, a difference ($V_{max} - V_{min}$) between the maximum content V_{max} and the minimum content V_{min} of retained austenite at positions in the thickness direction in a region between a position 0.1 mm from a front surface of the steel sheet and a position 0.1 mm from a back surface of the steel sheet is 3.0% by volume or less, and a total elongation equivalent to a thickness of 2 mm is 34% or more. Patent Literature 2 discloses a technique related to a hot-rolled steel sheet having a high total elongation and improved bending-unbending workability, the hot-rolled steel sheet having a microstructure that includes ferrite as a main phase and includes retained austenite.

- 30 **[0006]** Patent Literature 3 describes a hot-rolled steel sheet having a specific chemical composition and containing, in an amount of 50% or more in terms of area fraction. Crystal grains have orientation differences of 15° or more in grain boundaries between adjacent crystal grains, and an average orientation difference of 0° to 0.5° within the crystal grains. A total of martensite, tempered martensite, and retained austenite is 2% or more and 10% or less in terms of area fraction. Furthermore, Ti is present as titanium carbide in mass% of 40% or more of T_{ief} represented by a specific formula, and the mass of the titanium carbide having an equivalent circular grain diameter of 7 nm or more and 20 nm or less is 50% or more of the mass of all titanium carbides. Patent Literature 3 discloses a technique related to a hot-rolled steel sheet whose ductility is improved by controlling the orientation difference within crystal grains.

Citation List

Patent Literature

- 45 **[0007]**

PTL 1: Japanese Unexamined Patent Application Publication No. 2008-156729

PTL 2: Japanese Unexamined Patent Application Publication No. 2001-32041

- 50 PTL 3: Japanese Unexamined Patent Application Publication No. 2016-204690

Summary of Invention

Technical Problem

- 55 **[0008]** However, the technique of Patent Literature 1 studies only unbending cracking originated from coating, and does not study unbending cracking formed in a hot-rolled steel sheet having no coated layer. Patent Literature 2 discloses only findings in a strength of 900 MPa or less and includes no findings or suggestions related to ductility and an im-

provement in bending-unbending workability in the over 980 MPa-grade, which needs stricter requirements. While the technique of Patent Literature 3 can improve ductility, no study on bending-unbending workability is performed, and there is room for improvement.

[0009] The present invention has been made to solve the above problems, and an object of the present invention is to provide a high-strength hot-rolled steel sheet that is suitable as a material for automotive parts and that has excellent ductility and excellent bending-unbending workability and a method for manufacturing the high-strength hot-rolled steel sheet.

[0010] The term "high strength" as used herein means that TS (tensile strength) is 980 MPa or more. The term "excellent ductility" as used herein means that a uniform elongation of a tensile test is 5.0% or more. The term "excellent bending-unbending workability" as used herein means that, in a bending-unbending test described below, when 90° V-bending is performed with a punch with a bending radius of 5 mm, and unbending is then performed with a flat-bottomed punch to a bending angle of 10° or less, no cracks are formed on a ridge line of a test specimen.

In the present invention, the tensile test for measuring the TS and the uniform elongation, and the bending-unbending test can be performed by methods described in Examples below.

Solution to Problem

[0011] To solve the above problems, the inventors of the present invention focused on a hard phase and conceived that work hardening is promoted by controlling the fraction of the hard phase to increase the uniform elongation.

[0012] Furthermore, the inventors conceived that bending-unbending workability is improved by controlling the crystal orientation of the hard phase, and, when regions surrounded by boundaries between adjacent crystals having an orientation difference of 15° or more are defined as crystal grains, by controlling an aspect ratio of the crystal grains of a surface layer of a steel sheet.

[0013] As a result, the chemical composition of the hot-rolled steel sheet is adjusted to a specific range, martensite and bainite are present as main phases, martensite is dispersed in the bainite, and furthermore, while an aspect ratio of crystal grains of a surface layer of the steel sheet is lowered, a crystal orientation of each of the martensite in the bainite and crystal orientations of bainite surrounding the martensite (bainite adjacent to the martensite) are controlled to be different from each other. The inventors have found that this enables both ductility and bending-unbending workability to be improved even in an over 980 MPa-grade hot-rolled steel sheet, and completed the present invention.

[0014] The present invention is summarized as follows.

[1] A high-strength hot-rolled steel sheet having:

a chemical composition containing, by mass%,

C: 0.04% to 0.18%,

Si: 0.1% to 3.0%,

Mn: 0.5% to 3.5%,

P: more than 0% and 0.100% or less,

S: more than 0% and 0.020% or less, and

Al: more than 0% and 1.5% or less, and

further containing one or two or more selected from Cr: 0.005% to 2.0%, Ti: 0.005% to 0.20%, Nb: 0.005% to 0.20%, Mo: 0.005% to 2.0%, and V: 0.005% to 1.0%, with the balance being Fe and incidental impurities; and

a steel microstructure including, as main phases, 80% to 100% of martensite and bainite in terms of total area fraction,

wherein an entire area fraction of the martensite in the bainite is 2% to 20%,

among the martensite in the bainite, an area fraction of martensite each having an orientation difference of 15° or more between a crystal orientation of the martensite and a crystal orientation of at least one of bainite adjacent to the martensite is more than 50% relative to the whole martensite, and

when regions surrounded by boundaries between adjacent crystals having an orientation difference of 15° or more are defined as crystal grains, an average aspect ratio of the crystal grains present in a region extending from a surface of a steel sheet to a depth of 5 μm is 2.0 or less.

[2] The high-strength hot-rolled steel sheet according to [1], containing:

in addition to the chemical composition, by mass%,

one or two or more selected from:

Cu: 0.05% to 4.0%,
 Ni: 0.005% to 2.0%,
 B: 0.0002% to 0.0050%,
 Ca: 0.0001% to 0.0050%,
 REM: 0.0001% to 0.0050%,
 Sb: 0.0010% to 0.10%, and
 Sn: 0.0010% to 0.50%.

[3] A method for manufacturing a high-strength hot-rolled steel sheet, the method being a method for manufacturing the high-strength hot-rolled steel sheet according to [1] or [2], the method including:

heating a slab having the chemical composition; and
 subsequently subjecting the slab to hot rolling,
 wherein the hot rolling includes performing rough rolling, performing finish rolling under conditions in which a total number of passes at 1,000°C or higher is 3 times or more, a total rolling reduction at 1,000°C or lower is less than 50%, and a total rolling reduction from a final pass rolling temperature to the final pass rolling temperature + 50°C is 35% or less, subsequently starting cooling in less than 1.0 s, performing cooling under a condition in which an average cooling rate from a cooling start temperature to 550°C is 50°C/s or more, and subsequently performing coiling at a coiling temperature of (Ms temperature - 50)°C to 550°C.

Advantageous Effects of Invention

[0015] According to the present invention, it is possible to provide a high-strength hot-rolled steel sheet that is suitable as a material for automotive parts and that has excellent ductility and excellent bending-unbending workability and a method for manufacturing the high-strength hot-rolled steel sheet. The use of the high-strength hot-rolled steel sheet according to the present invention as a material for automotive parts enables production of, for example, high-strength automotive parts with complicated shapes.

Brief Description of Drawing

[0016] [Fig. 1] Fig. 1 is a schematic view illustrating an aspect ratio of a crystal grain in the present invention. Description of Embodiments

[0017] A high-strength hot-rolled steel sheet and a method for manufacturing the high-strength hot-rolled steel sheet according to the present invention will be described in detail below. The present invention is not limited to the following embodiments.

<High-Strength Hot-Rolled Steel Sheet>

[0018] The high-strength hot-rolled steel sheet according to the present invention is a so-called black surface hot-rolled steel sheet, which is as hot-rolled, or a so-called white surface hot-rolled steel sheet, which is further pickled after hot rolling. The high-strength hot-rolled steel sheet intended in the present invention preferably has a thickness of 0.6 mm or more and 10.0 mm or less. When the high-strength hot-rolled steel sheet is used as a material for automotive parts, the thickness is more preferably 1.0 mm or more and 6.0 mm or less. The high-strength hot-rolled steel sheet preferably has a width of 500 mm or more and 1,800 mm or less, more preferably 700 mm or more and 1,400 mm or less.

[0019] The high-strength hot-rolled steel sheet according to the present invention has a specific chemical composition and a specific steel microstructure. Here, the chemical composition and the steel microstructure will be described in this order.

[0020] First, the chemical composition of the high-strength hot-rolled steel sheet according to the present invention will be described. Note that the symbol "%" representing a content in the chemical composition means "mass%".

[0021] The chemical composition of the high-strength hot-rolled steel sheet according to the present invention contains, by mass%, C: 0.04% to 0.18%, Si: 0.1% to 3.0%, Mn: 0.5% to 3.5%, P: more than 0% and 0.100% or less, S: more than 0% and 0.020% or less, and Al: more than 0% and 1.5% or less and further contains one or two or more selected from Cr: 0.005% to 2.0%, Ti: 0.005% to 0.20%, Nb: 0.005% to 0.20%, Mo: 0.005% to 2.0%, and V: 0.005% to 1.0%, with the balance being Fe and incidental impurities.

C: 0.04% to 0.18%

[0022] C is an element effective in forming and strengthening bainite and martensite to increase TS. A C content of less than 0.04% does not sufficiently provide this effect and does not achieve a TS of 980 MPa or more. On the other hand, a C content of more than 0.18% results in a marked hardening of martensite, thus failing to achieve bending-unbending workability of the present invention. Accordingly, the C content is 0.04% to 0.18%. The C content is preferably 0.05% or more from the viewpoint of more stably achieving a TS of 980 MPa or more. The C content is preferably 0.16% or less, more preferably 0.10% or less from the viewpoint of improving bending-unbending workability.

Si: 0.1% to 3.0%

[0023] Si is an element effective in increasing TS through solid solution strengthening of steel and suppression of temper softening of martensite. Si is an element effective in suppressing the formation of cementite to obtain a microstructure in which martensite is dispersed in bainite. To provide this effect, the Si content needs to be 0.1% or more. On the other hand, a Si content of more than 3.0% results in excessive formation of polygonal ferrite, thus failing to obtain the steel microstructure of the present invention. Accordingly, the Si content is 0.1% to 3.0%. The Si content is preferably 0.2% or more. The Si content is preferably 2.0% or less, more preferably 1.5% or less.

Mn: 0.5% to 3.5%

[0024] Mn is an element effective in forming martensite and bainite to increase TS. A Mn content of less than 0.5% does not sufficiently provide this effect, results in the formation of polygonal ferrite, etc., thus failing to obtain the steel microstructure of the present invention. On the other hand, a Mn content of more than 3.5% suppresses the formation of bainite, thus failing to obtain the steel microstructure of the present invention. Accordingly, the Mn content is 0.5% to 3.5%. The Mn content is preferably 1.0% or more from the viewpoint of more stably achieving a TS of 980 MPa or more. The Mn content is preferably 3.0% or less, more preferably 2.3% or less from the viewpoint of stably obtaining bainite.

P: More Than 0% and 0.100% or Less

[0025] P deteriorates bending-unbending workability, and thus the amount thereof is desirably reduced as much as possible. In the present invention, a P content of up to 0.100% is allowable. Accordingly, the P content is 0.100% or less and is preferably 0.030% or less. The P content is more than 0% and is preferably 0.001% or more because a P content of less than 0.001% causes a decrease in production efficiency.

S: More Than 0% and 0.020% or Less

[0026] S deteriorates bending-unbending workability, and thus the amount thereof is desirably reduced as much as possible. However, a S content of up to 0.020% is allowable in the present invention. Accordingly, the S content is 0.020% or less, preferably 0.0050% or less, more preferably 0.0020% or less. The S content is more than 0% and is preferably 0.0002% or more because a S content of less than 0.0002% causes a decrease in production efficiency.

Al: More Than 0% and 1.5% or Less

[0027] Al acts as a deoxidizing agent and is preferably added in a deoxidization step. The lower limit of the Al content is more than 0%. From the viewpoint of using Al as a deoxidizing agent, the Al content is preferably 0.01% or more. If Al is contained in a large amount, a large amount of polygonal ferrite may be formed, thus failing to obtain the steel microstructure of the present invention. In the present invention, an Al content of up to 1.5% is allowable. Accordingly, the Al content is 1.5% or less. The Al content is preferably 0.50% or less.

[0028] One or Two or More Selected from Cr: 0.005% to 2.0%, Ti: 0.005% to 0.20%, Nb: 0.005% to 0.20%, Mo: 0.005% to 2.0%, and V: 0.005% to 1.0%

[0029] Cr, Ti, Nb, Mo, and V are elements effective in obtaining a microstructure in which martensite is dispersed in bainite. To provide this effect, the content or contents of one or two or more elements selected from the above elements need to be equal to or higher than their respective lower limits mentioned above. On the other hand, if the content or contents of one or two or more elements selected from the above elements exceed their respective upper limits mentioned above, the effect is not provided, thus failing to obtain the steel microstructure of the present invention. Accordingly, one or two or more selected from Cr: 0.005% to 2.0%, Ti: 0.005% to 0.20%, Nb: 0.005% to 0.20%, Mo: 0.005% to 2.0%, and V: 0.005% to 1.0% are contained. When the above elements are contained, the contents are preferably Cr: 0.1% or more, Ti: 0.010% or more, Nb: 0.010% or more, Mo: 0.10% or more, and V: 0.10% or more. When the above elements

are contained, the upper limits of the contents are preferably Cr: 1.0% or less, Ti: 0.15% or less, Nb: 0.10% or less, Mo: 1.0% or less, and V: 0.5% or less.

[0030] The balance is Fe and incidental impurities. An example of incidental impurity elements is N, and the acceptable upper limit of this element is preferably 0.010%.

[0031] The above components are the basic chemical composition of the high-strength hot-rolled steel sheet according to the present invention. In the present invention, the following elements may be further contained as needed.

[0032] One or Two or More Selected from Cu: 0.05% to 4.0%, Ni: 0.005% to 2.0%, B: 0.0002% to 0.0050%, Ca: 0.0001% to 0.0050%, REM: 0.0001% to 0.0050%, Sb: 0.0010% to 0.10%, and Sn: 0.0010% to 0.50%

[0033] Cu and Ni are elements effective in forming martensite to contribute to an increase in the strength. To provide this effect, when Cu and Ni are contained, the contents thereof are preferably equal to or higher than their respective lower limits mentioned above. If the contents of Cu and Ni each exceed the respective upper limits mentioned above, the formation of bainite may be suppressed, which may fail to obtain the steel microstructure of the present invention. The Cu content is more preferably 0.10% or more and more preferably 0.6% or less. The Ni content is more preferably 0.1% or more and more preferably 0.6% or less.

[0034] B is an element effective in improving the hardenability of a steel sheet and forming martensite to contribute to an increase in the strength. To provide this effect, when B is contained, the B content is preferably 0.0002% or more. On the other and, a B content of more than 0.0050% may increase the amounts of B-containing compounds and deteriorate the hardenability, which may fail to obtain the steel microstructure of the present invention. Accordingly, when B is contained, the content is preferably 0.0002% to 0.0050%. The B content is more preferably 0.0005% or more and more preferably 0.0040% or less.

[0035] Ca and REM (rare-earth metal) are elements effective in improving workability due to the morphological control of inclusions. To provide this effect, when Ca and REM are contained, the contents thereof are preferably Ca: 0.0001% to 0.0050% and REM: 0.0001% to 0.0050%. If the Ca content and the REM content exceed the respective upper limits mentioned above, the amount of inclusions may increase, which may result in the deterioration of workability. The Ca content is more preferably 0.0005% or more and more preferably 0.0030% or less. The REM content is more preferably 0.0005% or more and more preferably 0.0030% or less.

[0036] Sb is an element effective in suppressing denitrification, deboronization, and the like to suppress a decrease in the strength of steel. To provide this effect, when Sb is contained, the Sb content is preferably 0.0010% to 0.10%. An Sb content of more than the upper limit mentioned above may cause embrittlement of the steel sheet. The Sb content is more preferably 0.0050% or more and more preferably 0.050% or less.

[0037] Sn is an element effective in suppressing the formation of pearlite to suppress a decrease in the strength of steel. To provide this effect, when Sn is contained, the Sn content is preferably 0.0010% to 0.50%. A Sn content of more than the upper limit mentioned above may cause embrittlement of the steel sheet. The Sn content is more preferably 0.0050% or more and more preferably 0.050% or less.

[0038] Even if the contents of Cu, Ni, B, Ca, REM, Sb, and Sn are less than the respective lower limits mentioned above, the effects of the present invention are not impaired. Accordingly, when the contents of these components are less than their respective lower limits mentioned above, these elements are treated as being contained as incidental impurities.

[0039] Next, the steel microstructure of the high-strength hot-rolled steel sheet according to the present invention will be described below.

The steel microstructure of the high-strength hot-rolled steel sheet according to the present invention includes, as main phases, 80% to 100% of martensite and bainite in terms of total area fraction. An entire area fraction of the martensite in the bainite is 2% to 20%. Among the martensite in the bainite, an area fraction of a martensite each having an orientation difference of 15° or more between a crystal orientation of the martensite and a crystal orientation of at least one of bainite adjacent to the martensite is more than 50% relative to the whole martensite. When regions surrounded by boundaries between adjacent crystals having an orientation difference of 15° or more are defined as crystal grains, an average aspect ratio of the crystal grains present in a region extending from a surface of the steel sheet to a depth of 5 μm is 2.0 or less.

[0040] Total Area Fraction of Martensite and Bainite: 80% to 100%

[0041] In the present invention, in order to provide high TS and excellent bending-unbending workability, the steel microstructure mainly has martensite and bainite (includes martensite and bainite as main phases).

If the total area fraction of martensite and bainite is less than 80% relative to the whole steel sheet microstructure, either high TS or bending-unbending workability is not achieve. Accordingly, the total area fraction of martensite and bainite is 80% to 100%. The total area fraction is preferably 90% to 100%, more preferably 94% to 100%.

Entire Area Fraction of Martensite in Bainite: 2% to 20%

[0042] Martensite is a steel microstructure effective in increasing TS and, furthermore, is a steel microstructure effective

in increasing the uniform elongation when being dispersed in bainite. To provide this effect, an entire area fraction of martensite in bainite needs to be 2% or more. On the other hand, an entire area fraction of the above-mentioned martensite of more than 20% results in deterioration of the uniform elongation and bending-unbending workability. Accordingly, an entire area fraction of the above-mentioned martensite is 2% to 20%. The entire area fraction of the above-mentioned martensite is preferably 3% or more, more preferably 4% or more. The entire area fraction of the above-mentioned martensite is preferably 15% or less, more preferably 12% or less.

[0043] Among Martensite in Bainite, Area Fraction of Martensite Each Having Orientation Difference of 15° or More between Crystal Orientation of the Martensite and Crystal Orientation of at Least One of Bainite Adjacent to the Martensite: More Than 50% Relative to Whole Martensite

[0044] Among martensite in bainite, when an area fraction of martensite each having an orientation difference of 15° or more between a crystal orientation of the martensite and a crystal orientation in at least one of bainite adjacent to the martensite (hereinafter, may also be referred to as a "dispersed martensite phase") is more than 50% relative to the area of the whole martensite, bending-unbending workability of the present invention is achieved. Herein, the above-mentioned "martensite having an orientation difference of 15° or more between a crystal orientation of the martensite and a crystal orientation of at least one of bainite adjacent to the martensite portion" means that, for example, when a martensite surrounded by bainite having multiple of crystal orientations is present, it is sufficient that the orientation difference between one or more of the bainite having the multiple of crystal orientations and the crystal orientation of the martensite is 15° or more.

[0045] Although a detailed reason for this is not clear, it is presumably because a large difference in crystal orientations between a martensite in bainite and bainite surrounding the martensite (bainite adjacent to the martensite) is likely to serve as an obstacle for crack extension in bending and unbending.

[0046] For this reason, in the present invention, the area fraction of the above-mentioned dispersed martensite phase is more than 50%. As the amount of martensite serving as the obstacle for crack extension increases, crack extension in bending and unbending is further suppressed. Bending-unbending workability of the present invention can be achieved by setting the area fraction to more than 50%.

[0047] Accordingly, among martensite in bainite, the area fraction of the above-mentioned dispersed martensite phase is more than 50% relative to the whole martensite. The area fraction is preferably 60% or more, more preferably 70% or more. The upper limit of the area fraction of the above-mentioned dispersed martensite phase is not particularly specified. Since it is difficult to control the area fraction to substantially 100%, the area fraction is preferably less than 100%.

[0048] Herein, the above-mentioned "dispersed martensite phase" can be measured by a method described in Examples below. Specifically, crystal orientations of bainite and martensite are determined by electron backscatter diffraction (EBSD), and boundaries having orientation differences of 15° or more are displayed. Subsequently, among martensite dispersed in bainite, an area fraction of martensite each having an orientation difference of 15° or more between a crystal orientation of the martensite and a crystal orientation of at least one of bainite adjacent to the martensite (adjacent bainite) is determined.

[0049] The steel microstructure of the present invention may have ferrite, pearlite, and retained austenite as microstructures other than the martensite and bainite described above. Total area fraction of the microstructures other than martensite and bainite is less than 20% (including 0%). When the total area fraction is less than 20%, the characteristics of the present invention can be achieved.

[0050] Average Aspect Ratio in Crystal Grains Present in Region Extending from Surface of Steel Sheet to Depth of 5 μm : 2.0 or Less

[0051] A crystal grain of a surface layer of a steel sheet serves as an origin of a crack in bending and unbending, and a crystal grain having a larger aspect ratio is more likely to cause cracking. In order to provide bending-unbending workability intended in the present invention, an average aspect ratio of crystal grains present in a region extending from a surface of the steel sheet to a depth of 5 μm needs to be 2.0 or less. The average aspect ratio of crystal grains is preferably 1.7 or less, more preferably 1.5 or less.

[0052] Here, as illustrated in Fig. 1, the "crystal grain" indicates a region surrounded by boundaries between adjacent crystals having an orientation difference of 15° or more. When a maximum length of the crystal grain in a rolling direction is represented by RL, and a maximum length of the crystal grain in a thickness direction is represented by TL, the "aspect ratio" is determined as a ratio of the maximum length RL in the rolling direction to the maximum length TL in the thickness direction (maximum length RL in rolling direction/maximum length TL in thickness direction). The "average aspect ratio of crystal grains" refers to an average of aspect ratios of the crystal grains present in a region extending from the surface of the steel sheet to a depth of 5 μm .

[0053] In the present invention, the area fractions and the crystal orientations of the microstructures and the aspect ratio can be measured by methods described in Examples below.

<Method for Manufacturing High-Strength Hot-Rolled Steel Sheet>

[0054] The high-strength hot-rolled steel sheet according to the present invention is manufactured by heating a slab having the chemical composition described above, and subsequently subjecting the slab to hot rolling. In the hot rolling, the heated slab is subjected to rough rolling, and subjected to finish rolling under conditions in which a total number of passes at 1,000°C or higher is 3 times or more, a total rolling reduction at 1,000°C or lower is less than 50%, and a total rolling reduction from a final pass rolling temperature to the final pass rolling temperature + 50°C is 35% or less, cooling is then started in less than 1.0 s, cooling is performed under a condition in which an average cooling rate from a cooling start temperature to 550°C is 50°C/s or more, coiling is then performed at a coiling temperature of (Ms temperature - 50)°C to 550°C, and cooling is performed to room temperature.

[0055] The manufacturing method will be described in detail below. The temperature described above is the temperature (surface temperature) at a central portion of the width of the slab or steel sheet, and the average cooling rate described above is the average cooling rate at a central portion of the width of the steel sheet. These temperatures can be measured with, for example, a radiation thermometer.

Total Number of Passes at 1,000°C or Higher: 3 Times or More

[0056] In the finish rolling of the hot rolling, when a reduction at 1,000°C or higher is performed three times or more, recrystallization of austenite can be promoted to form grains having a small aspect ratio in the surface layer of the steel sheet. Accordingly, the total number of passes at 1,000°C or higher is three times or more, preferably four times or more. The upper limit of the total number of passes at 1,000°C or higher is not particularly specified. The total number of passes at 1,000°C or higher is preferably 20 times or less in view of, for example, production efficiency.

Total Rolling Reduction at 1,000°C or Lower: Less Than 50%

[0057] If the total rolling reduction at 1,000°C or lower in the finish rolling of the hot rolling is 50% or more, grains having a large aspect ratio are formed in the surface layer of the steel sheet, martensite having crystal orientations close to adjacent bainite is likely to be formed, and the steel microstructure of the present invention is not obtained. Accordingly, the total rolling reduction at 1,000°C or lower is less than 50%. The total rolling reduction at 1,000°C or lower is preferably less than 40%, more preferably less than 30%. The lower limit of the total rolling reduction at 1,000°C or lower is not particularly specified. The total rolling reduction at 1,000°C or lower is preferably 10% or more because abnormal grains may be formed in a case of a soft reduction.

Herein, the total rolling reduction is a percentage of a value determined by dividing the difference between a sheet thickness at the entry before the first pass in the above temperature region and a sheet thickness at the exit after the last pass in the temperature region by the sheet thickness at the entry before the first pass.

Specifically, the total rolling reduction is determined by (sheet thickness at entry before first pass in the temperature region - sheet thickness at exit after last pass in the temperature region)/(sheet thickness at entry before first pass in the temperature region) × 100 (%).

[0058] Total Rolling Reduction from Final Pass Rolling Temperature to Final Pass Rolling Temperature + 50°C: 35% or Less

[0059] If the rolling reduction exceeds 35% near the final pass temperature (hereinafter also referred to as FT), elongated grains are formed in the vicinity of the surface layer, thus failing to obtain the average aspect ratio of crystal grains present in a region extending from a surface of the steel sheet to a depth of 5 μm of the present invention. In addition, the amount of strain introduced in austenite becomes excessive, and martensite having the crystal orientation relationship of the present invention is not obtained. Accordingly, the total rolling reduction from the final pass rolling temperature to the final pass rolling temperature + 50°C is 35% or less, preferably 30% or less. The lower limit is not particularly specified; however, if the rolling reduction is excessively low, for example, surface defects may be caused. Thus, the above total rolling reduction is preferably 5% or more, more preferably 10% or more.

Natural Cooling Time after Finish Rolling: Less Than 1.0 s

[0060] After the finish rolling, cooling is started in less than 1.0 s (second). A natural cooling time after the finish rolling of 1.0 s or more fails to obtain the dispersed martensite phase having the crystal orientation of the present invention. Although the reason for this is not clear, presumably, the decrease in the natural cooling time suppresses the recovery of dislocations introduced by the finish rolling, which may affect orientation selections during the subsequent bainite transformation and martensite transformation. Accordingly, the natural cooling time after the finish rolling is less than 1.0 s. The natural cooling time is preferably 0.7 s or less.

The lower limit of the natural cooling time is not particularly specified. The natural cooling time is preferably 0.01 s or

more because it is difficult to start cooling immediately after rolling due to, for example, restrictions of the equipment structure.

Average Cooling Rate from Cooling Start Temperature to 550°C: 50°C/s or More

[0061] An average cooling rate from the cooling start temperature to 550°C of less than 50°C/s results in the formation of ferrite and pearlite, thus failing to obtain the steel microstructure of the present invention. Accordingly, the average cooling rate from the cooling start temperature to 550°C is 50°C/s or more. The average cooling rate is preferably 80°C/s or more. The upper limit of the average cooling rate is not particularly specified; however, the average cooling rate is preferably 1,000°C/s or less from the viewpoint of, for example, the shape stability of the steel sheet.

Coiling Temperature: (Ms Temperature - 50)°C to 550°C

[0062] A coiling temperature of lower than (Ms Temperature - 50)°C results in an increase in martensite, thus failing to obtain the steel microstructure of the present invention. On the other hand, a coiling temperature of higher than 550°C results in the formation of ferrite and pearlite, thus failing to obtain the steel microstructure of the present invention. Accordingly, the coiling temperature is (Ms temperature - 50)°C to 550°C. The coiling temperature is preferably (Ms temperature - 30)°C or higher and preferably 520°C or lower.

[0063] Herein, the Ms temperature is the martensite transformation start temperature and can be determined by performing actual measurement, such as electric resistance measurement or thermal expansion measurement during cooling by a formaster test or the like.

[0064] Conditions other than those of the manufacturing method described above are not particularly limited; however, the manufacturing is preferably performed while the conditions are appropriately adjusted as described below.

[0065] For example, the heating temperature of the slab is preferably 1,100°C or higher from the viewpoints of, for example, removing segregation and dissolving precipitates, and is preferably 1,300°C or lower from the viewpoint of, for example, energy efficiency.

The finish rolling is preferably performed in 4 or more passes from the viewpoint of, for example, decreasing coarse grains, which may cause deterioration of workability. Note that this number of passes of the finish rolling refers to a total number of passes in the finish rolling and includes the above-mentioned "total number of passes at 1,000°C or lower" described above.

EXAMPLES

[0066] The present invention will be further described with reference to Examples below. The present invention is not limited to the following Examples.

[0067] Steels having respective chemical compositions shown in Table 1 were obtained by steelmaking in a vacuum melting furnace to manufacture slabs. Subsequently, the slabs were heated to 1,200°C and subjected to hot rolling under the conditions shown in Table 2 to produce hot-rolled steel sheets. In the hot rolling, the total number of passes of finish rolling was 7 passes. A blank in Table 1 means that the element is not intentionally added and refers to not only the case where the element is not contained (0%) but also the case where the element is incidentally contained. N is an incidental impurity.

[0068] The resulting hot-rolled steel sheets were subjected to microstructure observation and evaluations of tensile properties and bending-unbending workability in accordance with test methods described below.

<Microstructure Observation>

(Area Fraction of Each Microstructure)

[0069] The area fractions of martensite and bainite are the ratios of the areas of the respective microstructures to the area of observation.

[0070] The area fraction of martensite is determined as follows.

A sample is cut out from the resulting hot-rolled steel sheet. A cross section of the sample that is taken in the thickness direction so as to be parallel to the rolling direction is polished and then etched in 3% nital. Images of cross sections at a position 1/4 of the thickness are captured with a scanning electron microscope (SEM) at a magnification of 1,500x in three fields of view. The area fraction of each microstructure is determined from the image data of the obtained secondary electron images using Image-Pro available from Media Cybernetics, Inc., and the average area fraction of the fields of view is defined as the area fraction of each microstructure.

[0071] In the image data, upper bainite is distinguished as black or dark gray containing carbide or martensite having

linear interfaces, or retained austenite. Lower bainite is distinguished as black, dark gray, gray, or light gray containing uniformly oriented carbide. Martensite is distinguished as black, dark gray, gray, or light gray containing carbides having multiple orientations, or white or light gray containing no carbide. Retained austenite is distinguished as white or light gray containing no carbide.

[0072] In some cases, martensite and retained austenite cannot be distinguished from each other. Accordingly, the area fraction of martensite was determined by subtracting the area fraction of retained austenite determined by a method described below from the total area fraction of martensite and retained austenite determined from the SEM images.

[0073] In the present invention, the martensite may be any martensite, such as fresh martensite, autotempered martensite, or tempered martensite. The bainite may be any bainite, such as upper bainite, lower bainite, or tempered bainite.

[0074] A microstructure subjected to a higher degree of tempering provides a contrast image in which the matrix appears blacker. Therefore, the colors of the above matrices serve only as a guide. In the present invention, the microstructures were identified in comprehensive consideration of the amount of carbide, the microstructural morphology, and the like and classified into any of those having similar characteristics and including microstructures described below. Carbides appear white dots or lines.

[0075] Although ferrite is not basically contained in the present invention, ferrite can be distinguished as a black or dark gray microstructure having no or a very small amount of carbide inside and surrounded mainly by a curvilinear boundary. Pearlite can be distinguished as a black and white lamellar or partially interrupted and substantially lamellar microstructure.

[0076] The area fraction of retained austenite is determined as follows. A steel sheet after annealing was ground to a position of $1/4$ of the thickness of the sheet + 0.1 mm and then further polished by 0.1 mm by chemical polishing. For the polished surface, integrated reflection intensities of (200), (220), and (311) planes of fcc iron (austenite) and (200), (211), and (220) planes of bcc iron (ferrite) were measured with an X-ray diffractometer using Mo-K α 1 radiation. The volume fraction was determined from the intensity ratios of the integrated reflection intensities from the above planes of fcc iron to the integrated reflection intensities from the above planes of bcc iron. This volume fraction is used as the area fraction of retained austenite.

[0077] The total area fraction of bainite and martensite and the total area fraction of other microstructures are determined using the obtained area fractions of the respective microstructures, and the total area fractions are shown in Table 3. In Table 3, "V (M)" means the area fraction (%) of martensite, "V(B + M)" means the total area fraction (%) of bainite and martensite, and "V (O)" means the total area fraction (%) of the other microstructures.

(Crystal Orientation)

[0078] The crystal orientations of bainite and martensite were determined by electron backscatter diffraction (EBSD) for the same field of view of the same sample used for the microstructure observation, and boundaries having an orientation difference of 15° or more were displayed. Thus, among martensite dispersed in bainite, an area fraction of martensite each having an orientation difference of 15° or more between the martensite and at least one of bainite adjacent to the martensite (adjacent bainite) was determined. A ratio of the area of the relevant martensite to the area of the whole martensite was then determined. The EBSD measurement was performed at an accelerating voltage of 30 kV and a step size of 0.05 μm in a region of 100 μm $\times$ 100 μm .

The resulting ratio is shown in Table 3. The "Ratio of M having orientation difference of 15° or more from adjacent B (%)" in Table 3 indicates the above ratio (%).

(Aspect Ratio of Crystal Grain)

[0079] For a surface layer portion of the same sample used for the microstructure observation, crystal orientations were determined by EBSD, boundaries between adjacent crystals having an orientation difference of 15° or more are displayed, and regions surrounded by the boundaries are defined as crystal grains. Among the crystal grains, for each crystal grain present in a region extending from a surface of the steel sheet to 5 μm in the depth direction (thickness direction), the maximum length RL in the rolling direction and the maximum length TL in the thickness direction are determined (see Fig. 1). The aspect ratio of each crystal grain is calculated from the ratio (RL/TL) of the maximum length RL in the rolling direction to the maximum length TL in the thickness direction in the crystal grains, and the average of the calculated values is used as the average aspect ratio of the crystal grains. The ratio of the maximum length RL in the rolling direction to the maximum length TL in the thickness direction is determined such that the minimum value of the aspect ratio is 1.0.

[0080] Note that a crystal grain extending through a position 5 μm from the surface of the steel sheet in the depth direction is counted as a crystal grain in the region extending from the surface of the steel sheet to 5 μm in the depth direction.

[0081] The EBSD measurement is performed at an accelerating voltage of 30 kV and a step size of 0.10 μm in a

region of $100\ \mu\text{m} \times 100\ \mu\text{m}$. The measurement of the aspect ratio of a crystal grain is performed for all the relevant crystal grains in the region (the region of $100\ \mu\text{m} \times 100\ \mu\text{m}$).

<Tensile Test>

[0082] The evaluation of tensile properties was performed by a tensile test. JIS No. 5 test pieces for a tensile test (JIS Z 2201) were collected from the resulting hot-rolled steel sheets in a direction parallel to the rolling direction. The tensile test was performed in accordance with JIS Z 2241 at a strain rate of $10^{-3}/\text{s}$ to determine a TS and a uniform elongation. In the present invention, a TS of 980 MPa or more and a uniform elongation of 5.0% or more were each evaluated as pass.

<Bending-Unbending Test>

[0083] The evaluation of bending-unbending workability was performed by a bending-unbending test. Test specimens having a width of 30 mm and a length of 100 mm were collected from the resulting hot-rolled steel sheets such that the longitudinal direction was parallel to the rolling direction. A 90° V-bending is performed using the test specimens under the conditions of a stroke rate of 10 mm/min, a bending radius of 5 mm, and a maximum pressing load of 10 ton. Subsequently, each of the test specimens was reversed, a flat-bottomed punch is pressed under the condition of a stroke rate of 10 mm/min and stopped at a stroke at which the bending angle becomes 10° or less, the load is removed, and the sample is then taken out. Subsequently, bending ridge line portions of the samples are visually observed.

In the present invention, when no cracks were formed on a surface corresponding to the inside of bending in the first bending (V-bending), bending-unbending workability was evaluated as pass. The "No" in the "bending-unbending cracking" in Table 3 indicates pass.

[0084] Table 3 shows various evaluation results.

[Table 1]

Steel	Chemical composition (mass%)								Remarks
	C	Si	Mn	P	S	Al	N	Others	
A	0.11	0.50	1.7	0.014	0.0018	0.031	0.003	Ti:0.060	Within scope of invention
B	0.07	0.30	2.0	0.023	0.0022	0.033	0.002	Nb:0.060	Within scope of invention
C	0.04	1.00	2.1	0.015	0.0029	0.036	0.004	Mo:0.30	Within scope of invention
D	0.11	0.10	3.3	0.008	0.0014	0.038	0.003	V:0.20	Within scope of invention
E	0.17	0.70	2.4	0.004	0.0004	0.027	0.003	Ti:0.03, Cu:0.2, Ca: 0.0010, Sn:0.04	Within scope of invention
F	0.05	0.90	2.5	0.015	0.0018	0.044	0.003	Nb:0.04, REM: 0.0020, Sb:0.010	Within scope of invention
G	0.06	0.40	0.7	0.010	0.0014	0.082	0.002	Cr:0.30, Ni:0.60, Ti: 0.080, B:0.0020	Within scope of invention
H	<u>0.03</u>	0.30	1.9	0.010	0.0021	0.019	0.006	Cr:0.30	Outside scope of invention
I	<u>0.19</u>	0.50	2.2	0.009	0.0013	0.015	0.004	Ti:0.040	Outside scope of invention
J	0.09	<u>3.10</u>	1.8	0.010	0.0012	0.028	0.003	Nb:0.020	Outside scope of invention
K	0.10	0.50	<u>0.4</u>	0.013	0.0016	0.036	0.003	Mo:0.30	Outside scope of invention
L	0.05	0.40	<u>3.9</u>	0.011	0.0010	0.035	0.004	V:0.10	Outside scope of invention

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(continued)

Steel	Chemical composition (mass%)								Remarks
	C	Si	Mn	P	S	Al	N	Others	
M	0.13	0.10	2.2	0.018	0.0008	0.033	0.003	—	Outside scope of invention
N	0.15	1.40	2.4	0.003	0.0004	0.030	0.004	Ti:0.03 ,Mo:0.4, B:0.0020	Within scope of invention
O	0.10	1.00	2.4	0.012	0.0005	0.029	0.004	Cr:0.8	Within scope of invention
P	0.10	1.00	2.4	0.012	0.0006	0.029	0.003	<u>Cr:2.3</u>	Outside scope of invention
Q	0.10	1.00	2.4	0.012	0.0006	0.030	0.003	<u>Ti:0.23</u>	Outside scope of invention
R	0.10	1.00	2.4	0.011	0.0005	0.031	0.003	<u>Nb:0.22</u>	Outside scope of invention
S	0.10	1.00	2.4	0.011	0.0007	0.030	0.003	<u>Mo:2.1</u>	Outside scope of invention
T	0.10	1.00	2.4	0.012	0.0006	0.030	0.003	<u>V:2.1</u>	Outside scope of invention
* Underlined portions are outside the scope of the present invention.									

[Table 2]

Steel sheet No.	Steel	Finish rolling conditions			Natural cooling time after finish rolling (s)	Average cooling rate from cooling start temperature to 550°C (°C/s)	Coiling temperature (°C)	Ms temperature (°C)	Remarks
		Total number of passes at 1,000°C or higher (times)	Total rolling reduction at 1,000°C lower (%)	Total rolling reduction from FT to FT + 50°C (%)					
1	A	4	30	27	0.9	200	480	444	Inventive Example
2		4	<u>55</u>	27	0.9	200	480	444	Comparative Example
3	B	3	48	11	0.6	60	450	447	Inventive Example
4		3	48	11	0.6	60	<u>560</u>	447	Comparative Example
5		3	48	11	0.6	60	<u>380</u>	447	Comparative Example
6	C	4	30	25	0.5	100	460	452	Inventive Example
7		4	30	25	<u>1.5</u>	100	460	452	Comparative Example
8	D	4	30	32	0.3	50	530	382	Inventive Example
9	E	5	40	23	0.4	100	450	395	Inventive Example
10		5	40	23	0.4	<u>30</u>	450	395	Comparative Example
11		<u>2</u>	40	23	0.4	100	450	395	Comparative Example
12		5	40	23	0.4	100	<u>580</u>	395	Comparative Example
13	F	4	40	26	0.6	100	420	434	Inventive Example

(continued)

Steel sheet No.	Steel	Finish rolling conditions			Natural cooling time after finish rolling (s)	Average cooling rate from cooling start temperature to 550°C (°C/s)	Coiling temperature (°C)	Ms temperature (°C)	Remarks
		Total number of passes at 1,000°C or higher (times)	Total rolling reduction at 1,000°C lower (%)	Total rolling reduction from FT to FT + 50°C (%)					
14	G	4	40	27	0.6	100	480	485	Inventive Example
15	H ₁	4	40	12	0.6	100	470	459	Comparative Example
16	I ₁	4	40	28	0.6	100	400	396	Comparative Example
17	J ₁	4	40	28	0.6	100	500	447	Comparative Example
18	K ₁	4	40	28	0.6	100	500	497	Comparative Example
19	L ₁	4	40	12	0.6	100	370	380	Comparative Example
20	M ₁	4	40	12	0.6	100	500	417	Comparative Example
21	N	4	40	11	0.6	100	460	400	Inventive Example
22	F	4	40	38	0.6	100	420	434	Comparative Example
23	G	4	40	57	0.6	100	480	485	Comparative Example
24	O	4	40	27	0.6	100	400	404	Inventive Example
25	P ₁	4	40	27	0.6	100	400	374	Comparative Example
26	Q ₁	4	40	27	0.6	100	400	420	Comparative Example

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(continued)

Steel sheet No.	Steel	Finish rolling conditions			Natural cooling time after finish rolling (s)	Average cooling rate from cooling start temperature to 550°C (°C/s)	Coiling temperature (°C)	Ms temperature (°C)	Remarks
		Total number of passes at 1,000°C or higher (times)	Total rolling reduction at 1,000°C lower (%)	Total rolling reduction from FT to FT + 50°C (%)					
27	<u>R</u>	4	40	27	0.6	100	400	420	Comparative Example
28	<u>S</u>	4	40	27	0.6	100	400	408	Comparative Example
29	<u>T</u>	4	40	27	0.6	100	400	420	Comparative Example
* Underlined portions are outside the scope of the present invention.									

[Table 3]

Steel sheet No.	Steel microstructure					Mechanical properties			Remarks
	V (M+B) (%)	V (M) (%)	V (O) (%)	Ratio of M having orientation difference of 15° or more from adjacent B (%)	Average aspect ratio of crystal grains present in region extending from surface of steel sheet to depth of 5 μm	TS (MPa)	Uniform elongation (%)	Bending-unbending cracking	
1	100	4	0	72	1.3	1042	7.5	No	Inventive Example
2	100	5	0	<u>44</u>	<u>2.3</u>	1045	7.9	Yes	Comparative Example
3	100	4	0	62	1.9	1017	7.1	No	Inventive Example
4	<u>73</u>	5	29	61	1.8	957	6.7	No	Comparative Example
5	100	<u>56</u>	0	58	1.9	1121	4.3	No	Comparative Example
6	97	8	3	82	1.3	1095	9.2	No	Inventive Example
7	96	10	4	<u>46</u>	1.2	1100	9.1	Yes	Comparative Example
8	98	19	2	84	1.2	1183	6.8	No	Inventive Example
9	98	13	2	77	1.5	1189	8.4	No	Inventive Example
10	91	<u>25</u>	9	79	1.6	1204	8.7	Yes	Comparative Example
11	98	15	2	74	<u>2.5</u>	1183	8.7	Yes	Comparative Example
12	<u>63</u>	3	37	55	1.6	1099	7.0	Yes	Comparative Example
13	99	18	1	60	1.6	1088	6.3	No	Inventive Example
14	98	3	2	69	1.5	996	7.6	No	Inventive Example
15	100	2	0	70	1.2	952	5.8	No	Comparative Example
16	99	19	1	66	1.4	1152	9.9	Yes	Comparative Example
17	<u>62</u>	3	38	58	1.1	1165	9.5	Yes	Comparative Example

(continued)

Steel sheet No.	Steel microstructure					Mechanical properties			Remarks
	V (M+B) (%)	V (M) (%)	V (O) (%)	Ratio of M having orientation difference of 15° or more from adjacent B (%)	Average aspect ratio of crystal grains present in region extending from surface of steel sheet to depth of 5 μm	TS (MPa)	Uniform elongation (%)	Bending-unbending cracking	
18	93	0	7	—	1.3	938	4.6	No	Comparative Example
19	96	<u>82</u>	4	89	1.4	1158	4.3	Yes	Comparative Example
20	100	<u>1</u>	0	68	1.2	1135	4.5	No	Comparative Example
21	90	10	10	75	1.7	1246	8.8	No	Inventive Example
22	98	20	2	53	<u>2.1</u>	1096	5.7	Yes	Comparative Example
23	98	3	2	<u>40</u>	<u>2.5</u>	1020	5.9	Yes	Comparative Example
24	96	19	4	75	1.2	1084	6.5	No	Inventive Example
25	99	<u>62</u>	1	76	1.3	1195	5.3	Yes	Comparative Example
26	99	<u>51</u>	1	65	2.0	1233	5.6	Yes	Comparative Example
27	99	<u>59</u>	1	67	2.0	1260	5.2	Yes	Comparative Example
28	98	<u>85</u>	2	64	1.9	1267	4.8	Yes	Comparative Example
29	99	<u>88</u>	1	60	1.8	1245	4.6	Yes	Comparative Example
* Underlined portions are outside the scope of the present invention.									

[0085] Referring to Table 3, all Inventive Examples provide high-strength hot-rolled steel sheets having an excellent uniform elongation and excellent bending-unbending workability. In contrast, in Comparative Examples, which are outside the scope of the present invention, one or more of the desired strength, uniform elongation, and bending-unbending workability are not achieved.

Industrial Applicability

[0086] According to the present invention, it is possible to provide a high-strength hot-rolled steel sheet having a TS of 980 MPa or more, excellent ductility, and excellent bending-unbending workability. The use of the high-strength hot-rolled steel sheet according to the present invention for automotive parts can contribute greatly to the improvements in

crash safety and fuel economy of automobiles.

Claims

1. A high-strength hot-rolled steel sheet comprising:

a chemical composition containing, by mass%,

C: 0.04% to 0.18%,

Si: 0.1% to 3.0%,

Mn: 0.5% to 3.5%,

P: more than 0% and 0.100% or less,

S: more than 0% and 0.020% or less, and

Al: more than 0% and 1.5% or less, and

further containing one or two or more selected from Cr: 0.005% to 2.0%, Ti: 0.005% to 0.20%, Nb: 0.005% to 0.20%, Mo: 0.005% to 2.0%, and V: 0.005% to 1.0%,

with the balance being Fe and incidental impurities; and

a steel microstructure including, as main phases, 80% to 100% of martensite and bainite in terms of total area fraction,

wherein an entire area fraction of the martensite in the bainite is 2% to 20%,

among the martensite in the bainite, an area fraction of martensite each having an orientation difference of 15° or more between a crystal orientation of the martensite and a crystal orientation of at least one of bainite adjacent to the martensite is more than 50% relative to the whole martensite, and

when regions surrounded by boundaries between adjacent crystals having an orientation difference of 15° or more are defined as crystal grains, an average aspect ratio of the crystal grains present in a region extending from a surface of a steel sheet to a depth of 5 μm is 2.0 or less.

2. The high-strength hot-rolled steel sheet according to Claim 1, comprising:

in addition to the chemical composition, by mass%,

one or two or more selected from:

Cu: 0.05% to 4.0%,

Ni: 0.005% to 2.0%,

B: 0.0002% to 0.0050%,

Ca: 0.0001% to 0.0050%,

REM: 0.0001% to 0.0050%,

Sb: 0.0010% to 0.10%, and

Sn: 0.0010% to 0.50%.

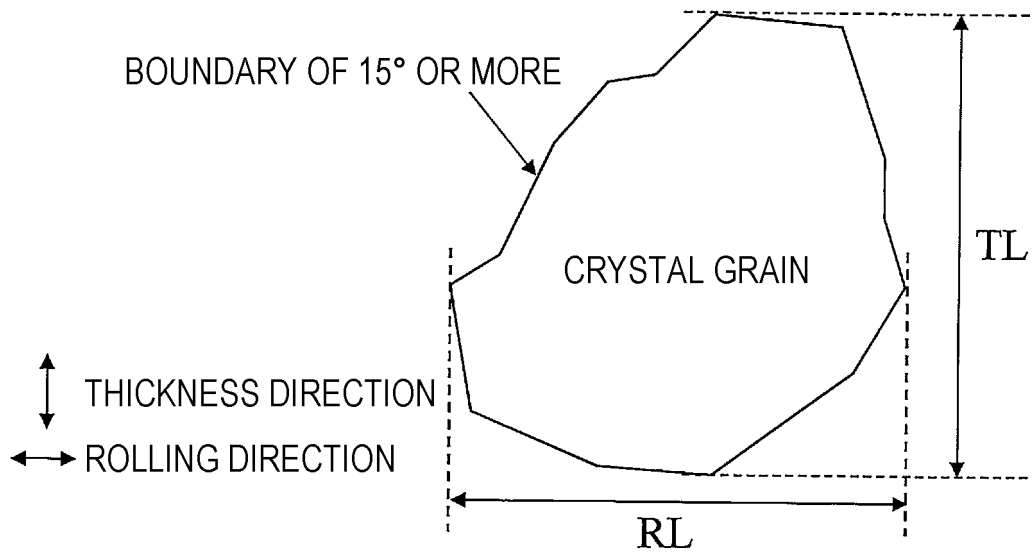
3. A method for manufacturing a high-strength hot-rolled steel sheet according to Claim 1 or 2, the method comprising:

heating a slab having the chemical composition; and

subsequently subjecting the slab to hot rolling,

wherein the hot rolling includes performing rough rolling, performing finish rolling under conditions in which a total number of passes at 1,000°C or higher is 3 times or more, a total rolling reduction at 1,000°C or lower is less than 50%, and a total rolling reduction from a final pass rolling temperature to the final pass rolling temperature + 50°C is 35% or less, subsequently starting cooling in less than 1.0 s, performing cooling under a condition in which an average cooling rate from a cooling start temperature to 550°C is 50°C/s or more, and subsequently performing coiling at a coiling temperature of (Ms temperature - 50)°C to 550°C.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/020292

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; *C21D 8/02*(2006.01)i; *C21D 9/46*(2006.01)i; *C22C 38/38*(2006.01)i; *C22C 38/60*(2006.01)i
FI: C22C38/00 301W; C21D8/02 A; C21D9/46 T; C22C38/38; C22C38/60

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)

C22C38/00-38/60; C21D8/02; C21D9/46-9/48

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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	WO 2017/017933 A1 (JFE STEEL CORPORATION) 02 February 2017 (2017-02-02)	1-3
A	WO 2020/080553 A1 (NIPPON STEEL CORPORATION) 23 April 2020 (2020-04-23)	1-3
A	WO 2021/090642 A1 (NIPPON STEEL CORPORATION) 14 May 2021 (2021-05-14)	1-3
A	WO 2018/150955 A1 (JFE STEEL CORPORATION) 23 August 2018 (2018-08-23)	1-3

☐ 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

08 July 2022

Date of mailing of the international search report

19 July 2022

Name and mailing address of the ISA/JP

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Telephone No.

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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REFERENCES CITED IN THE DESCRIPTION

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