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(54) HOT-ROLLED STEEL SHEET

(57) This hot-rolled steel sheet has a predetermined chemical composition and a microstructure, in which, in a texture of a surface layer region, pole densities of {001 }<110>, I 111 }<110>, and {112}<110> orientation groups are 2.0 or more, in a texture of an internal region, a pole density of a { 110}<112> orientation is 5.0 or less, and a tensile strength is 1,180 MPa or more.

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Description

[Technical Field of the Invention]

[0001] The present invention relates to a hot-rolled steel sheet.

[0002] Priority is claimed on Japanese Patent Application No. 2021-168623, filed October 14, 2021, the content of which is incorporated herein by reference.

[Background Art]

[0003] In recent years, a weight of a vehicle body has been reduced by applying a high strength steel sheet for the purpose of improving fuel efficiency and collision safety of a vehicle. However, high-strengthening of a steel sheet generally causes deterioration of toughness. Therefore, in the development of the high strength steel sheet, it is an important issue to achieve high-strengthening without deteriorating the toughness.

[0004] In general, in order to improve toughness, a method of improving toughness by performing rolling at a low temperature and applying a high cumulative strain in a state of unrecrystallized austenite is known. However, when a rolling reduction in the state of unrecrystallized austenite is increased, there is a problem that an aspect ratio of prior austenite grains increases and anisotropy in toughness increases.

[0005] For example, Patent Document 1 discloses a hot-rolled steel sheet which has a texture in which, in a thickness middle portion which is a steel sheet portion partitioned between a 3/8 thickness position and a 5/8 thickness position of a sheet thickness from a surface of a steel sheet, an average value of X-ray random intensity ratios of {100}<011> to {223}<110> orientation groups on a sheet surface is 6.5 or less and an X-ray random intensity ratio of a {332}<113> crystal orientation is 5.0 or less, and has a microstructure in which a total area ratio of tempered martensite, martensite, and lower bainite is more than 85% and an average grain size is 12.0 μm or less.

[Prior Art Document]

[Patent Document]

[0006] [Patent Document 1] Japanese Patent No. 5621942

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0007] However, in the technique disclosed in Patent Document 1, from the viewpoint of improving the fuel efficiency of a vehicle and improving collision safety, there is room for further improvement in a reduction in anisotropy in toughness in a high strength steel sheet.

[0008] The present invention has been made in view of the above circumstances, and an object of the present invention is to provide a hot-rolled steel sheet having high strength, excellent toughness, and reduced anisotropy in toughness.

[Means for Solving the Problem]

[0009] The present inventors investigated a relationship between a texture and mechanical properties of a hot-rolled steel sheet, and as a result, found that anisotropy in toughness can be further reduced even in a hot-rolled steel sheet having a tensile strength of 1,180 MPa or more. The present inventors found that in a rolled steel sheet, different textures develop on a surface and an inside. In addition, the present inventors found that, in order to reduce the anisotropy in toughness, it is more effective to control a texture in an austenite region than a texture of martensite after rapid cooling. Furthermore, the present inventors found that it is effective to preferably control hot rolling conditions in order to obtain a texture having a desired crystal orientation.

[0010] The gist of the present invention made on the basis of the above-mentioned findings is as follows.

[0011]

(1) A hot-rolled steel sheet according to an aspect of the present invention includes, as a chemical composition, by mass%:

C: 0.100% to 0.500%;
Si: 0.100% to 3.000%;

Mn: 0.50% to 3.00%;
P: 0.100% or less;
S: 0.0100% or less;
Al: 1.000% or less;
N: 0.0100% or less;
Ti: 0% to 0.20%;
Nb: 0% to 0.100%;
Ca: 0% to 0.0060%;
Mo: 0% to 0.50%;
Cr: 0% to 1.00%;
V: 0% to 0.50%;
Cu: 0% to 0.50%;
Ni: 0% to 0.50%;
Sn: 0% to 0.050%; and
a remainder comprising Fe and impurities,
in which a microstructure in a region from a depth of 1/8 of a sheet thickness from a surface to a depth of 3/8 of the sheet thickness from the surface includes, by area%,

90% to 100% of martensite, and
0% to 10% of a remainder in microstructure,

in a texture of a region from the surface to the depth of 1/8 of the sheet thickness from the surface,
pole densities of {001}<110>, {111}<110>, and {112}<110> orientation groups are 2.0 or more,
in a texture of a region from the depth of 1/8 of the sheet thickness from the surface to a depth of 1/2 of the sheet thickness from the surface,
a pole density of a { 110 } <112> orientation is 5.0 or less, and
a tensile strength of the hot-rolled steel sheet is 1,180 MPa or more.

(2) In the hot-rolled steel sheet according to (1), the chemical composition may contain, by mass%, one or two or more selected from the group consisting of

Ti: 0.02% to 0.20%,
Nb: 0.010% to 0.100%,
Ca: 0.0001 % to 0.0060%,
Mo: 0.01% to 0.50%,
Cr: 0.01% to 1.00%,
V: 0.01% to 0.50%,
Cu: 0.01% to 0.50%,
Ni: 0.01% to 0.50%, and
Sn: 0.001% to 0.050%.

[Effects of the Invention]

[0012] According to the above-described aspect according to the present invention, it is possible to provide a hot-rolled steel sheet having high strength, excellent toughness, and reduced anisotropy in toughness.

[Embodiments of the Invention]

[0013] Hereinafter, a hot-rolled steel sheet according to the present embodiment will be described in detail.
[0014] First, reasons for limiting a chemical composition of the hot-rolled steel sheet according to the present embodiment will be described. In addition, numerical limiting ranges described below using "to" include the lower limit and the upper limit in the ranges. Numerical values indicated as "less than" or "more than" do not fall within the numerical range. In addition, all % regarding the chemical composition means mass%.
[0015] The hot-rolled steel sheet according to the present embodiment includes, as a chemical composition, by mass%: C: 0.100% to 0.500%; Si: 0.100% to 3.000%; Mn: 0.50% to 3.00%; P: 0.100% or less; S: 0.0100% or less; Al: 1.000% or less; N: 0.0100% or less; and a remainder: Fe and impurities. Hereinafter, each element will be described in detail.

C: 0.100% to 0.500%

[0016] C is an important element for improving strength of the hot-rolled steel sheet. When a C content is less than 0.100%, the strength of the hot-rolled steel sheet decreases. Therefore, the C content is set to 0.100% or more. The C content is preferably 0.150% or more, 0.170% or more, 0.200% or more, or 0.220% or more.
[0017] On the other hand, when the C content is more than 0.500%, toughness of the hot-rolled steel sheet deteriorates. Therefore, the C content is set to 0.500% or less. The C content is preferably 0.450% or less, 0.400% or less, or 0.370% or less.

Si: 0.100% to 3.000%

[0018] Si is an element having an effect of improving the strength of the hot-rolled steel sheet. When a Si content is less than 0.100%, the strength of the hot-rolled steel sheet deteriorates. Therefore, the Si content is set to 0.100% or more. The Si content is preferably 0.200% or more, 0.300% or more, 0.400% or more, or 0.500% or more. The Si content is more preferably more than 1.000%, and still more preferably 1 .100% or more.
[0019] However, when the Si content is more than 3.000%, the toughness of the hot-rolled steel sheet deteriorates. Therefore, the Si content is set to 3.000% or less. The Si content is preferably 2.700% or less, 2.500% or less, or 2.300% or less.

Mn: 0.50% to 3.00%

[0020] Mn is an element effective for improving the strength of the hot-rolled steel sheet by improving hardenability and solid solution strengthening. When a Mn content is less than 0.50%, the strength of the hot-rolled steel sheet decreases. Therefore, the Mn content is set to 0.50% or more. The Mn content is preferably 1.00% or more, 1.20% or more, or 1.50% or more.
[0021] On the other hand, when the Mn content is more than 3.00%, MnS that increases anisotropy in the toughness of the hot-rolled steel sheet is generated. Therefore, the Mn content is set to 3.00% or less. The Mn content is preferably 2.50% or less, 2.30% or less, or 2.00% or less.

P: 0.100% or Less

[0022] P is an impurity element, and the lower a P content is, the more preferable it is. When the P content is more than 0.100%, deterioration of workability and weldability of the hot-rolled steel sheet becomes significant, and fatigue properties also deteriorate. Therefore, the P content is set to 0.100% or less. The P content is preferably 0.070% or less, 0.050% or less, or 0.030% or less.
[0023] A lower limit of the P content is not particularly specified. However, since an excessive reduction in the P content causes an increase in manufacturing cost, the P content may be set to 0.001% or more or 0.005% or more.

S: 0.0100% or Less

[0024] S is an impurity element, and the lower a S content is, the more preferable it is. When the S content is more than 0.0100%, a large amount of inclusions such as MnS that increase the anisotropy in the toughness of the hot-rolled steel sheet are generated. Therefore, the S content is set to 0.0100% or less. The S content is preferably 0.0080% or less, 0.0060% or less, or 0.0040% or less.
[0025] A lower limit of the S content is not particularly specified. However, since an excessive reduction in the S content causes an increase in the manufacturing cost, the S content may be set to 0.0005% or more, or 0.0010 or more.

Al: 1.000% or Less

[0026] Al is an element that acts as a deoxidizing agent in a steelmaking stage and is effective for improving cleanliness of steel. However, when an Al content is more than 1.000%, alumina precipitated in the form of clusters is generated, and the toughness of the hot-rolled steel sheet deteriorates. Therefore, the Al content is set to be 1.000% or less. The Al content is preferably 0.700% or less, 0.500% or less, or 0.400% or less.
[0027] A lower limit of the Al content is not particularly specified. However, since an excessive reduction in the Al content causes an increase in the manufacturing cost, the Al content may be set to 0.001% or more, or 0.005% or more.

N: 0.0100% or Less

[0028] N is an impurity element. When a N content is more than 0.0100%, a coarse Ti nitride is formed at a high temperature, and the toughness of the hot-rolled steel sheet deteriorates. Therefore, the N content is set to 0.0100% or less. The N content is preferably 0.0080% or less, 0.0060% or less, or 0.0040% or less.
[0029] A lower limit of the N content is not particularly specified. However, since an excessive reduction in the N content causes an increase in the manufacturing cost, the N content may be set to 0.0010% or more.
[0030] The hot-rolled steel sheet according to the present embodiment may contain the above elements, and the remainder of Fe and impurities. Examples of the impurities include those that are unavoidably incorporated from steel raw materials or scrap and/or in a steelmaking process or elements that are allowed in a range in which the properties of the hot-rolled steel sheet according to the present embodiment are not inhibited.
[0031] In order to improve various properties, the hot-rolled steel sheet according to the present embodiment may contain optional elements shown below instead of a portion of Fe. In order to reduce an alloy cost, it is not necessary to intentionally include these optional elements in steel. Therefore, lower limits of the amounts of these optional elements are all 0%.

Ti: 0.02% to 0.20%

[0032] Ti is an element effective for suppressing austenite recrystallization and grain growth between stands of hot rolling. By suppressing the recrystallization of austenite between the stands, strain can be further accumulated. As a result, the texture of the hot-rolled steel sheet can be preferably controlled. In a case of reliably obtaining the effect, a Ti content is preferably set to 0.02% or more.
[0033] On the other hand, when the Ti content is more than 0.20%, inclusions attributed to TiN are generated, and the toughness of the hot-rolled steel sheet deteriorates. Therefore, the Ti content is set to 0.20% or less.

Nb: 0.010% to 0.100%

[0034] Nb is an element effective for suppressing austenite recrystallization and grain growth between the stands of hot rolling. By suppressing the recrystallization of austenite between the stands, strain can be further accumulated. As a result, the texture of the hot-rolled steel sheet can be preferably controlled. In a case of reliably obtaining the effect, a Nb content is preferably set to 0.010% or more.
[0035] On the other hand, when the Nb content is more than 0.100%, the effect is saturated. Therefore, the Nb content is set to 0.100% or less.

Ca: 0.0001% to 0.0060%

[0036] Ca is an element having an effect of refining the structure of the hot-rolled steel sheet by dispersing a number of fine oxides during deoxidation of molten steel. In addition, Ca is also an element that fixes S in steel as spherical CaS, suppresses the generation of elongated inclusions such as MnS, and reduces the anisotropy in the toughness of the hot-rolled steel sheet. In a case of reliably obtaining these effects, a Ca content is preferably set to 0.0001% or more.
[0037] On the other hand, when the Ca content is more than 0.0060%, the above effects are saturated. Therefore, the Ca content is set to 0.0060% or less.

Mo: 0.01 % to 0.50%

[0038] Mo is an element effective for precipitation hardening of ferrite. In a case of reliably obtaining this effect, a Mo content is preferably set to 0.01 % or more.
[0039] On the other hand, when the Mo content is more than 0.50%, cracking susceptibility of a slab increases, and it becomes difficult to handle the slab. Therefore, the Mo content is set to 0.50% or less.

Cr: 0.01% to 1.00%

[0040] Cr is an effective element for improving the strength of the hot-rolled steel sheet. In a case of reliably obtaining this effect, a Cr content is preferably set to 0.01% or more.
[0041] However, when the Cr content is more than 1.00%, ductility of the hot-rolled steel sheet deteriorates. Therefore, the Cr content is set to 1.00% or less.

V: 0.01% to 0.50%

[0042] V improves the strength of the hot-rolled steel sheet through strengthening with precipitates and refinement of ferrite grains. In a case of reliably obtaining this effect, a V content is preferably set to 0.01% or more.
[0043] On the other hand, when the V content is more than 0.50%, a large amount of carbonitrides is precipitated, and formability of the hot-rolled steel sheet deteriorates. Therefore, the V content is set to be 0.50% or less.

Cu: 0.01% to 0.50%

[0044] Cu is an element that is solid-solubilized in steel and contributes to an improvement in the strength of steel. Cu is also an element that improves hardenability. In a case of reliably obtaining these effects, a Cu content is preferably set to 0.01% or more.
[0045] On the other hand, when the Cu content is more than 0.50%, surface properties of the hot-rolled steel sheet deteriorate, and there are cases where chemical convertibility and corrosion resistance deteriorate. Therefore, the Cu content is set to 0.50% or less.

Ni: 0.01% to 0.50%

[0046] Ni is an element that is solid-solubilized in steel and contributes to an increase in the strength of the steel. Ni is also an element that improves hardenability. In a case of reliably obtaining these effects, a Ni content is preferably set to 0.01% or more.
[0047] On the other hand, since an alloy cost of Ni is high, including a large amount of Ni causes an increase in the cost. In addition, when the Ni content is more than 0.50%, there are cases where the weldability of the hot-rolled steel sheet deteriorates. Therefore, the Ni content is set to 0.50% or less.

Sn: 0.001% to 0.050%

[0048] Sn has an effect of suppressing internal oxidation and an effect of improving the strength. In a case of reliably obtaining the effects, a Sn content is preferably set to 0.001% or more.
[0049] On the other hand, when a large amount of Sn is contained, there are cases where defects occur during hot rolling. Therefore, the Sn content is set to 0.050% or less.
[0050] The chemical composition described above may be measured by a general analysis method. For example, the chemical composition may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). C and S may be measured using a combustion-infrared absorption method, and N may be measured using an inert gas fusion-thermal conductivity method.
[0051] In a case where the hot-rolled steel sheet includes a plating layer on a surface, the chemical composition may be analyzed after removing the plating layer from the surface by mechanical grinding.
[0052] Next, a microstructure of the hot-rolled steel sheet according to the present embodiment will be described.
[0053] In the hot-rolled steel sheet according to the present embodiment, a microstructure in a region from a depth of 1/8 of a sheet thickness from a surface to a depth of 3/8 of the sheet thickness from the surface includes, by area%, 90% to 100% of martensite, and 0% to 10% of a remainder in microstructure, in a texture of a region from the surface to the depth of 1/8 of the sheet thickness from the surface, pole densities of {001}<110>, {111}<110>, and {112}<110> orientation groups are 2.0 or more, and in a texture of a region from the depth of 1/8 of the sheet thickness from the surface to a depth of 1/2 of the sheet thickness from the surface, a pole density of a { 110}<112> orientation is 5.0 or less.
[0054] In the present embodiment, area% of martensite and the remainder in microstructure in the region from the depth of 1/8 of the sheet thickness from the surface to the depth of 3/8 of sheet thickness from the surface is specified because the microstructure at this position represents a typical microstructure of the hot-rolled steel sheet. Hereinafter, each specifying will be described in detail.

Area Ratio of Martensite: 90% to 100%

[0055] When an area ratio of martensite is less than 90%, the strength of the hot-rolled steel sheet deteriorates, and a desired strength cannot be obtained. Therefore, the area ratio of martensite is set to 90% or more. The area ratio of martensite is preferably 92% or more, 95% or more, or 97% or more, and more preferably 100%.
[0056] In the present embodiment, martensite refers to fresh martensite and tempered martensite. In the present embodiment, it is not necessary to distinguish between fresh martensite and tempered martensite, and thus both will be collectively referred to as martensite.
[0057] Tempered martensite is obtained by tempering fresh martensite and has a lower dislocation density than fresh

martensite. A preferred manufacturing method of the hot-rolled steel sheet according to the present embodiment, which will be described later, does not include a heat treatment for the purpose of tempering after rapid cooling. However, there are cases where tempered martensite is generated during cooling after hot rolling or by reheating after coiling.

Area Ratio of Remainder in Microstructure: 0% to 10%

[0058] The microstructure of the hot-rolled steel sheet according to the present embodiment may contain bainite as the remainder in microstructure. When an area ratio of the remainder in microstructure is more than 10%, the strength of the hot-rolled steel sheet decreases, and a desired strength cannot be obtained. Therefore, the area ratio of the remainder in microstructure is set to 10% or less. The area ratio of the remainder in microstructure is preferably 8% or less, 5% or less, or 3% or less, and more preferably 0%.

[0059] The area ratio of each structure is obtained by the following method.

[0060] A test piece for structure observation is collected from a 1/4 thickness position of the hot-rolled steel sheet (a region from the depth of 1/8 of the sheet thickness from the surface to the depth of 3/8 of the sheet thickness from the surface) and from a sheet width center position so that a sheet thickness cross section parallel to a rolling direction serves an observed section. The observed section is mirror-polished and then corroded with a 3 volume% Nital solution. Three visual fields of the observed section after the corrosion were photographed at a magnification of 2,000-fold using an optical microscope and a scanning electron microscope (SEM). Each photographed visual field is set to 500 μm × 500 μm. Image analysis is performed on the photographs, and the area ratio of each structure is calculated. The area ratio of each structure is obtained by calculating an average value of the area ratios obtained for the three visual fields.

[0061] Since martensite is a structure having a substructure called a block or a packet in grains, it is possible to distinguish martensite from other microstructures in an electron channeling contrast image for which the scanning electron microscope is used.

[0062] Among structures that are each an aggregate of lath-shaped crystal grains and do not contain any Fe-based carbides having a major axis of 20 nm or more in the structure, a structure that is not martensite or a structure in which Fe-based carbides having a major axis of 20 nm or more are contained in the structure and the Fe-based carbides have a single variant, that is, the Fe-based carbides extend in the same direction, is regarded as the bainite. Here, the Fe-based carbides extending in the same direction refer to Fe-based carbides for which a difference in extending direction between the Fe-based carbides is 5° or less.

Average Grain Size of Prior Austenite Grains: More Than 5.0 μm and 30.0 μm or Less

[0063] In the hot-rolled steel sheet according to the present embodiment, at the 1/4 thickness position (the region from the depth of 1/8 of the sheet thickness from the surface to the depth of 3/8 of the sheet thickness from the surface), an average grain size of prior austenite grains may be more than 5.0 μm and 30.0 μm or less. By setting the average grain size of the prior austenite grains to more than 5.0 μm, the predetermined texture required in the present embodiment can be stably obtained, and the anisotropy in the toughness of the hot-rolled steel sheet can be further reduced. The average grain size of the prior austenite grains is preferably 6.0 μm or more, 7.0 μm or more, 8.0 μm or more, or 9.0 μm or more.

[0064] On the other hand, when the average grain size of the prior austenite grains is more than 30.0 μm, there are cases where a desired strength cannot be obtained. Therefore, the average grain size of the prior austenite grains is preferably set to 30.0 μm or less.

[0065] The average grain size of the prior austenite grains is obtained by the following method.

[0066] A test piece for structure observation is collected from the 114 thickness position of the hot-rolled steel sheet (the region from the depth of 1/8 of the sheet thickness from the surface to the depth of 3/8 of the sheet thickness from the surface) and from the sheet width center position so that the sheet thickness cross section parallel to the rolling direction serves an observed section. The observed section is mirror-polished and then corroded with a 3 volume% Nital solution, and the microstructure is observed with a scanning electron microscope (SEM). A range in which approximately 10,000 crystal grains are observed in one visual field is photographed in three visual fields by SEM observation. The obtained photograph is subjected to image analysis using image analysis software (WinROOF) to calculate the average grain size of the prior austenite grains. For one of the prior austenite grains included in the observed visual field, an average value of a shortest diameter and a longest diameter is calculated, and the average value is used as the grain size of the prior austenite grains. The above operation is performed on all the prior austenite grains except for the prior austenite grains which are not entirely included in the photographed visual fields, such as crystal grains in an end portion of the photographed visual field, and the grain sizes of all the prior austenite grains in the photographed visual fields are obtained. The average grain size of the prior austenite grains in the photographed visual fields is obtained by calculating a value obtained by dividing the sum of the obtained grain sizes of the prior austenite grains by the total number of prior austenite grains of which grain sizes are measured. This operation is performed for each of all the photographed visual fields, and the average grain size of the prior austenite grains of all the photographed visual fields is calculated, thereby obtaining the average grain size of the prior austenite grains.

[0067] Pole Densities of {001}<110>, {111}<110>, and {112}<110> Orientation Group in Texture of Region from Surface to Depth of 1/8 of Sheet Thickness from Surface: 2.0 or More

[0068] When the pole densities of the {001}<11 0>, {111}<110>, and {112}<110> orientation groups in the texture of the region (hereinafter, sometimes referred to as a surface layer region) from the surface to the depth of 1/8 of the sheet thickness from the surface are less than 2.0, the occurrence of fine cracks in the surface layer region cannot be suppressed. As a result, the anisotropy in the toughness of the hot-rolled steel sheet increases. Therefore, the pole densities of the {001}<110>, {111 }<110>, and {112 } <110> orientation groups in the texture of the surface layer region are set to 2.0 or more. The pole densities of the {001 }<110>, {111}<110>, and {112}<110> orientation groups in the texture of the surface layer region are preferably 2.2 or more, 2.5 or more, or 2.7 or more.

[0069] An upper limit of the pole densities of the {001 }<110>, { 111 }<110>, and { 112}<110> orientation groups in the texture of the surface layer region is not particularly specified, but may be set to 9.0 or less, 8.0 or less, 7.0 or less, or 5.0 or less from the viewpoint of suppressing the deterioration of ductility.

[0070] Pole Density of { 110 }<112> Orientation in Texture of Region from Depth of 1/8 of Sheet Thickness from Surface to Depth of 1/2 of Sheet Thickness from Surface: 5.0 or Less

[0071] The pole density of the { 110 }<112> orientation in the texture of the region (hereinafter, sometimes referred to as an internal region) from the depth of 1/8 of the sheet thickness from the surface to the depth of 1/2 of the sheet thickness from the surface is more than 5.0, the anisotropy in the toughness of the hot-rolled steel sheet increases. Therefore, the pole density of the { 110}<112> orientation in the texture of the internal region is set to 5.0 or less. The pole density of the { 110}<112> orientation in the texture of the internal region is preferably 4.6 or less, 4.2 or less, or 4.0 or less.

[0072] A lower limit of the pole density of the { 110}<112> orientation in the texture of the internal region is not particularly specified, but may be set to 2.0 or more or 2.5 or more from the viewpoint of suppressing the deterioration of the strength.

[0073] For the pole densities, a device in which a scanning electron microscope and an EBSD analyzer are combined and OIM analysis (registered trademark) manufactured by AMETEK Inc. are used. From an orientation distribution function (ODF) that is calculated by using orientation data measured by an electron backscattering diffraction (EBSD) method and a spherical harmonic function and displays a three-dimensional texture, the pole densities of the {001 } <110>, { 111 }<110>, and { 112}<110> orientation groups in the texture of the surface layer region and the pole density of the {110}<112> in the texture of the internal region are obtained.

[0074] A measurement range is set to, for the surface layer region, the region from the surface to the depth of 1/8 of the sheet thickness from the surface and for the internal region, the region from the depth of 1/8 of the sheet thickness from the surface to the depth of 1/2 of the sheet thickness from the surface. Measurement pitches are set to 5 μm/step.

[0075] It should be noted that {hkl) indicates a crystal plane parallel to a rolled surface and <uvw> indicates a crystal direction parallel to the rolling direction. That is, {hkl}<uvw> indicates a crystal in which {hkl} is oriented in a sheet surface normal direction and <uvw> is oriented in the rolling direction.

[0076] The rolling direction of the hot-rolled steel sheet can be determined by the following method.

[0077] First, a test piece is collected so that a sheet thickness cross section of the hot-rolled steel sheet can be observed. The sheet thickness cross section of the collected test piece is finished by mirror polishing and then observed using an optical microscope. An observation range is set to an overall thickness of the sheet thickness, and a region with dark brightness is determined to be an inclusion. Among inclusions, in inclusions having a major axis length of 40 μm or more, a direction parallel to a direction in which the inclusion extends is determined to be the rolling direction.

Tensile Strength: 1,180 MPa or More

[0078] A tensile strength of the hot-rolled steel sheet according to the present embodiment is set to 1,180 MPa or more from the viewpoint of improving collision safety of a vehicle or the like or reducing a weight of a vehicle body. The tensile strength is preferably 1,250 MPa or more, 1,300 MPa or more, 1,350 MPa or more, or 1,400 MPa or more.

[0079] An upper limit of the tensile strength is not particularly specified, but is preferably 2,000 MPa or less, 1,600 MPa or less, 1,500 MPa or less, or 1,400 MPa or less.

[0080] The tensile strength is measured according to JIS Z 2241: 2011. A No. 5 test piece of JIS Z 2241: 2011 is used as a test piece, and a test direction is set to a direction perpendicular to the rolling direction.

[0081] The sheet thickness of the hot-rolled steel sheet according to the present embodiment is not particularly limited and may be set to 1.2 to 8.0 mm. When the sheet thickness of the hot-rolled steel sheet is less than 1.2 mm, it is difficult to secure a rolling completion temperature, a rolling force becomes excessive, and there are cases where it is difficult to perform hot rolling.

[0082] When the sheet thickness is more than 8.0 mm, it becomes difficult to control the texture, and there are cases where it is difficult to obtain the above-described texture. Therefore, the sheet thickness may be set to 8.0 mm or less.

[0083] The hot-rolled steel sheet according to the present embodiment may have a plating layer on the surface. As the plating layer, an aluminum plating layer, an aluminum-zinc plating layer, an aluminum-silicon plating layer, a hot-dip galvanized layer, an electrogalvanized layer, a hot-dip galvannealed layer, or the like is an exemplary example.

[0084] Next, a preferred manufacturing method of the hot-rolled steel sheet according to the present embodiment will be described. The preferred manufacturing method of the hot-rolled steel sheet according to the present embodiment includes the following steps (a) to (d). Unless otherwise specified, a temperature in the following description refers to a surface temperature of the steel sheet.

[0085]

(a) A heating step of heating a slab having the above-described chemical composition to a temperature range of 1,100°C or higher and lower than 1,350°C.

(b) A finish rolling step of performing finish rolling on the heated slab using a rolling mill having a plurality of stands, in which the following conditions (1) to (V) are satisfied.

(I) A finish rolling start temperature is set to 800°C or higher.

(II) In each of the last four stands among the plurality of stands, rolling is performed so that σ represented by Expression (1) becomes 40 to 80.

$$\sigma = \exp(0.753 + 3000/T) \times \varepsilon^{0.21} \times \varepsilon'^{0.13} \ldots(1)$$

Here, T is a temperature (°C) immediately before entering each stand, ε is an equivalent plastic strain, and ε' is a strain rate.

(III) Interpass times between the last four stands are set to 0.2 to 10.0 seconds.

(IV) A cumulative rolling reduction of the last four stands is set to 60% or larger.

(V) A finishing temperature is set to 800°C to 950°C.

(c) A cooling step of starting cooling within 1.0 second after completion of the finish rolling, and performing cooling to a temperature range of 300°C or lower so that an average cooling rate in a temperature range of the finishing temperature to 300°C is 100 °C/s or faster.

(d) A coiling step of performing coiling after the cooling.

[0086] Hereinafter, each step will be described.

(a) Heating Step

[0087] In the heating step, it is preferable to heat the slab having the above-mentioned chemical composition to a temperature range of 1,100°C or higher and lower than 1,350°C. A method of manufacturing the slab does not need to be particularly limited, and a commonly used method can be applied in which molten steel having the above-described chemical composition is melted in a converter or the like and is cast into a slab by a casting method such as continuous casting. In addition, an ingot-making and blooming method may be used.

[0088] In the slab, most of carbonitride-forming elements such as Ti are present in the slab as coarse carbonitrides in a non-uniform distribution. The coarse precipitates (carbonitrides) present in a non-uniform distribution deteriorate various properties (for example, tensile strength, toughness, and hole expansibility) of the hot-rolled steel sheet. Therefore, the slab before hot rolling is heated to solid-solubilize the coarse precipitates. In order to sufficiently solid-solubilize these coarse precipitates before hot rolling, a heating temperature of the slab is preferably set to 1,100°C or higher. However, an excessively high heating temperature for the slab causes the generation of surface defects and a decrease in yield due to scale removal. Therefore, the heating temperature of the steel material is preferably set to lower than 1,350°C.

[0089] The slab is heated to the temperature range of 1,100°C or higher and lower than 1,350°C and held for a predetermined time. However, when a holding time is longer than 4,800 seconds, the amount of scale generated increases. As a result, a rolled-in scale or the like is likely to occur in the subsequent finish rolling step, and there are cases where surface quality of the hot-rolled steel sheet deteriorates. Therefore, the holding time in the temperature range of 1,100°C or higher and lower than 1,350°C is preferably set to 4,800 seconds or shorter.

Rough Rolling Step

[0090] Rough rolling may be performed on the slab between the heating step and the finish rolling step. Conditions of the rough rolling are not particularly limited as long as desired sheet bar dimensions can be obtained.

(b) Finish Rolling Step

[0091] In the finish rolling step, the heated slab is subjected to finish rolling using the rolling mill having the plurality of stands. Here, it is preferable to satisfy the conditions (I) to (V) to be described below.
[0092] It is preferable to perform descaling before the finish rolling or during rolling between the rolling stands during the finish rolling.

(I) Finish Rolling Start Temperature: 800°C or Higher

[0093] The finish rolling start temperature (an entry-side temperature of a first pass of the finish rolling) is preferably set to 800°C or higher. When the finish rolling start temperature is lower than 800°C, rolling in some of the plurality of rolling stands (particularly the stands in the first half) is performed at a temperature in a ferrite/austenite dual phase region. As a result, a worked structure remains after the finish rolling, and there are cases where the strength and toughness of the hot-rolled steel sheet deteriorate. Therefore, the finish rolling start temperature is preferably set to 800°C or higher.
[0094] The finish rolling start temperature is preferably set to 1,100°C or lower in order to suppress coarsening of austenite and to preferably control the texture in the surface layer region and in the internal region.

(II) In Each of Last Four Stands, σ Represented by Expression (1): 40 to 80

[0095]

$$\sigma = \exp(0.753 + 3000/T) \cdot \varepsilon^{0.21} \cdot \varepsilon'^{0.13} \ldots(1)$$

[0096] Here, T is the temperature (°C) immediately before entering each stand (that is, the entry-side temperature), ε is the equivalent plastic strain, and ε' is the strain rate.
[0097] The fact that σ in each of the last four stands is 40 to 80 can be rephrased as follows: σ of the fourth stand from the last stand, σ of the third stand from the last stand, σ of the second stand from the last stand, and σ of the last stand are all 40 to 80.
[0098] When there is even one stand in which σ is less than 40, there are cases where strain necessary for the development of the texture in the surface layer region is not suitably applied in each of the last four stands. As a result, there are cases where in the texture of the region from the surface to the depth of 1/8 of the sheet thickness from the surface, the pole densities of the {001}<110>, { 111 }<110>, and {112}<110> orientation groups cannot be preferably controlled. Therefore, σ in each of the last four stands is preferably set to 40 or more.
[0099] In addition, when there is even one stand in which σ is more than 80, the texture of the internal region cannot be preferably controlled, and there are cases where the anisotropy in the toughness of the hot-rolled steel sheet increases. Therefore, σ in each of the last four stands is preferably set to 80 or less.
[0100] In addition, ε, which is the equivalent plastic strain, can be obtained by $\varepsilon = (2/\sqrt{3}) \times (h/H)$ when an entry-side sheet thickness is represented by h and an exit-side sheet thickness is represented by H. In addition, the strain rate ε' can be obtained by $\varepsilon' = \varepsilon/t$ when a rolling time is t (s). In addition, the rolling time t refers to a time during which strain is applied to the steel sheet when the steel sheet and the rolling roll come into contact with each other.

(111) Interpass Times between Last Four Stands: 0.2 to 10.0 Seconds

[0101] When there is even one pass in which the interpass time is longer than 10.0 seconds between the last four stands, recovery and recrystallization between the passes progresses. As a result, it becomes difficult to accumulate strain, and there are cases where a desired structure cannot be obtained in the hot-rolled steel sheet. Therefore, the interpass times between the last four stands are preferably set to 10.0 seconds or shorter.
[0102] The interpass times between the last four stands are preferably short, but a reduction in the interpass times are limited in terms of an installation space of each stand and a rolling rate. In addition, when the interpass times between the last four stands become shorter than 0.2 seconds, the number of unrecrystallized grains significantly increases, and there are cases where a desired texture cannot be obtained. Therefore, the interpass times between the last four stands are preferably set to 0.2 seconds or longer.
[0103] The interpass times between the last four stands are 0.2 to 10.0 seconds can be rephrased as follows: interpass time between the fourth stand from the last stand and the third stand from the last stand, the interpass time between

the third stand from the last stand and the second stand from the last stand, and the interpass time between the second stand from the last stand and the last stand are all 0.2 to 10.0 seconds.

(IV) Cumulative Rolling Reduction of Last Four Stands: 60% or Larger

[0104] When the cumulative rolling reduction of the last four stands is smaller than 60%, there are cases where a dislocation density introduced into unrecrystallized austenite decreases. When the dislocation density introduced into unrecrystallized austenite decreases, it becomes difficult to obtain a desired structure, and there are cases where the strength and toughness of the hot-rolled steel sheet deteriorate. Therefore, the cumulative rolling reduction of the last four stands is preferably set to 60% or larger.

[0105] When the cumulative rolling reduction of the last four stands is larger than 97%, there are cases where a shape of the hot-rolled steel sheet deteriorates. Therefore, the cumulative rolling reduction of the last four stands may be set to 97% or smaller.

[0106] The cumulative rolling reduction of the last four stands can be represented by $\{1 - (t1/t0)\} \times 100$ (%) when an inlet sheet thickness of the fourth stand from the last stand is represented by t0 and an outlet sheet thickness of the last stand is represented by t1.

(V) Finishing temperature: 800°C to 950°C

[0107] When the finish rolling finishing temperature (exit-side temperature of the last stand) is lower than 800°C, the rolling is performed at a temperature in the ferrite/austenite dual phase region. Therefore, there are cases where the worked structure remains after the rolling and the strength and toughness of the hot-rolled steel sheet decrease. Therefore, the finishing temperature is preferably set to 800°C or higher.

[0108] In addition, in the slab having the chemical composition according to the present embodiment, an unrecrystallized austenite region is a temperature range of approximately 950°C or lower. Therefore, when the finishing temperature is higher than 950°C, austenite grains grow, and a grain length of martensite in the hot-rolled steel sheet obtained after the cooling increases. As a result, it becomes difficult to obtain a desired texture, and there are cases where the strength and toughness of the hot-rolled steel sheet decrease. Therefore, the finishing temperature is preferably set to 950°C or lower.

(c) Cooling Step

[0109] In the cooling step, it is preferable that cooling is started within 1.0 second after the completion of the finish rolling, and cooling to a temperature range of 300°C or lower is performed so that an average cooling rate in a temperature range of the finishing temperature to 300°C is 100 °C/s or faster.

[0110] In the present embodiment, it is preferable that cooling equipment is installed at a rear stage of finish rolling equipment, and the cooling is performed while the steel sheet after the finish rolling passes through the cooling equipment. The cooling equipment is preferably equipment that can cool the steel sheet at an average cooling rate of 100 °C/s or faster. Examples of the cooling equipment include water cooling equipment using water as a cooling medium.

[0111] The average cooling rate in the cooling step is a value obtained by dividing a temperature drop width of the steel sheet from when the cooling is started to when the cooling is ended by a time required from when the cooling is started to when the cooling is ended. When the cooling is started refers to a time when the steel sheet is introduced into the cooling equipment, and when the cooling is ended refers to a time when the steel sheet is taken out of the cooling equipment.

[0112] Examples of the cooling equipment include equipment having no intermediate air cooling section and equipment having at least one intermediate air cooling section. In the present embodiment, any cooling equipment may be used. Even in a case where cooling equipment having an air cooling section is used, the average cooling rate from the start of cooling to the end of cooling may be 100 °C/s or faster.

[0113] Hereinafter, the reasons for limiting cooling conditions will be described. A cooling stop temperature is 300°C or lower, and this condition will be described in the coiling step.

Cooling Start Time: Within 1.0 Second after Completion of Finish Rolling

[0114] It is preferable to start cooling immediately after the completion of the finish rolling. When the cooling start time is longer than 1.0 second, recrystallization proceeds, cooling is performed in a state where the strain is released, and there are cases where a desired texture cannot be obtained in the hot-rolled steel sheet. Therefore, it is preferable to start the cooling within 1.0 second after the completion of the finish rolling.

Average Cooling Rate in Temperature Range of Finishing temperature to 300°C: 100 °C/s or Faster

[0115] When the average cooling rate in the temperature range of the finishing temperature to 300°C is slower than 100 °C/s, bainite or ferrite is likely to be formed, and there are cases where a desired amount of martensite cannot be obtained. Therefore, the average cooling rate in the temperature range of the finishing temperature to 300°C is preferably set to 100 °C/s or faster.

(d) Coiling Step

[0116] In the coiling step, the steel sheet cooled to a temperature range of 300°C or lower is preferably coiled. Since the steel sheet is coiled immediately after the cooling, a coiling temperature is almost equal to the cooling stop temperature. When the coiling temperature is higher than 300°C, polygonal ferrite or bainite is generated, and there are cases where the strength of the hot-rolled steel sheet decreases. Therefore, the coiling temperature is preferably set to a temperature range of 300°C or lower.

[0117] After the coiling, the hot-rolled steel sheet may be subjected to temper rolling according to a conventional method, or subjected to pickling to remove the scale formed on the surface. Alternatively, a plating treatment such as aluminum plating, aluminum-zinc plating, aluminum-silicon plating, hot-dip galvanizing, electrogalvanizing, and hot-dip galvannealing, or a chemical conversion treatment may be performed.

[0118] The hot-rolled steel sheet according to the present embodiment can be stably manufactured by the preferred manufacturing method described above.

[Examples]

[0119] Next, examples of the present invention will be described. Conditions in the examples are one example of conditions adopted to confirm the feasibility and effects of the present invention, and the present invention is not limited to this example of conditions. The present invention may adopt various conditions to achieve the object of the present invention without departing from the scope of the present invention.

[0120] Molten steels having the chemical compositions shown in Table 1 were melted in a converter and slabs were obtained by a continuous casting method. Next, these slabs were heated under the conditions shown in Tables 2A and 2B, subjected to rough rolling, and then subjected to finish rolling under the conditions shown in Tables 2A and 2B. After the finish rolling was completed, the slabs were cooled and coiled under the conditions shown in Tables 3A and 3B to obtain hot-rolled steel sheets having the sheet thicknesses shown in Tables 3A and 3B.

[0121] In the heating step, holding times at the heating temperatures shown in Tables 2A and 2B were set to 4,800 seconds or shorter.

[0122] In addition, as cooling after the finish rolling, water cooling was performed in which the steel sheet was passed through water cooling equipment having no intermediate air cooling section. An average cooling rate in Tables 3A and 3B is a value obtained by dividing a temperature drop width of the steel sheet from when the steel sheet was introduced into the water cooling equipment to when the steel sheet was taken out of the water cooling equipment by a time required for the steel sheet to be passed through the water cooling equipment.

[0123] A test piece was collected from the obtained hot-rolled steel sheet, an area ratio of each structure and pole densities of textures were measured and a tensile test was conducted by the above-described methods.

The obtained results are shown in Tables 4A and 4B.

[0124] In a case where an obtained tensile strength was 1,180 MPa or more, the hot-rolled steel sheet was determined to be acceptable as having high strength. On the other hand, in a case where the obtained tensile strength was less than 1,180 MPa, the hot-rolled steel sheet was determined to be unacceptable as not having high strength.

[0125] A Charpy impact test was conducted to evaluate the toughness of the hot-rolled steel sheets, and a ductile-brittle transition temperature was measured. For the measurement of the ductile-brittle transition temperature, a C-direction notch Charpy impact test was conducted using a V-notch test piece having a subsize of 2.5 mm according to JIS Z 2242: 2018. A temperature at which a brittle fracture surface ratio became 50% was defined as the ductile-brittle transition temperature. In addition, for hot-rolled steel sheets having a final sheet thickness of less than 2.5 mm, an overall thickness was measured.

[0126] In a case where the obtained ductile-brittle transition temperature was -50°C or lower, the hot-rolled steel sheet was determined to be acceptable as having excellent toughness. On the other hand, in a case where the obtained ductile-brittle transition temperature was higher than -50°C, the hot-rolled steel sheet was determined to be unacceptable as being inferior in toughness.

[0127] Furthermore, the anisotropy in toughness was evaluated by the following method. According to JIS Z 2242:

2018, an absorbed energy of a C-direction notch and an absorbed energy of an L-direction notch were measured by a Charpy impact test using a V-notch test piece having a subsize of 2.5 mm. The Charpy impact test was conducted at -60°C. A difference between the absorbed energy of the L-direction notch and the absorbed energy of the C-direction notch was calculated, and in a case where the difference was ±15 J or less, the hot-rolled steel sheet was determined to be acceptable as having reduced anisotropy in toughness. On the other hand, in a case where the difference between the absorbed energy of the L-direction notch and the absorbed energy of the C-direction notch was more than ±15 J, the hot-rolled steel sheet was determined to be unacceptable as not having reduced anisotropy in toughness.

[Table 1]

Kind of steel	Chemical composition (mass%), remainder: Fe and impurities								Note
	C	Si	Mn	P	S	Al	N	Others	
A	0.210	1.100	1.50	0.013	0.0010	0.010	0.0030	-	Present Invention Steel
B	0.180	1.100	1.60	0.014	0.0020	0.020	0.0030	Ti: 0.03, Nb: 0.020	Present Invention Steel
C	0.150	1.400	1.40	0.014	0.0020	0.010	0.0030	Nb: 0.015, Mo: 0.40	Present Invention Steel
D	0.150	1.400	1.40	0.014	0.0020	0.010	0.0030	Ti: 0.02, Ca: 0.0030, Cr: 0.70	Present Invention Steel
E	0.150	1.800	1.20	0.014	0.0020	0.010	0.0030	Ti: 0.02, V: 0.20	Present Invention Steel
F	0.240	1.400	1.40	0.015	0.0020	0.010	0.0030	Ti: 0.03, Cu: 0.40	Present Invention Steel
G	0.130	1.400	1.40	0.014	0.0020	0.010	0.0030	Ti: 0.02, Nb: 0.020, Ni: 0.02, Sn: 0.001	Present Invention Steel
H	0.130	3.100	1.20	0.014	0.0020	0.010	0.0030	-	Comparative Example
I	0.080	1.000	1.10	0.014	0.0020	0.010	0.0030	-	Comparative Example
J	0.100	1.000	1.10	0.014	0.0020	0.010	0.0030		Present Invention Steel
K	0.490	1.400	1.40	0.015	0.0020	0.010	0.0030	Ti: 0.03	Present Invention Steel
L	0.180	0.200	1.60	0.014	0.0020	0.020	0.0030		Present Invention Steel
M	0.150	0.800	1.40	0.014	0.0020	0.010	0.0030		Present Invention Steel

(continued)

Kind of steel	Chemical composition (mass%), remainder: Fe and impurities								Note
	C	Si	Mn	P	S	Al	N	Others	
N	0.150	2.900	1.40	0.014	0.0020	0.010	0.0030	Ti: 0.03	Present Invention Steel
O	0.150	0.900	0.60	0.014	0.0020	0.010	0.0030		Present Invention Steel
P	0.150	0.900	2.80	0.014	0.0020	0.010	0.0030		Present Invention Steel
Q	0.150	0.900	1.40	0.090	0.0020	0.010	0.0030		Present Invention Steel
R	0.150	0.900	1.40	0.014	0.0100	0.010	0.0030	Ti: 0.03	Present Invention Steel
s	0.150	0.900	1.40	0.014	0.0020	1.000	0.0030		Present Invention Steel
T	0.150	0.900	1.40	0.014	0.0020	0.010	0.0100		Present Invention Steel
U	<u>0.600</u>	0.900	1.40	0.014	0.0020	0.010	0.0030	Ti: 0.03	Comparative Steel
V	0.150	<u>0.050</u>	1.40	0.014	0.0020	0.010	0.0030		Comparative Steel
W	0.150	0.900	<u>0.30</u>	0.014	0.0020	0.010	0.0030		Comparative Steel
X	0.150	0.900	<u>3.10</u>	0.014	0.0020	0.010	0.0030		Comparative Steel

[0128] The underlined value indicates outside of the range of the present invention.

[Table 2A]

Test No.	Kind of steel	Heating temperature of slab °C	Finish rolling										Note
			(I) Finish rolling start temperature °C	(II) σ of fourth stand from last stand -	(II) σ of third stand from last stand -	(II) σ of second stand from last stand -	(II) σ of last stand -	(III) Inter-pass time between fourth stand from last stand and third stand from last stand s	(III) Inter-pass time between third stand from last stand and second stand from last stand s	(III) Inter-pass time between second stand from last stand and last stand s	(IV) Cumulative rolling reduction of last four stands %	(V) Finishing temperature °C	
1	A	1,241	1,094	50	52	56	58	8.0	3.0	0.7	94	919	Present Invention Example
2	A	1.263	1,077	51	59	56	58	6.0	4.0	0.9	90	862	Present Invention Example
3	A	1,208	965	52	52	50	58	5.0	5.0	0.9	93	833	Present Invention Example
4	A	1,206	962	53	52	44	62	7.0	6.0	1.0	96	907	Present Invention Example
5	A	1,251	966	49	42	41	42	9.0	4.0	0.8	<u>57</u>	824	Comparative Example
6	B	1,207	1,006	51	61	52	46	6.0	7.0	3.8	95	904	Present Invention Example
7	B	1,221	1,039	50	44	57	65	6.0	4.0	0.7	89	942	Present Invention Example
8	B	1,275	1,000	41	70	52	38	8.0	7.0	0.6	88	823	Comparative Example

(continued)

Test No.	Kind of steel	Heating temperature of slab °C	Finish rolling										Note
			(I) Finish rolling start temperature °C	(II) σ of fourth stand from last stand -	(II) σ of third stand from last stand -	(II) σ of second stand from last stand -	(II) σ of last stand -	(III) Inter-pass time between fourth stand from last stand and third stand from last stand s	(III) Inter-pass time between third stand from last stand and second stand from last stand s	(III) Inter-pass time between second stand from last stand and last stand s	(IV) Cumulative rolling reduction of last four stands %	(V) Finishing temperature °C	
9	C	1,300	1,003	51	55	59	68	9.0	3.0	0.3	92	842	Present Invention Example
10	C	1,249	1,006	43	69	42	55	8.0	6.0	0.3	92	905	Present Invention Example
11	C	1,246	1,060	69	42	54	47	5.0	5.0	1.0	92	888	Present Invention Example
12	D	1,233	1,066	40	63	54	50	9.0	3.0	0.9	97	920	Present Invention Example
13	D	1.220	1,038	66	67	53	61	6.0	5.0	0.3	94	917	Present Invention Example
14	D	1,263	966	56	64	42	67	<u>11.0</u>	7.0	5	96	929	Comparative Example
15	E	1.264	1,014	47	49	54	66	9.0	3.0	0.7	93	897	Present Invention Example
16	E	1,264	993	55	42	41	42	7.0	5.0	0.9	93	885	Present Invention Example

(continued)

Test No.	Kind of steel	Heating temperature of slab °C	Finish rolling										Note
			(I) Finish rolling start temperature °C	(II) σ of fourth stand from last stand -	(II) σ of third stand from last stand -	(II) σ of second stand from last stand -	(II) σ of last stand -	(III) Interpass time between fourth stand from last stand and third stand from last stand s	(III) Interpass time between third stand from last stand and second stand from last stand s	(III) Interpass time between second stand from last stand and last stand s	(IV) Cumulative rolling reduction of last four stands %	(V) Finishing temperature °C	
17	E	1,282	1,060	45	42	43	82	5.0	5.0	0.4	93	805	Comparative Example
18	F	1,262	1,044	40	49	42	63	9.0	6.0	0.5	94	920	Present Invention Example
19	F	1,215	1,048	47	70	58	52	7.0	7.0	0.2	92	855	Present Invention Example
20	F	1,296	953	54	58	59	62	5.0	4.0	1.2	89	780	Comparative Example
21	G	1,212	1,091	68	53	59	51	9.0	4.0	0.2	95	912	Present Invention Example
22	G	1,246	987	60	52	69	44	8.0	3.0	2.0	94	897	Present Invention Example
23	G	1,240	1,220	76	40	41	33	6.0	7.0	0.9	91	832	Comparative Example
24	H	1,286	1,075	64	49	67	51	6.0	4.0	0.8	98	960	Comparative Example
25	I	1,245	974	43	68	62	59	8.0	7.0	0.1	76	818	Comparative Example

[0129] The underlined value indicates undesirable manufacturing conditions.

[Table 2B]

Test No.	Kind of steel	Heating temperature of slab °C	Finish rolling										Note
			(1) Finish rolling start temperature °C	(II) α of fourth stand from last stand-	(II) σ of (II) third stand from last stand -	(II) σ of second standfrom last stand-	(II) σ of last stand-	(III) inter-pass time between fourth stand from last stand and third stand from last stand s	(III) Inter-pass time between third stand from last stand and second stand from last stand s	(III) Inter-pass time between second stand from last stand and last stand s	(IV) Cumulative rolling reduction of last four stands %	(V) Finishing temperature °C	
26	J	1,201	1,048	48	75	51	41	3.0	6.0	8.0	77	810	Present Invention Example
27	K	1,137	903	65	58	61	58	2.0	4.0	7.0	79	808	Present Invention Example
28	L	1,235	981	60	43	53	52	4.0	6.0	5.0	96	905	Present Invention Example
29	M	1,266	1,011	77	45	70	55	5.0	2.0	7.0	70	803	Present Invention Example
30	N	1,102	951	78	74	59	75	5.0	8.0	8.0	86	868	Present Invention Example
31	O	1,134	953	58	47	47	60	6.0	9.0	9.0	79	849	Present Invention Example
32	P	1,255	875	45	54	65	79	6.0	5.0	7.0	74	809	Present Invention Example
33	Q	1,157	1,040	56	47	78	51	5.0	7.0	6.0	92	826	Present Invention Example

(continued)

Test No.	Kind of steel	Heating temperature of slab °C	Finish rolling										Note
			(1) Finish rolling start temperature °C	(II) α of fourth stand from last stand-	(II) σ of (II) third stand from last stand -	(II) σ of second stand from last stand-	(II) σ of last stand-	(III) inter-pass time between fourth stand from last stand and third stand from last stand s	(III) Inter-pass time between third stand from last stand and second stand from last stand s	(III) Inter-pass time between second stand from last stand and last stand s	(IV) Cumulative rolling reduction of last four stands %	(V) Finishing temperature °C	
34	R	1,307	1,012	55	62	71	64	5.0	7.0	2.0	70	850	Present Invention Example
35	S	1,188	860	42	77	47	63	3.0	7.0	3.0	95	919	Present Invention Example
36	T	1,346	948	46	44	42	70	3.0	8.0	8.0	65	921	Present Invention Example
37	U	1,298	863	57	68	75	54	4.0	5.0	3.0	78	884	Comparative Example
38	V	1.122	972	63	67	72	62	5.0	2.0	3.0	68	826	Comparative Example
39	W	1.138	917	73	77	65	69	2.0	2.0	3.0	68	891	Comparative Example
40	X	1,283	1,002	65	75	73	52	2.0	3.0	6.0	67	937	Comparative Example
41	C	1,228	910	78	71	45	66	5.0	5.0	9.0	89	852	Present Invention Example
42	A	1.314	893	45	65	51	42	6.0	4.0	4.0	86	863	Present Invention Example

(continued)

Test No.	Kind of steel	Heating temperature of slab °C	Finish rolling										Note
			(1) Finish rolling start temperature °C	(II) α of fourth stand from last stand-	(II) σ of (II) third stand from last stand -	(II) σ of second stand from last stand-	(II) σ of last stand-	(III) inter-pass time between fourth stand from last stand and third stand from last stand s	(III) Inter-pass time between third stand from last stand and second stand from last stand s	(III) Inter-pass time between second stand from last stand and last stand s	(IV) Cumulative rolling reduction of last four stands %	(V) Finishing temperature °C	
43	C	1,231	899	56	65	46	75	5.0	9.0	3.0	87	934	Comparative Example
44	B	1,200	<u>1.120</u>	70	72	63	68	4.0	9.0	5.0	73	900	Comparative Example
45	B	1,145	<u>790</u>	71	51	47	61	3.0	3.0	3.0	77	809	Comparative Example
46	C	1.118	<u>1,150</u>	57	63	60	42	5.0	5.0	7.0	81	837	Comparative Example
47	J	1,299	895	32	58	67	61	5.0	5.0	3.0	82	882	Comparative Example
48	O	1,335	1,045	82	41	66	64	3.0	5.0	2.0	81	824	Comparative Example
49	B	1.144	869	58	35	68	71	4.0	8.0	8.0	71	922	Comparative Example
50	A	1,140	863	46	86	64	75	2.0	8.0	7.0	70	909	Comparative Example
51	C	1,236	924	69	45	32	64	6.0	8.0	6.0	82	813	Comparative Example
52	A	1,312	918	69	69	86	64	6.0	9.0	7.0	81	854	Comparative Example
53	F	1,255	873	79	72	64	68	2.0	11.0	9.0	93	885	Comparative Example

(continued)

Test No.	Kind of steel	Heating temperature of slab °C	Finish rolling										Note
			(1) Finish rolling start temperature °C	(II) α of fourth stand from last stand-	(II) σ of (II) third stand from last stand -	(II) σ of second standfrom last stand-	(II) σ of last stand-	(III) inter-pass time between fourth stand from last stand and third stand from last stand s	(III) Inter-pass time between third stand from last stand and second stand from last stand s	(III) Inter-pass time between second stand from last stand and last stand s	(IV) Cumulative rolling reduction of last four stands %	(V) Finishing temperature °C	
54	D	1,240	1,014	42	60	78	52	2.0	3.0	11.0	87	926	Comparative Example
55	E	1,305	970	56	71	56	71	6.0	6.0	8.0	67	886	Comparative Example
56	B	1,114	978	46	42	60	78	4.0	2.0	7.0	63	888	Comparative Example
57	A	1,119	970	70	45	64	51	3.0	2.0	5.0	86	936	Comparative Example

[0130] The underlined value indicates undesirable manufacturing conditions.

[Table 3A]

Test No.	Kind of steel	Time until cooling is started s	Average cooling rate in temperature range of finishing temperature to 300°C °C/s	Coiling temperature °C	Sheet thickness mm	Note
1	A	0.5	180	244	3.0	Present Invention Example
2	A	0.6	114	219	4.0	Present Invention Example
3	A	0.7	118	233	5.0	Present Invention Example
4	A	0.5	102	235	5.0	Present Invention Example
5	A	0.6	169	253	7.0	Comparative Example
6	B	0.6	168	228	6.0	Present Invention Example
7	B	0.7	115	214	6.0	Present Invention Example
8	B	0.1	182	207	3.0	Comparative Example
9	C	0.6	174	220	6.0	Present Invention Example
10	C	0.3	152	224	2.0	Present Invention Example
11	C	0.9	170	247	4.0	Present Invention Example
12	D	0.2	116	300	2.0	Present Invention Example
13	D	0.3	125	280	5.0	Present Invention Example
14	D	0.4	104	204	3.0	Comparative Example
15	E	0.2	139	212	5.0	Present Invention Example

(continued)

Test No.	Kind of steel	Time until cooling is started s	Average cooling rate in temperature range of finishing temperature to 300°C °C/s	Coiling temperature °C	Sheet thickness mm	Note
16	E	0.2	142	223	4.0	Present Invention Example
17	E	0.3	137	217	4.0	Comparative Example
18	F	0.8	190	256	6.0	Present Invention Example
19	F	1.0	118	278	6.0	Present Invention Example
20	F	0.7	134	259	5.0	Comparative Example
21	G	0.4	176	219	7.0	Present Invention Example
22	G	0.6	151	247	7.0	Present Invention Example
23	G	0.6	145	300	4.0	Comparative Example
24	<u>H</u>	0.3	<u>80</u>	<u>400</u>	6.0	Comparative Example
25	<u>I</u>	<u>2.0</u>	111	229	6.0	Comparative Example

[0131] The underlined value indicates undesirable manufacturing conditions.

[Table 3B]

Test No.	Kind of steel	Time until cooling is started s	Average cooling rate in temperature range of finishing temperature to 300°C °C/s	Coiling temperature °C	Sheet thickness mm	Note
26	J	0.6	249	258	3.0	Present Invention Example
27	K	0.2	145	298	4.0	Present Invention Example
28	L	0.6	173	264	5.0	Present Invention Example
29	M	1.0	159	293	5.0	Present Invention Example

(continued)

Test No.	Kind of steel	Time until cooling is started s	Average cooling rate in temperature range of finishing temperature to 300°C °C/s	Coiling temperature °C	Sheet thickness mm	Note
30	N	0.2	138	298	7.0	Present Invention Example
31	O	0.2	208	297	6.0	Present Invention Example
32	P	0.8	146	245	6.0	Present Invention Example
33	Q	0.1	142	215	3.0	Present Invention Example
34	R	0.7	234	279	3.0	Present Invention Example
35	S	0.5	164	261	3.0	Present Invention Example
36	T	0.7	187	202	4.0	Present Invention Example
37	U	0.6	216	205	5.0	Comparative Example
38	V	0.2	160	225	5.0	Comparative Example
39	W	0.7	126	237	7.0	Comparative Example
40	X	0.8	230	243	6.0	Comparative Example
41	C	0.6	260	228	6.0	Present Invention Example
42	A	0.1	151	233	3.0	Present Invention Example
43	B	0.2	217	273	6.0	Comparative Example
44	B	0.4	106	283	2.0	Comparative Example
45	B	0.7	213	214	4.0	Comparative Example
46	C	0.9	218	244	2.0	Comparative Example

(continued)

Test No.	Kind of steel	Time until cooling is started s	Average cooling rate in temperature range of finishing temperature to 300°C °C/s	Coiling temperature °C	Sheet thickness mm	Note
47	J	1.0	127	239	5.0	Comparative Example
48	O	0.6	226	258	3.0	Comparative Example
49	B	0.3	194	247	5.0	Comparative Example
50	A	0.4	151	295	4.0	Comparative Example
51	C	0.9	137	264	4.0	Comparative Example
52	A	0.4	109	219	6.0	Comparative Example
53	F	0.6	219	206	6.0	Comparative Example
54	D	0.8	148	236	5.0	Comparative Example
55	E	1.2	197	230	7.0	Comparative Example
56	B	0.2	88	220	7.0	Comparative Example
57	A	0.0	201	350	4.0	Comparative Example

[0132] The underlined value indicates undesirable manufacturing conditions.

[Table 4A]

Test No.	Kind of steel	Microstructure			Surface layer region	Internal region	Tensile strength MPa	Ductile-brittle transition temperature °C	Difference between absorbed energy of L-direction notch and absorbed energy of C-direction notch (L-direction - C-direction) J	Note
		Martensite area%	Remainder in microstructure area%	Average grain size of prior austenite grains μm	Pole densities of {001}<110>, {111}<110>, and {112}<110> orientation groups-	Pole density of {110} <112> orientation-				
1	A	92	8	19.0	3.2	3.1	1,262	-70	-8	Present Invention Example
2	A	93	7	10.0	3.4	3.4	1.205	-80	11	Present Invention Example
3	A	95	5	12.0	2.8	3.9	1,319	-56	-13	Present Invention Example
4	A	97	3	15.0	3.7	4.2	1,397	-62	10	Present Invention Example
5	A	92	8	7.0	6.6	6.0	1,351	-68	21	Comparative Example
6	B	91	9	16.0	2.3	4.6	1,364	-63	6	Present Invention Example
7	B	93	7	7.0	2.7	4.7	1,286	-77	2	Present Invention Example
8	B	99	1	8.0	1.7	43	1,227	-73	-16	Comparative Example
9	C	91	9	7.0	3.2	3.8	1,237	-69	1	Present Invention Example

(continued)

Test No.	Kind of steel	Microstructure			Surface layer region	Internal region	Tensile strength MPa	Ductile-brittle transition temperature °C	Difference between absorbed energy of L-direction notch and absorbed energy of C-direction notch (L-direction - C-direction) J	Note
		Martensite area%	Remainder in microstructure area%	Average grain size of prior austenite grains μm	Pole densities of {001}<110>, {111}<110>, and {112}<110> orientation groups-	Pole density of {110} <112> orientation-				
10	C	95	5	8.0	3.4	3.1	1.287	-74	-12	Present Invention Example
11	c	97	3	21.0	3.5	2.9	1,231	-70	-2	Present Invention Example
12	D	97	3	21.0	3.2	4.6	1,256	-61	4	Present Invention Example
13	D	98	2	10.0	2.7	4.7	1,282	-81	-8	Present Invention Example
14	D	92	8	7.0	1.6	43	1,239	-54	-17	Comparative Example
15	E	100	0	8.0	4.0	3.8	1.279	-71	6	Present Invention Example
16	E	98	2	21.0	3.2	3.1	1,227	-51	4	Present Invention Example
17	E	97	3	21.0	5.8	6.4	1.346	-79	22	Comparative Example
18	F	93	7	10.0	3.2	4.6	1,393	-63	-6	Present Invention Example

(continued)

Test No.	Kind of steel	Microstructure			Surface layer region	Internal region	Tensile strength MPa	Ductile-brittle transition temperature °C	Difference between absorbed energy of L-direction notch and absorbed energy of C-direction notch (L-direction - C-direction) J	Note
		Martensite area%	Remainder in microstructure area%	Average grain size of prior austenite grains μm	Pole densities of {001}<110>, {111}<110>, and {112}<110> orientation groups-	Pole density of {110} <112> orientation-				
19	F	99	1	21.0	3.2	4.7	1,252	-58	-8	Present Invention Example
20	F	91	9	21.0	7.0	6.2	1,358	-52	18	Comparative Example
21	G	95	5	10.0	3.2	4.6	1,396	-77	4	Present Invention Example
22	G	97	3	10.0	3.4	4.7	1,393	-76	-11	Present Invention Example
23	c	97	3	38.0	1.8	4.3	1,349	42	-22	Comparative Example
24	H	81	19	10.0	3.1	3.8	1,150	-80	-19	Comparative Example
25	I	93	7	10.0	4.1	1.9	1020	-55	18	Comparative Example

[0133] The underlined value indicates outside of the range of the present invention, or undesirable properties.

[Table 4B]

Test No.	Kind of steel	Microstructure			Surface layer region	internal region	Tensile strength MPa	Ductile-brittle transition temperature °C	Difference between absorbed energy of L-direction notch and absorbed energy of C-direction notch (L-direction - C-direction) J	Note
		Martensite area%	Remainder in microstructure area%	Average grain size of prior austenite grains μm	Pole densities of {001}<110>, {1111}<110>, and {112}<110> orientation groups	Pole density of {110} <112> orientation				
26	J	92	8	19.0	3.2	4.7	1,262	-70	1	Present Invention Example
27	K	93	7	10.0	3.4	4.3	1.205	-80	-12	Present Invention Example
28	L	95	5	12.0	2.8	3.8	1,319	-56	-2	Present Invention Example
29	M	97	3	15.0	3.7	3.1	1,397	-62	4	Present Invention Example
30	N	92	8	7.0	6.6	2.9	1,351	-68	-8	Present Invention Example
31	O	91	9	16.0	2.3	4.7	1.364	-63	9	Present Invention Example
32	P	93	7	7.0	2.7	4.3	1,286	-77	2	Present Invention Example
33	Q	99	1	8.0	3.2	3.8	1,227	-73	10	Present Invention Example

(continued)

Test No.	Kind of steel	Microstructure			Surface layer region	internal region	Tensile strength MPa	Ductile-brittle transition temperature °C	Difference between absorbed energy of L-direction notch and absorbed energy of C-direction notch (L-direction - C-direction) J	Note
		Martensite area%	Remainder in microstructure area%	Average grain size of prior austenite grains μm	Pole densities of {001}<110>, {1111}<110>, and {112}<110> orientation groups	Pole density of {110} <112> orientation				
34	R	91	9	7.0	3.4	3.1	1,262	-70	8	Present Invention Example
35	S	95	5	8.0	2.8	2.9	1,205	-80	-2	Present Invention Example
36	T	97	3	21.0	3.7	4.6	1,262	-70	6	Present Invention Example
37	U	92	8	21.0	7.8	4.7	1,262	-70	29	Comparative Example
38	V	93	7	10.0	2.3	4.3	1.262	-70	-16	Comparative Example
39	W	95	5	7.0	2.7	3.8	1.170	-80	18	Comparative Example
40	X	97	3	8.0	3.2	1.9	1,319	-56	21	Comparative Example
41	C	92	8	21.0	3.4	2.0	1.397	-62	-4	Present Invention Example
42	A	91	9	21.0	5.2	4.7	1,180	-68	2	Present Invention Example
43	B	88	12	8.0	3.7	4.3	1,150	-63	18	Comparative Example

(continued)

Test No.	Kind of steel	Microstructure			Surface layer region	internal region	Tensile strength MPa	Ductile-brittle transition temperature °C	Difference between absorbed energy of L-direction notch and absorbed energy of C-direction notch (L-direction - C-direction) J	Note
		Martensite area%	Remainder in microstructure area%	Average grain size of prior austenite grains μm	Pole densities of {001}<110>, {1111}<110>, and {112}<110> orientation groups	Pole density of {110} <112> orientation				
44	B	99	1	21.0	7.3	3.8	1,286	-77	16	Comparative Example
45	B	91	9	21.0	2.3	1.9	1.090	-73	16	Comparative Example
46	C	95	5	10.0	2.7	1.8	1,237	-69	18	Comparative Example
47	J	97	3	7.0	3.2	1.9	1.287	-74	16	Comparative Example
48	O	97	3	8.0	8.0	4.6	1,231	-70	23	Comparative Example
49	B	98	2	21.0	2.8	5.2	1,256	-61	-19	Comparative Example
50	A	92	8	21.0	7.6	4.3	1,282	-81	22	Comparative Example
51	C	100	0	10.0	6.6	5.2	1,239	-54	-19	Comparative Example
52	A	98	2	21.0	7.3	3.1	1,279	-71	12	Comparative Example
53	F	97	3	21.0	3.2	5.9	1,227	-51	-18	Comparative Example
54	D	93	7	10.0	7.3	4.6	1,346	-79	17	Comparative Example
55	E	99	1	21.0	7.9	4.7	1,393	-63	-19	Comparative Example

(continued)

Test No.	Kind of steel	Microstructure			Surface layer region	internal region	Tensile strength MPa	Ductile-brittle transition temperature °C	Difference between absorbed energy of L-direction notch and absorbed energy of C-direction notch (L-direction - C-direction) J	Note
		Martensite area%	Remainder in microstructure area%	Average grain size of prior austenite grains µm	Pole densities of {001}<110>, {1111}<110>, and {112}<110> orientation groups	Pole density of {110} <112> orientation				
56	B	69	31	21.0	3.7	1.8	0.881	-58	18	Comparative Example
57	A	67	33	21.0	6.6	2.9	1.100	-52	-16	Comparative Example

[0134] The underlined value indicates outside of the range of the present invention, or undesirable properties.

[0135] From Tables 4A and 4B, it can be seen that the hot-rolled steel sheets according to the present invention examples had high strength, excellent toughness, and reduced anisotropy in toughness. On the other hand, it can be seen that in the hot-rolled steel sheets according to the comparative examples, any of the properties deteriorated.

Claims

1. A hot-rolled steel sheet comprising, as a chemical composition, by mass%:

C: 0.100% to 0.500%;
Si: 0.100% to 3.000%;
Mn: 0.50% to 3.00%;
P: 0.100% or less;
S: 0.0100% or less;
Al: 1.000% or less;
N: 0.0100% or less;
Ti: 0% to 0.20%;
Nb: 0% to 0.100%;
Ca: 0% to 0.0060%;
Mo: 0% to 0.50%;
Cr: 0% to 1.00%;
V: 0% to 0.50%;
Cu: 0% to 0.50%;
Ni: 0% to 0.50%;
Sn: 0% to 0.050%; and
a remainder comprising Fe and impurities,
wherein a microstructure in a region from a depth of 1/8 of a sheet thickness from a surface to a depth of 3/8 of the sheet thickness from the surface includes, by area%,

90% to 100% of martensite, and
0% to 10% of a remainder in microstructure,

in a texture of a region from the surface to the depth of 1/8 of the sheet thickness from the surface,
pole densities of {001}<110>, { 111 }<110>, and {112}<110> orientation groups are 2.0 or more,
in a texture of a region from the depth of 1/8 of the sheet thickness from the surface to a depth of 1/2 of the sheet thickness from the surface,
a pole density of a { 110}<112> orientation is 5.0 or less, and a tensile strength of the hot-rolled steel sheet is 1,180 MPa or more.

2. The hot-rolled steel sheet according to claim 1, wherein the chemical composition comprises, by mass%, one or two or more selected from the group consisting of

Ti: 0.02% to 0.20%,
Nb: 0.010% to 0.100%,
Ca: 0.0001% to 0.0060%,
Mo: 0.01 % to 0.50%,
Cr: 0.01% to 1.00%,
V: 0.01 % to 0.50%,
Cu: 0.01% to 0.50%,
Ni: 0.01 % to 0.50%, and
Sn: 0.001% to 0.050%.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/038035

A. CLASSIFICATION OF SUBJECT MATTER

B21B 3/00(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/58***(2006.01)i
FI: C22C38/00 301W; C22C38/58; C21D9/46 S; B21B3/00 A

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)

B21B3/00; C21D9/46; C22C38/00; C22C38/58

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 2021/167079 A1 (NIPPON STEEL CORPORATION) 26 August 2021 (2021-08-26)	1-2
A	WO 2020/110855 A1 (NIPPON STEEL CORPORATION) 04 June 2020 (2020-06-04)	1-2
A	WO 2006/011503 A1 (NIPPON STEEL CORPORATION) 02 February 2006 (2006-02-02)	1-2

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

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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
21 December 2022	**10 January 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/038035

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REFERENCES CITED IN THE DESCRIPTION

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- JP 5621942 B **[0006]**