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(54) HOT-ROLLED STEEL SHEET

(57) In this hot-rolled steel sheet, a microstructure at a 1/4 position from a surface includes, by area%, ferrite: 2.0% to 30.0%, bainite: 60.0% to 93.0%, and martensite: 5.0% to 20.0%, an area ratio of martensite, which is in contact with a 30° grain boundary, when a maximum value of a GAIQ value of the ferrite is indicated as $I\alpha$, which has a relative GAIQ value of $I\alpha/3$ or less, and which has a grain size of 2.0 μm or more, is 5.0% or more, and a tensile strength is 980 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. 2021-191745, filed November 26, 2021, the content of which is incorporated herein by reference.

[Background Art]

[0003] In recent years, from the viewpoint of protecting the global environment, efforts have been made to reduce the amount of carbon dioxide gas emitted in many fields. Vehicle manufacturers are also actively developing techniques for reducing the weight of vehicle bodies for the purpose of reducing fuel consumption. However, it is not easy to reduce the weight of vehicle bodies since the emphasis is placed on improvement in collision resistance to secure safety of occupants.
[0004] In order to achieve both the reduction in the weight of vehicle bodies and collision resistance, thinning a member using a high strength steel sheet has been examined. Therefore, a steel sheet having both high strength and excellent workability is strongly desired. Several techniques have been hitherto proposed to meet these demands.
[0005] For example, Patent Document 1 discloses a low yield ratio type high-burring high-strength hot-rolled steel sheet in which the amount of insoluble Ti measured by an extraction residue method in a steel sheet is 30% or more and 70% or less of a total Ti content.

[Prior Art Document]

[Patent Document]

[0006] [Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2009-263774

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0007] Vehicle members are formed by press forming, and blank sheets for the press forming are often manufactured by punching. In particular, for a high strength steel sheet of 980 MPa or more, it is desired to control an end surface after punching with high accuracy, that is, to have excellent punching property.
[0008] As a result of an investigation by the present inventors, it was found that in Patent Document 1, it is necessary to further increase the strength, and there is room for improvement in yield ratio and punching property in a case where the strength is increased.
[0009] The present invention has been made in view of the above circumstances. An object of the present invention is to provide a hot-rolled steel sheet having high strength and yield ratio and excellent punching property.

[Means for Solving the Problem]

[0010] The gist of the present invention is as follows.

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

C: 0.045% to 0.150%;
Si: 0.10% to 2.50%;
Mn: 1.50% to 3.50%;
sol. Al: 0.010% to 1.000%;
Ti: 0.050% to 0.200%;
P: 0.100% or less;
S: 0.0300% or less;
N: 0.1000% or less;
O: 0.0100% or less;
Nb: 0% to 0.050%;

V: 0% to 0.050%;
B: 0% to 0.0100%;
Cu: 0% to 2.00%;
Cr: 0% to 2.00%;
Mo: 0% to 1.000%;
Ni: 0% to 2.00%;
Ca: 0% to 0.0200%;
Mg: 0% to 0.0200%;
REM: 0% to 0.1000%;
Bi: 0% to 0.0200%;
one or two or more of Zr, Co, Zn, and W: 0% to 1.0000% in total;
Sn: 0% to 0.050%; and
a remainder comprising Fe and impurities,
in which a microstructure at a 1/4 position from a surface includes,
by area%,

ferrite: 2.0% to 30.0%,
bainite: 60.0% to 93.0%, and
martensite: 5.0% to 20.0%,

an area ratio of martensite,

which is in contact with a 30° grain boundary,
which has a relative GAIQ value of $I\alpha/3$ or less, where $I\alpha$ is a maximum value of a GAIQ value of the ferrite, and
which has a grain size of 2.0 μm or more, is 5.0% or more, and a tensile strength of the hot-rolled steel sheet is 980 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 of the group consisting of

Nb: 0.001% to 0.050%,
V: 0.001% to 0.050%,
B: 0.0001% to 0.0100%,
Cu: 0.01% to 2.00%,
Cr: 0.01% to 2.00%,
Mo: 0.001% to 1.000%,
Ni: 0.01% to 2.00%,
Ca: 0.0005% to 0.0200%,
Mg: 0.0005% to 0.0200%,
REM: 0.0005% to 0.1000%, and
Bi: 0.0005% to 0.0200%.

[Effects of the Invention]

[0011] According to the aspect of the present invention, it is possible to provide a hot-rolled steel sheet having high strength and yield ratio, and excellent punching property.

[Embodiments of the Invention]

[0012] Hereinafter, a chemical composition and a microstructure of a hot-rolled steel sheet according to the present embodiment will be more specifically described. However, the present invention is not limited to configurations disclosed in the present embodiment, and various modifications can be made without departing from the gist of the present invention.
[0013] The numerical limit range described below with "to" includes the lower limit and the upper limit. Numerical values indicated as "less than" or "more than" do not fall within the numerical range. In the following description, % regarding the chemical composition of the hot-rolled steel sheet is mass% unless otherwise specified.

Chemical Composition

[0014] The hot-rolled steel sheet according to the present embodiment includes, by mass%, C: 0.045% to 0.150%, Si: 0.10% to 2.50%, Mn: 1.50% to 3.50%, sol. Al: 0.010% to 1.000%, Ti: 0.050% to 0.200%, P: 0.100% or less, S: 0.0300% or less, N: 0.1000% or less, O: 0.0100% or less, and a remainder: Fe and impurities. Each element will be described in detail below.

C: 0.045% to 0.150%

[0015] C is an element necessary to obtain a desired strength. When a C content is less than 0.045%, a desired strength cannot be obtained. Therefore, the C content is set to 0.045% or more. The C content is preferably 0.050% or more, 0.055% or more, or 0.060% or more.
[0016] On the other hand, when the C content is more than 0.150%, weldability of the hot-rolled steel sheet decreases. Therefore, the C content is set to 0.150% or less. The C content is preferably 0.120% or less, 0.100% or less, or 0.080% or less.

Si: 0.10% to 2.50%

[0017] Si has an action of improving ductility of the hot-rolled steel sheet by promoting the generation of ferrite and has an action of increasing the strength of the hot-rolled steel sheet by solid solution strengthening of ferrite. In addition, Si has an action of achieving soundness of steel by deoxidation (suppressing the occurrence of a defect such as a blowhole in steel). When a Si content is less than 0.10%, an effect by the above action cannot be obtained. Therefore, the Si content is set to 0.10% or more. The Si content is preferably 0.50% or more or 0.70% or more.
[0018] On the other hand, when the Si content is more than 2.50 %, the weldability of the hot-rolled steel sheet decreases. Therefore, the Si content is set to 2.50% or less. The Si content is preferably 2.00% or less, 1.80% or less, or 1.50% or less.

Mn: 1.50% to 3.50%

[0019] Mn is an element that improves hardenability and increases the strength of the hot-rolled steel sheet. When the Mn content is less than 1.50%, a desired strength cannot be obtained. Therefore, the Mn content is set to 1.50% or more. The Mn content is preferably 1.80% or more, 2.00% or more, or 2.30% or more.
[0020] On the other hand, when the Mn content is more than 3.50%, the hardenability becomes excessive and a yield ratio of the hot-rolled steel sheet decreases. Therefore, the Mn content is set to 3.50% or less. The Mn content is preferably 3.30% or less, 3.00% or less, or 2.80% or less.

sol. Al: 0.010% to 1.000%

[0021] Al has an action of achieving soundness of steel by deoxidation and also has an action of controlling ferritic transformation. When a sol. Al content is less than 0.010%, an effect by the above action cannot be obtained. Therefore, the sol. Al content is set to 0.010% or more. The sol. Al content is preferably 0.030% or more, 0.050% or more, 0.080% or more, or 0.100% or more.
[0022] On the other hand, when the sol. Al content is more than 1.000%, alumina precipitated in the form of a cluster is generated and the yield ratio of the hot-rolled steel sheet decreases. Therefore, the sol. Al content is set to 1.000% or less. The sol. Al content is preferably 0.800% or less, 0.600% or less, 0.400% or less, or 0.200% or less.
[0023] In addition, sol. Al means acid-soluble Al, and indicates solute Al present in the steel in a solid solution state.

Ti: 0.050% to 0.200%

[0024] Ti is precipitated in steel as a carbide or a nitride and has an action of refining the microstructure by an austenite pinning effect and increasing the strength and yield ratio of the hot-rolled steel sheet by precipitation hardening. When a Ti content is less than 0.050%, an effect by the above action cannot be obtained. Therefore, the Ti content is set to 0.050% or more. The Ti content is preferably 0.080% or more, 0.100% or more, or 0.130% or more.
[0025] On the other hand, when the Ti content is more than 0.200%, punching property of the hot-rolled steel sheet deteriorates due to excessive precipitation of TiC. Therefore, the Ti content is set to 0.200% or less. The Ti content is preferably 0.180% or less or 0.150% or less.

P: 0.100% or Less

[0026] P is an element that is generally contained in steel as an impurity, and the lower a P content is, the more preferable it is. In particular, when the P content is more than 0.100%, deterioration of workability and weldability of the hot-rolled steel sheet becomes significant, and the punching property also deteriorates. Therefore, the P content is set to 0.100% or less. The P content is preferably 0.080% or less, 0.060% or less, or 0.040% or less.
[0027] The P content is preferably 0%, but may be set to 0.001% or more from the viewpoint of a refining cost.

S: 0.0300% or Less

[0028] S is an element that is generally contained in steel as an impurity, and the lower a S content is, the more preferable it is. When the S content is more than 0.0300%, the yield ratio of the hot-rolled steel sheet significantly decreases. Therefore, the S content is set to 0.0300% or less. The S content is preferably 0.0200% or less or 0.0100% or less.
[0029] The S content is preferably 0%, but may be set to 0.0001% or more from the viewpoint of a refining cost.

N: 0.1000% or Less

[0030] N is an element that is generally contained in steel as an impurity, and the lower a N content is, the more preferable it is. When the N content is more than 0.1000%, the yield ratio of the hot-rolled steel sheet significantly decreases. Therefore, the N content is set to 0.1000% or less. The N content is preferably 0.0800% or less, 0.0600% or less, or 0.0400% or less.
[0031] The N content is preferably 0%, but may be set to 0.0010% or more from the viewpoint of a refining cost.

O: 0.0100% or Less

[0032] O is an element that, when contained in steel in a large amount, forms a coarse oxide that becomes an origin of fracture, causing brittle fractures and hydrogen-induced cracks. When an O content is more than 0.0100%, brittle fractures and hydrogen-induced cracks are likely to be initiated. Therefore, the O content is set to 0.0100% or less. The O content is preferably 0.0080% or less, 0.0060% or less, or 0.0040% or less.
[0033] The O content may be set to 0.0005% or more or 0.0010% or more to disperse a large number of fine oxides when molten steel is deoxidized.
[0034] The remainder of the chemical composition of the hot-rolled steel sheet according to the present embodiment may be Fe and impurities. In the present embodiment, the impurities mean substances that are incorporated from ore as a raw material, scrap, a manufacturing environment, or the like and/or substances that are permitted to an extent that the hot-rolled steel sheet according to the present embodiment is not adversely affected.
[0035] The hot-rolled steel sheet according to the present embodiment may contain the following elements as optional elements instead of a portion of Fe. In a case where such optional elements are not contained, a lower limit of amounts thereof is 0%. Hereinafter, the optional elements will be described in detail.

Nb: 0.001% to 0.050%

[0036] Nb is an element that is finely precipitated in steel as a carbide and a nitride and improves the strength of steel by precipitation hardening. In order to reliably obtain this effect, a Nb content is preferably set to 0.001% or more.
[0037] However, when the Nb content is more than 0.050%, the yield ratio of the hot-rolled steel sheet deteriorates. Therefore, the Nb content is set to 0.050% or less.

V: 0.001% to 0.050%

[0038] V is, similar to Nb, an element that is finely precipitated in steel as a carbide and a nitride and improves the strength of steel by precipitation hardening. In order to reliably obtain the effect, a V content is preferably set to 0.001% or more.
[0039] However, when the V content is more than 0.050%, the yield ratio of the hot-rolled steel sheet deteriorates. Therefore, the V content is set to 0.050% or less.

B: 0.0001% to 0.0100%

[0040] B has an action of enhancing the hardenability of the hot-rolled steel sheet. In order to reliably obtain this effect,

a B content is preferably set to 0.0001% or more.
[0041] However, when the B content is more than 0.0100%, the yield ratio of the hot-rolled steel sheet significantly decreases. Therefore, the B content is set to 0.0100% or less.

Cu: 0.01% to 2.00%

[0042] Cu has an action of enhancing the hardenability of the hot-rolled steel sheet and an action of increasing the strength of the hot-rolled steel sheet by being precipitated as a carbide in steel at a low temperature. In order to reliably obtain these effects, a Cu content is preferably set to 0.01% or more.
[0043] However, when the Cu content is more than 2.00%, there are cases where grain boundary cracking occurs in a slab. Therefore, the Cu content is set to 2.00% or less.

Cr: 0.01% to 2.00%

[0044] Cr has an action of enhancing the hardenability of the hot-rolled steel sheet. In order to reliably obtain this effect, a Cr content is preferably set to 0.01 % or more.
[0045] However, when the Cr content is more than 2.00%, chemical convertibility of the hot-rolled steel sheet significantly decreases. Therefore, the Cr content is set to 2.00% or less.

Mo: 0.001% to 1.000%

[0046] Mo has an action of enhancing the hardenability of the hot-rolled steel sheet and an action of increasing the strength of the hot-rolled steel sheet by being precipitated as a carbide in steel. In order to reliably obtain these effects, a Mo content is preferably set to 0.001% or more.
[0047] However, even when the Mo content is set to more than 1.000%, the effect by the actions is saturated, which is not economically preferable. Therefore, the Mo content is set to 1.000% or less.

Ni: 0.01% to 2.00%

[0048] Ni has an action of enhancing the hardenability of the hot-rolled steel sheet. In order to reliably obtain this effect, a Ni content is preferably set to 0.01% or more.
[0049] However, since Ni is an expensive element, it is not economically preferable to contain a large amount of Ni. Therefore, the Ni content is set to 2.00% or less.

Ca: 0.0005% to 0.0200%

[0050] Ca has an action of enhancing the yield ratio of the hot-rolled steel sheet by adjusting a shape of an inclusion in steel to a preferable shape. In order to reliably obtain this effect, a Ca content is preferably set to 0.0005% or more.
[0051] However, when the Ca content is more than 0.0200%, an excessive amount of the inclusion is generated in steel, and the yield ratio of the hot-rolled steel sheet decreases. Therefore, the Ca content is set to 0.0200% or less.

Mg: 0.0005% to 0.0200%

[0052] Mg has an action of enhancing the yield ratio of the hot-rolled steel sheet by adjusting a shape of an inclusion in steel to a preferable shape. In order to reliably obtain this effect, a Mg content is preferably set to 0.0005% or more.
[0053] However, when the Mg content is more than 0.0200%, an excessive amount of the inclusion is generated in steel, and the yield ratio of the hot-rolled steel sheet decreases. Therefore, the Mg content is set to 0.0200% or less.

REM: 0.0005% to 0.1000%

[0054] REM has an action of enhancing the yield ratio of the hot-rolled steel sheet by adjusting a shape of an inclusion in steel to a preferable shape. In order to reliably obtain this effect, a REM content is preferably set to 0.0005% or more.
[0055] However, when the REM content is more than 0.1000%, an excessive amount of the inclusion is generated in steel, and the yield ratio of the hot-rolled steel sheet decreases. Therefore, the REM content is set to 0.1000% or less.
[0056] Here, REM refers to a total of 17 elements consisting of Sc, Y, and lanthanoids, and the REM content refers to the total amount of these elements. Lanthanoids are added in the form of mischmetal in industry.

Bi: 0.0005% to 0.0200%

[0057] In addition, Bi has an action of enhancing the yield ratio of the hot-rolled steel sheet by refining a solidification structure. In order to more reliably obtain an effect by this action, a Bi content is preferably 0.0005% or more.
[0058] However, when the Bi content is more than 0.0200%, the effect by the action is saturated, which is not economically preferable. Therefore, the Bi content is set to 0.0200% or less.

One or Two or More of Zr, Co, Zn, and W: 0% to 1.0000% in Total

Sn: 0% to 0.050%

[0059] Regarding Zr, Co, Zn, and W, the present inventors have confirmed that, even when these elements are contained in a total amount of 1.0000% or less, the effects of the hot-rolled steel sheet according to the present embodiment are not impaired. Therefore, one or two or more of Zr, Co, Zn, and W may be contained in a total amount of 1.0000% or less.
[0060] In addition, the present inventors have confirmed that, even when a small amount of Sn is contained, the effects of the hot-rolled steel sheet according to the present embodiment are not impaired. However, when a large amount of Sn is contained, there are cases where a defect occurs during hot rolling. Therefore, a Sn content is set to 0.050% or less.
[0061] The chemical composition of the above-described hot-rolled steel sheet may be measured by a general analytical method. For example, the chemical composition may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). In addition, sol. Al may be measured by ICP-AES using a filtrate that is obtained after a sample is heated and decomposed with an acid. C and S may be measured using a combustion-infrared absorption method, N may be measured using an inert gas fusion-thermal conductivity method, and O may be measured using an inert gas fusion-non-dispersive infrared absorption method.
[0062] In a case where the hot-rolled steel sheet is a surface-treated steel sheet having a plating layer, the chemical composition is analyzed after front and back surfaces of the steel sheet including the plating layer on a surface are mechanically ground by 150 μm or more.

Microstructure of Hot-Rolled Steel Sheet

[0063] Next, the microstructure of the hot-rolled steel sheet according to the present embodiment will be described.
[0064] In the hot-rolled steel sheet according to the present embodiment, the microstructure at a 1/4 position from the surface includes,

by area%,

ferrite: 2.0% to 30.0%,
bainite: 60.0% to 93.0%, and
martensite: 5.0% to 20.0%, and

an area ratio of martensite,

which is in contact with a 30° grain boundary,
which has a relative GAIQ value of $I\alpha/3$ or less, where $I\alpha$ is a maximum value of a GAIQ value of the ferrite, and
which has a grain size of 2.0 μm or more, is 5.0% or more.

[0065] In the present embodiment, the 1/4 position from the surface indicates a region from a 1/8 thickness depth from the surface to a 3/8 thickness depth from the surface of the hot-rolled steel sheet. The reason for specifying the microstructure at this position is that the microstructure at this position indicates a typical microstructure of the hot-rolled steel sheet.

Hereinafter, each specification will be described.

Area Ratio of Ferrite: 2.0% to 30.0%

[0066] Ferrite is a structure generated when fcc transforms into bcc at a relatively high temperature. When an area ratio of ferrite is less than 2.0%, a desired yield ratio cannot be obtained. Therefore, the area ratio of ferrite is set to 2.0% or more. The area ratio of ferrite is preferably 5.0% or more, 8.0% or more, or 10.0% or more.

[0067] On the other hand, when the area ratio of ferrite is more than 30.0%, a desired strength cannot be obtained. Therefore, the area ratio of ferrite is set to 30.0% or less. The area ratio of ferrite is preferably 27.0% or less, 25.0% or less, or 20.0% or less.

Bainite: 60.0% to 93.0%

[0068] Bainite is a structure including fine grains and a carbide. When an area ratio of bainite is less than 60.0%, a desired strength and yield ratio cannot be obtained. Therefore, the area ratio of bainite is set to 60.0% or more. The area ratio of bainite is preferably 65.0% or more, 70.0% or more, 75.0% or more, or 80.0% or more.
[0069] On the other hand, when the area ratio of bainite is more than 93.0%, a desired yield ratio cannot be obtained. Therefore, the area ratio of bainite is set to 93.0% or less. The area ratio of bainite is preferably 90.0% or less, 87.0% or less, or 80.0% or less.

Martensite: 5.0% to 20.0%

[0070] Martensite is a structure that increases the strength of the hot-rolled steel sheet. When an area ratio of martensite is less than 5.0%, a desired strength cannot be obtained. Therefore, the area ratio of martensite is set to 5.0% or more. The area ratio of martensite is preferably 8.0% or more or 10.0% or more.
[0071] On the other hand, when the area ratio of martensite is more than 20.0%, a desired yield ratio cannot be obtained. Therefore, the area ratio of martensite is set to 20.0% or less. The area ratio of martensite is preferably 18.0% or less or 15.0% or less.
[0072] The hot-rolled steel sheet according to the present embodiment may contain retained austenite and pearlite as a remainder in the microstructure in a total amount of less than 5.0%.
[0073] The area ratio of each structure is measured by the following method.
[0074] First, a test piece is collected from the hot-rolled steel sheet in a sheet thickness cross section parallel to a rolling direction so that the microstructure at the 1/4 position from the surface (the region from the 1/8 depth from the surface to the 3/8 depth from the surface) and at a center position in a sheet width direction can be observed.
[0075] The cross section of the test piece is polished using #600 to #1500 silicon carbide paper and is thereafter mirror-finished using a liquid obtained by dispersing a diamond powder having a particle size of 1 to 6 μm in a diluted solution such as alcohol or in pure water. Next, the cross section of the test piece is polished at room temperature using colloidal silica containing no alkaline solution to remove strain introduced into a surface layer of the sample. At a random position of the sample cross section in a longitudinal direction, a region having a length of 50 μm from the 1/8 thickness depth from the surface to the 3/8 thickness depth from the surface is measured by electron backscatter diffraction at a measurement interval of 0.1 μm to obtain crystal orientation information.
[0076] For the measurement, an EBSD analyzer including a thermal field-emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd) and an EBSD detector (DVC5 type detector manufactured by TSL solutions) is used. In this case, a degree of vacuum in the EBSD analyzer is set to 9.6×10^{-5} Pa or less, an accelerating voltage is set to 15 kV, an irradiation current level is set to 13, and an irradiation level of an electron beam is set to 62.
[0077] From the obtained crystal orientation information, using the "Grain Orientation Spread" function installed in the software "OIM Analysis (registered trademark)" attached to the EBSD analyzer, a region having a "Grain Orientation Spread" of 1° or less is extracted as ferrite under a condition in which a boundary with a crystal orientation difference of 15° or more is regarded as a grain boundary. By calculating an area ratio of the extracted ferrite, the area ratio of ferrite is obtained.
[0078] Subsequently, a Grain Average Image Quality map (GAIQ map) is obtained using the "Grain Average Image Quality" function. In the obtained GAIQ map, a region surrounded by grain boundaries having a crystal orientation difference of 15° or more is defined as a grain. When a maximum value of a "Grain Average Image Quality Value (GAIQ Value)" of the region extracted as ferrite is defined as $I\alpha$, a region having a relative GAIQ value of more than $I\alpha/2$ is extracted as bainite, and a region having a relative GAIQ value of $I\alpha/2$ or less is extracted as martensite. The area ratio of each of bainite and martensite is obtained by calculating an area ratio of the region of the extracted bainite and an area ratio of the region of the extracted martensite.
[0079] The area ratio of the remainder in the microstructure is obtained by subtracting the area ratios of the structures from 100%.
[0080] For the removal of contamination on a surface layer of an observed section, a method such as buffing using alumina particles having a particle size of 0.1 μm or less or Ar ion sputtering may be used.
[0081] Area Ratio of Martensite, Which Is in Contact with 30° Grain Boundary, When Maximum Value of GAIQ Value of Ferrite Is Indicated as $I\alpha$, Relative GAIQ Value of $I\alpha/3$ or Less, and Which Has Grain Size of 2.0 μm or More: 5.0% or More
[0082] The martensite can be rephrased as martensite that satisfies the following conditions (I) to (III).

(I) Is in contact with a 30° grain boundary.
(II) When the maximum value of the GAIQ value of ferrite is indicated by Iα, the relative GAIQ value is Iα/3 or less.
(III) The grain size is 2.0 μm or more.

[0083] When the area ratio of the martensite that satisfies the above conditions (1) to (III) is less than 5.0%, the punching property of the hot-rolled steel sheet deteriorates. Therefore, the area ratio of the martensite is set to 5.0% or more. The area ratio of martensite is preferably 8.0% or more or 10.0% or more.

[0084] Although an upper limit thereof is not particularly specified, the area ratio of the martensite may be set to 20.0% or less or 15.0% or less.

[0085] A higher GAIQ value indicates a lower dislocation density, while a lower GAIQ value indicates a higher dislocation density. Therefore, the GAIQ value is a parameter that can reflect a dislocation density of a grain.

[0086] When the maximum value of the GAIQ value of ferrite is indicated as Iα, the martensite having a relative GAIQ value of Iα/3 or less is a harder type of martensite among other types of martensite. In the present embodiment, in order to improve the punching property of the hot-rolled steel sheet, the area ratio of the hard martensite that is in contact with a 30° grain boundary is controlled. The martensite having a grain size of less than 2.0 μm does not affect the punching property of the hot-rolled steel sheet and therefore does not need to be particularly controlled.

[0087] The area ratio of the martensite is measured by the following method.

[0088] First, a test piece is collected and treated by the same method as in the measurement of the area ratios of the structures. A measurement position is set to a 1/4 position from a surface (a region from a 1/8 depth from the surface to a 3/8 depth from the surface) and a center position in a sheet width direction. Next, the 30° grain boundary is specified using the "Grain Orientation Spread" function installed in the software "OIM Analysis (registered trademark)" attached to the EBSD analyzer. Next, a GAIQ map is obtained by the same method as in the measurement of the area ratios of the structures, and ferrite and martensite are extracted. The maximum value Iα of the GAIQ value of the ferrite is obtained, and the martensite having a relative GAIQ value of Iα/3 or less is specified. Accordingly, the martensite that is in contact with a 30° grain boundary and has a relative GAIQ value of Iα/3 or less is specified (condition (I) and condition (II)). The martensite that is in contact with a 30° grain boundary also includes martensite that is present on a 30° grain boundary.

[0089] In the GAIQ map, the grain size of the martensite is obtained by calculating an equivalent circle diameter of the martensite that satisfies condition (I) and condition (II). Accordingly, martensite having a grain size of 2.0 μm or more is specified (Condition (III)).

[0090] In the above GAIQ map, by calculating the area ratio of the martensite that satisfies the conditions (I) to (III), the area ratio of the martensite that is in contact with a 30° grain boundary, has a relative GAIQ value of Iα/3 or less, and has a grain size of 2.0 μm or more is obtained.

Strength

[0091] The hot-rolled steel sheet according to the present embodiment has a tensile strength of 980 MPa or more. A tensile strength of 980 MPa or more can contribute to a further reduction in the weight of vehicle bodies. An upper limit of the tensile strength is not particularly specified, but may be set to 1,400 MPa or less.

[0092] The tensile strength is measured by a tensile test according to JIS Z 2241: 2011. As a test piece, a No. 5 test piece of JIS Z 2241: 2011 is used. A position from which the tensile test piece is collected is set to a 1/4 portion from an end portion in a sheet width direction, and a longitudinal direction thereof may be a direction perpendicular to a rolling direction.

Yield Ratio

[0093] The hot-rolled steel sheet according to the present embodiment has a yield ratio of 0.75 or more. The yield ratio is obtained by dividing a yield stress by a tensile strength (yield stress / tensile strength).

[0094] The yield stress is obtained by conducting a tensile test in the above-described method. In a case where the hot-rolled steel sheet yields discontinuously, an upper yield point is regarded as the yield stress, and in a case where the hot-rolled steel sheet yields continuously, a 0.2% proof stress is regarded as the yield stress.

Punching Property

[0095] It is preferable that the hot-rolled steel sheet according to the present embodiment has excellent punched end surface properties when subjected to a punching test. The punched end surface properties are evaluated by the following method.

[0096] A test piece is collected from the hot-rolled steel sheet. A punched hole is prepared from the test piece with a hole diameter of 20 mm, a shear angle of 5°, a clearance of 15.0%, and a punching speed of 80 mm/s. For the punched hole, a test piece is collected so that four cross sections can be checked at intervals of about 90°, the test piece is embedded in a resin, and a punched end surface is photographed with a scanning electron microscope. The obtained picture is observed, and in a case where no large cracks of more than 100 μm are observed in a direction perpendicular to the sheet thickness direction, the hot-rolled steel sheet can be determined to have excellent punching property. In a case where no cracks of 50 μm or more are observed in the direction perpendicular to the sheet thickness direction, the hot-rolled steel sheet can be determined to have particularly excellent punching property.

Sheet Thickness

[0097] A sheet thickness of the hot-rolled steel sheet according to the present embodiment is not particularly limited and may be set to 0.6 to 8.0 mm. By setting the sheet thickness of the hot-rolled steel sheet to 0.6 mm or more, an excessive rolling force can be suppressed, thereby facilitating hot rolling. In addition, by setting the sheet thickness to 8.0 mm or less, the above-described microstructure can be easily obtained.

Plating Layer

[0098] The hot-rolled steel sheet may be a surface-treated steel sheet provided with a plating layer on the surface for the purpose of improving corrosion resistance or the like. The plating layer may be an electroplating layer or a hot-dip plating layer. Examples of the electroplating layer include electrogalvanizing, and electro Zn-Ni alloy plating. Examples of the hot-dip plating layer include hot-dip galvanizing, hot-dip galvannealing, hot-dip aluminum plating, hot-dip Zn-Al alloy plating, hot-dip Zn-Al-Mg alloy plating, and hot-dip Zn-Al-Mg-Si alloy plating. A plating adhesion amount is not particularly limited and may be the same as in the related art. In addition, it is also possible to further enhance the corrosion resistance by performing an appropriate chemical conversion treatment (for example, application and drying of a silicate-based chromium-free chemical conversion liquid) after plating.

Manufacturing Conditions

[0099] In a suitable manufacturing method for the hot-rolled steel sheet according to the present embodiment, the following steps (1) to (7) are sequentially performed. A temperature of a slab and a temperature of a steel sheet in the present embodiment refer to a surface temperature of the slab and a surface temperature of the steel sheet.

(1) After casting a slab having the above-described chemical composition, the slab is heated before being cooled to a temperature range of 500°C or lower and retained in a temperature range of 1,220°C or higher for 30 minutes or longer.
(2) Slab width reduction is performed at a rolling reduction of 10% or larger in a temperature range of 1,200°C or higher.
(3) In rough rolling, a rough rolling finishing temperature is set to a temperature range of 1,100°C or higher, a cumulative rolling reduction of all stands is set to 70% or larger, a rolling reduction of each of final three stands is set to smaller than 20%, and a rolling reduction of each of all the stands is set to smaller than 40%.
(4) Retention is performed in a temperature range of 1,000°C or higher for 30 seconds or longer after the completion of the rough rolling and before the start of finish rolling.
(5) A finishing temperature FT is set to a temperature range of T1 (°C) - 100°C or higher, a cumulative rolling reduction of the finish rolling is set to 75% or larger, a cumulative rolling reduction of final two stands is set to smaller than 30%.
Here, T1 (°C) can be obtained by Formula (A) below. An element symbol in the following formula represents the amount of each element by mass%, and is substituted with 0 in a case where the corresponding element is not contained.

$$T1 = 937 + 168 \times Ti + 3545 \times Nb + 4500 \times B \ldots(A)$$

(6) An average cooling rate in a temperature range of the finishing temperature FT to 700°C is set to 30 °C/s or faster.
(7) Coiling is performed in a temperature range of 450°C to 650°C.

[0100] The hot-rolled steel sheet according to the present embodiment can be stably manufactured by a manufacturing method in which the above steps are closely and inseparably controlled.
[0101] Hereinafter, each step will be described.

(1) Slab Heating

[0102] It is preferable that the slab to be subjected to the hot rolling is heated after casting and before being cooled to a temperature range of 500°C or lower and retained in a temperature range of 1,220°C or higher for 30 minutes or longer. In addition, in the retention in a temperature range of 1,220°C or higher, the temperature of the steel sheet may be changed or may be kept constant.

[0103] In the slab stage, the slab is not cooled to a temperature range of 500°C or lower, whereby the precipitation of coarse Ti is suppressed, and Ti can be sufficiently solutionized. Accordingly, a precipitation hardening ability of ferrite and bainite can be enhanced, and the strength and yield ratio of the hot-rolled steel sheet can be increased. In addition, by performing retention in a temperature range of 1,220°C or higher for 30 minutes or longer, sufficient solutionizing can be achieved, and prior austenite grains are coarsened, whereby an effect of the slab width reduction in the subsequent step can be maximized. As a result, the area ratio of the martensite that is in contact with a 30° grain boundary, when the maximum value of the GAIQ value of ferrite is indicated as $I\alpha$, which has a relative GAIQ value of $I\alpha/3$ or less, and which has a grain size of 2.0 μm or more (hereinafter, sometimes referred to as martensite area ratio at a 30° grain boundary) can be increased.

[0104] Other manufacturing steps preceding the hot rolling are not particularly limited. Subsequent to melting by a blast furnace, an electric furnace, or the like, various secondary smelting processes may be performed, and then the slab may be cast by a method such as ordinary continuous casting. Scrap may be used as a raw material.

(2) Slab Width Reduction

[0105] After the above heating and retention, it is preferable that the slab width reduction is performed in a temperature range of 1,200°C or higher with a rolling reduction of 10% or larger. By performing the slab width reduction under this condition, the coarsened prior austenite grains can be elongated in the sheet thickness direction. As a result, the martensite area ratio at a 30° grain boundary can be increased.

[0106] In addition, the rolling reduction of the slab width reduction can be expressed as, when a length of the slab in a width direction before the reduction is indicated as w0 and the length of the slab in the width direction after the reduction is indicated as w1, $(1 - w1/w0) \times 100$ (%). As a method of performing the slab width reduction, for example, there is a method of rolling a slab using rolls installed so that a rotation axis is perpendicular to a sheet surface of the slab.

(3) Rough Rolling

[0107] In the rough rolling, it is preferable that the rough rolling finishing temperature is set to a temperature range of 1,100°C or higher, the cumulative rolling reduction of all the stands is set to 70% or larger, the rolling reduction of each of the final three stands is set to smaller than 20%, and the rolling reduction of each of all the stands is smaller than 40%. By setting the rough rolling finishing temperature to the temperature range of 1,100°C or higher, setting the cumulative rolling reduction of all the stands to 70% or larger, and setting the rolling reduction of each of the final three stands to smaller than 20%, prior austenite grains elongated in the sheet thickness direction can be made equiaxed, and uniform prior austenite grains can be obtained by promoting recrystallization in an intragranular deformation band. As a result, the martensite area ratio at a 30° grain boundary can be increased.

[0108] In addition, by setting the rolling reduction of each of all the stands to smaller than 40%, elongation of the prior austenite grains in the rolling direction can be suppressed. As a result, the martensite area ratio at a 30° grain boundary can be increased.

[0109] In the rough rolling, reverse rolling is not desirable. This is because when reverse rolling is performed during the rough rolling, a shape of the prior austenite grains cannot be preferably controlled, and as a result, the martensite area ratio at a 30° grain boundary cannot be preferably controlled.

(4) Retention After Completion of Rough Rolling and Before Start of Finish Rolling

[0110] It is preferable to perform retention in a temperature range of 1,000°C or higher for 30 seconds or longer after the completion of the rough rolling and before the start of the finish rolling. By performing retention under this condition, recrystallization in the intragranular deformation band is promoted, and uniform prior austenite grains can be obtained. As a result, the martensite area ratio at a 30° grain boundary can be increased.

[0111] As a method of performing retention in the above temperature range, for example, there is a method of performing heating in a heating furnace after the completion of rough rolling or a method of using a heat-retaining cover. In addition, in the retention, the temperature of the steel sheet may be kept constant or may be changed in a temperature range of 1,000°C or higher.

(5) Finish Rolling

[0112] It is preferable that the finishing temperature FT is set to a temperature range of T1 (°C) - 100°C or higher, the cumulative rolling reduction of the finish rolling is set to 75% or larger, the cumulative rolling reduction of final two stands is set to smaller than 30%. By performing the finish rolling under this condition, it is possible to control the prior austenite grains to be equiaxed while promoting recrystallization. As a result, the martensite area ratio at a 30° grain boundary can be increased.

(6) Cooling After Completion of Finish Rolling

[0113] After the completion of the finish rolling, the average cooling rate in the temperature range of the finishing temperature FT to 700°C is preferably set to 30 °C/s or faster. By performing cooling under this condition, desired amounts of ferrite and bainite can be obtained.

[0114] In the present embodiment, the average cooling rate refers to a value obtained by dividing a temperature drop width of the steel sheet from the start of the cooling to the completion of the cooling by a time required from the start of the cooling to the completion of the cooling.

(7) Coiling

[0115] Coiling is preferably performed in a temperature range of 450°C to 650°C. By setting a coiling temperature to a temperature range of 450°C or higher, desired amounts of ferrite and martensite can be obtained. In addition, by setting the coiling temperature to a temperature range of 650°C or lower, desired amounts of ferrite and bainite can be obtained.

[0116] After the coiling, cooling to room temperature may be performed. Thereafter, pickling and cold rolling may be performed by an ordinary method as necessary. In the cold rolling, a cumulative rolling reduction may be 50% or larger. Furthermore, as necessary, temper rolling may be performed in order to flatten the hot-rolled steel sheet and adjust a surface roughness.

[Examples]

[0117] Next, effects of one aspect of the present invention will be more specifically described using examples, but conditions in the examples are simply examples of the conditions adopted to confirm the feasibility and effects of the present invention, and the present invention is not limited to these examples of the 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.

[0118] Steels having the chemical composition shown in Table 1 were melted and continuously cast to manufacture slabs having a thickness of 240 to 300 mm. The obtained slabs were used to obtain hot-rolled steel sheets shown in Tables 4A and 4B under the manufacturing conditions shown in Tables 2A to 3B.

[0119] The obtained hot-rolled steel sheets were subjected to microstructure observation, a tensile test, and a punching test by the above-described methods. The obtained measurement results are shown in Tables 4A and 4B.

[0120] In a case where the tensile strength was 980 MPa or more, the hot-rolled steel sheet was considered to be a hot-rolled steel sheet having high strength and determined to be acceptable. On the other hand, in a case where the tensile strength was less than 980 MPa, the hot-rolled steel sheet was not regarded as a hot-rolled steel sheet having high strength and determined to be unacceptable.

[0121] In a case where the yield ratio (yield stress / tensile strength) was 0.75 or more, the hot-rolled steel sheet was considered to be a hot-rolled steel sheet having a high yield ratio and determined to be acceptable. On the other hand, in a case where the yield ratio was less than 0.75, the hot-rolled steel sheet was not considered to be a hot-rolled steel sheet having a high yield ratio and determined to be unacceptable.

[0122] At the punching test, in a case where no cracks of 50 μm or more in the direction perpendicular to the sheet thickness direction were observed in the obtained structure photograph, the punching property was considered to be particularly good and indicated as "E" (Excellent) in the tables. In addition, in a case where a crack of more than 50 μm and 100 μm or less in the direction perpendicular to the sheet thickness direction was observed, the punching property was considered to be good and indicated as "G" (Good) in the tables. In addition, in a case where a crack of more than 100 μm in the direction perpendicular to the sheet thickness direction was observed, the punching property was considered to be inferior and indicated as "B" (Bad) in the tables.

[0123] In a case of being evaluated as "E" and "G", the hot-rolled steel sheet was considered to be a hot-rolled steel sheet having excellent punching property and determined to be acceptable. On the other hand, in a case of being evaluated as "B", the hot-rolled steel sheet was not considered to be a hot-rolled steel sheet having excellent punching property and determined to be unacceptable.

[Table 1]

Kind of steel	Chemical composition (mass%), remainder: Fc and impurities										T1 (°C)	Note
	C	Si	Mn	sol. Al	Ti	P	S	N	O	Others		
A	0.090	0.70	1.90	0.100	0.130	0.008	0.0010	0.0020	0.0020	Nb: 0.020	1030	Present Invention Steel
B	0.065	1.48	1.95	0.305	0.120	0.010	0.0020	0.0040	0.0010		957	Present Invention Steel
C	0.051	1.28	2.30	0.030	0.110	0.011	0.001 0	0.0020	0.0010		955	Present Invention Steel
D	0.121	0.80	1.80	0.020	0.140	0.010	0.0010	0.0020	0.0020		961	Present Invention Steel
E	0.080	0.24	2.30	0.030	0.120	0.009	0.0010	0.0020	0.0010		957	Present Invention Steel
F	0.058	2.20	2.20	0.020	0.130	0.010	0.0010	0.0010	0.0030		959	Present Invention Steel
G	0.081	0.90	1.61	0.030	0.060	0.009	0.0020	0.0020	0.0020		947	Present Invention Steel
H	0.078	1.10	3.10	0.020	0.080	0.011	0.0010	0.0020	0.0010		950	Present Invention Steel
I	0.100	1.20	2.50	0.030	0.101	0.010	0.0020	0.0020	0.0020		954	Present Invention Steel
J	0.131	1.10	1.70	0.020	0.160	0.010	0.0020	0.0030	0.0010		964	Present Invention Steel
K	0.075	0.70	2.10	0.030	0.091	0.010	0.0010	0.0020	0.0010	Nb: 0.041	1098	Present Invention Steel
L	0.065	0.40	2.10	0.030	0.098	0.013	0.0020	0.0010	0.0010	V: 0.040	953	Present Invention Steel
M	0.068	0.50	1.87	0.030	0.112	0.010	0.0020	0.0020	0.0010	Cu: 0.25	956	Present Invention Steel
N	0.058	0.38	1.94	0.020	0.110	0.011	0.0010	0.0010	0.0020	Cr: 0.44	955	Present Invention Steel
O	0.084	0.83	2.10	0.030	0.056	0.013	0.0010	0.0010	0.0020	Mo: 0.100	946	Present Invention Steel
P	0.059	1.20	1.75	0.030	0.100	0.010	0.0010	0.0020	0.0010	Ni: 0.80	954	Present Invention Steel
Q	0.110	1.12	2.21	0.030	0.089	0.010	0.0010	0.0020	0.0010	Ca: 0.0150	952	Present Invention Steel
R	0.065	1.32	1.89	0.030	0.078	0.013	0.0010	0.0010	0.0010	Mg: 0.0120	950	Present Invention Steel
S	0.049	1.38	2.71	0.030	0.084	0.010	0.0010	0.0010	0.0020	REM: 0.0700	951	Present Invention Steel
T	0.094	1.75	1.86	0.030	0.110	0.011	0.0020	0.0020	0.0010	Bi: 0.0180	955	Present Invention Steel
U	0.081	1.83	2.42	0.020	0.124	0.013	0.0010	0.0010	0.0010	Zr: 0.0025	958	Present Invention Steel
V	0.076	2.11	2.15	0.020	0.142	0.011	0.0020	0.0010	0.0010	Co: 0.0040	961	Present Invention Steel
W	0.058	2.31	1.51	0.040	0.095	0.013	0.0010	0.0010	0.0030	Zn: 0.0210	953	Present Invention Steel
X	0.140	1.81	1.95	0.030	0.055	0.010	0.0020	0.0020	0.0010	W: 0.0400	946	Present Invention Steel

(continued)

Kind of steel	Chemical composition (mass%), remainder: Fc and impurities										T1 (°C)	Note
	C	Si	Mn	sol. Al	Ti	P	S	N	O	Others		
Y	0.071	1.25	2.41	0.050	0.112	0.010	0.0010	0.0010	0.0010	Sn: 0.050	956	Present Invention Steel
Z	0.070	1.22	2.20	0.030	0.130	0.010	0.0010	0.0030	0.0010	Nb: 0.018, B: 0.0020	1032	Present Invention Steel
AA	0.085	0.35	1.89	0.730	0.110	0.010	0.0010	0.0020	0.0010	Nb: 0.010	991	Present Invention Steel
AB	<u>0.034</u>	1.45	1.98	0.020	0.095	0.012	0.0020	0.0020	0.0020		953	Comparative Steel
AC	0.065	<u>0.05</u>	2.45	0.020	0.098	0.012	0.0020	0.0010	0.0010		953	Comparative Steel
AD	0.098	1.30	<u>4.80</u>	0.030	0.123	0.013	0.0010	0.0010	0.0020		958	Comparative Steel
AE	0.100	1.05	<u>1.02</u>	0.020	0.109	0.015	0.0010	0.0010	0.0010		955	Comparative Steel
AF	0.089	1.05	2.30	0.030	<u>0.250</u>	0.012	0.0020	0.0020	0.0010		979	Comparative Steel
AG	0.067	1.53	2.21	0.030	<u>0.032</u>	0.011	0.0010	0.0010	0.0010		942	Comparative Steel

The underlined indicates outside of the range of the present invention.

[Table 2A]

Sample No.	Kind of steel	Slab heating		Slab width reduction		Rough rolling				Retention	Note
		Heating start temperature °C	Retention time in temperature range of 1,220°C or higher min	Rolling reduction %	Rolling temperature °C	Rough rolling finishing temperature °C	Cumulative rolling reduction of all stands %	Maximum rolling reduction %	Maximum rolling reduction of final three stands %	Retention time in temperature range of 1000°C or higher after completion of rough rolling and before start of finish rolling s	
1	A	550	60	15	1230	1150	84	34	18	78	Present Invention Example
2	A	650	75	18	<u>1165</u>	1102	78	38	18	58	Comparative Example
3	B	620	55	21	1215	1120	79	38	17	81	Present Invention Example
4	B	590	68	16	1208	<u>1056</u>	76	39	19	64	Comparative Example
5	C	520	54	13	1240	1185	75	35	18	90	Present Invention Example
6	C	610	89	<u>6</u>	1235	1176	78	36	16	85	Comparative Example
7	C	580	70	15	1225	1145	78	37	16	77	Comparative Example
8	D	580	63	13	1220	1118	77	31	16	68	Present Invention Example
9	D	530	75	17	1218	1146	<u>65</u>	29	14	90	Comparative Example
10	D	550	80	21	1231	1155	80	35	18	76	Comparative Example

(continued)

Sample No.	Kind of steel	Slab heating		Slab width reduction		Rough rolling				Retention	Note
		Heating start temperature °C	Retention time in temperature range of 1,220°C or higher min	Rolling reduction %	Rolling temperature °C	Rough rolling finishing temperature °C	Cumulative rolling reduction of all stands %	Maximum rolling reduction %	Maximum rolling reduction of final three stands %	Retention time in temperature range of 1000°C or higher after completion of rough rolling and before start of finish rolling s	
11	E	600	75	15	1230	1115	86	34	17	75	Present Invention Example
12	E	620	70	16	1211	1127	76	43	17	87	Comparative Example
13	F	650	59	14	1210	1117	76	36	18	70	Present Invention Example
14	F	570	78	18	1221	1148	79	33	17	80	Comparative Example
15	F	580	65	17	1235	1121	78	38	17	85	Comparative Example
16	G	580	120	19	1220	1135	81	35	16	69	Present Invention Example
17	G	520	10	15	1205	1113	78	36	19	75	Comparative Example
18	G	550	85	15	1230	1140	79	33	17	8	Comparative Example
19	H	860	89	24	1230	1141	88	34	17	70	Present Invention Example

(continued)

Sample No.	Kind of steel	Slab heating		Slab width reduction		Rough rolling				Retention	Note
		Heating start temperature °C	Retention time in temperature range of 1,220°C or higher min	Rolling reduction %	Rolling temperature °C	Rough rolling finishing temperature °C	Cumulative rolling reduction of all stands %	Maximum rolling reduction %	Maximum rolling reduction of final three stands %	Retention time in temperature range of 1000°C or higher after completion of rough rolling and before start of finish rolling s	
20	H	560	65	16	1224	1135	83	35	16	85	Comparative Example
21	I	730	130	14	1230	1108	84	31	15	68	Present Invention Example
22	I	<u>30</u>	45	12	1220	1136	90	29	16	75	Comparative Example
23	J	550	69	19	1240	1121	85	29	19	73	Present Invention Example
24	J	600	74	18	1229	1135	91	39	19	80	Comparative Example
25	K	530	40	24	1210	1110	83	38	17	77	Present Invention Example
26	L	610	77	21	1220	1105	76	33	17	80	Present Invention Example
27	M	570	250	11	1230	1115	77	35	18	75	Present Invention Example

The underlined indicates that the manufacturing conditions arc not preferable.

[Table 2B]

Sample No.	Kind of steel	Slab heating		Slab width reduction		Rough rolling				Retention	Note
		Heating start temperature °C	Retention time in temperature range of 1,220°C or higher min	Rolling reduction %	Rolling temperature °C	Rough rolling finishing temperature °C	Cumulative rolling reduction of all stands %	Maximum rolling reduction %	Maximum rolling reduction of final three stands %	Retention time in temperature range of 1,000°C or higher after completion of rough rolling and before start of finish rolling s	
28	N	600	180	14	1210	1109	82	39	16	76	Present Invention Example
29	O	650	100	12	1220	1142	74	31	17	80	Present Invention Example
30	P	610	110	19	1215	1130	85	33	18	75	Present Invention Example
31	Q	510	120	15	1230	1115	81	29	19	77	Present Invention Example
32	R	550	47	11	1210	1125	83	38	16	65	Present Invention Example
33	S	630	95	13	1220	1155	82	31	17	60	Present Invention Example
34	T	580	66	23	1240	1135	84	29	16	65	Present Invention Example
35	U	620	43	19	1225	1140	85	38	17	63	Present Invention Example

(continued)

Sample No.	Kind of steel	Slab heating		Slab width reduction		Rough rolling				Retention	Note
		Heating start temperature °C	Retention time in temperature range of 1,220°C or higher min	Rolling reduction %	Rolling temperature °C	Rough rolling finishing temperature °C	Cumulative rolling reduction of all stands %	Maximum rolling reduction %	Maximum rolling reduction of final three stands %	Retention time in temperature range of 1,000°C or higher after completion of rough rolling and before start of finish rolling s	
36	V	630	38	27	1230	1135	73	35	17	61	Present Invention Example
37	W	630	65	17	1215	1150	78	34	19	83	Present Invention Example
38	X	610	80	21	1210	1145	75	38	18	82	Present Invention Example
39	Y	580	100	14	1230	1150	74	31	15	71	Present Invention Example
40	Z	540	35	15	1210	1145	85	39	16	68	Present Invention Example
41	Z	520	60	12	1245	1151	80	37	33	73	Comparative Example
42	AA	590	80	23	1220	1130	76	33	18	73	Present Invention Example
43	AB	540	55	19	1230	1140	82	36	16	95	Comparative Example

(continued)

Sample No.	Kind of steel	Slab heating		Slab width reduction		Rough rolling				Retention	Note
		Heating start temperature °C	Retention time in temperature range of 1,220°C or higher min	Rolling reduction %	Rolling temperature °C	Rough rolling finishing temperature °C	Cumulative rolling reduction of all stands %	Maximum rolling reduction %	Maximum rolling reduction of final three stands %	Retention time in temperature range of 1,000°C or higher after completion of rough rolling and before start of finish rolling s	
44	AC	630	80	19	1230	1140	79	32	19	78	Comparative Example
45	AD	520	99	15	1220	1130	83	37	17	75	Comparative Example
46	AE	560	75	21	1220	1125	77	39	16	68	Comparative Example
47	AF	530	81	15	1210	1150	78	34	17	63	Comparative Example
48	AG	550	75	12	1215	1130	83	39	is	71	Comparative Example
49	A	510	62	16	1210	1118	91	39	18	81	Present Invention Example
50	B	600	81	12	1220	1126	78	31	19	71	Present Invention Example
51	E	580	54	21	1225	1139	88	33	16	66	Present Invention Example
52	H	520	91	11	1240	1154	82	39	17	82	Present Invention Example

(continued)

Sample No.	Kind of steel	Slab heating		Slab width reduction		Rough rolling				Retention	Note
		Heating start temperature °C	Retention time in temperature range of 1,220°C or higher min	Rolling reduction %	Rolling temperature °C	Rough rolling finishing temperature °C	Cumulative rolling reduction of all stands %	Maximum rolling reduction %	Maximum rolling reduction of final three stands %	Retention time in temperature range of 1,000°C or higher after completion of rough rolling and before start of finish rolling s	
53	H	550	73	16	1230	1141	78	35	18	85	Present Invention Example

The underlined indicates that the manufacturing conditions arc not preferable.

[Table 3A]

Sample No.	Kind of steel	Finish rolling					Coiling	Note
		Cumulative rolling reduction %	Cumulative rolling reduction of final two stands %	Finishing temperature FT °C	T1 - 100 °C	Average cooling rate in temperature range of FT to 700°C °C/s	Coiling temperature °C	
1	A	89	29	980	930	35	500	Present Invention Example
2	A	82	28	955	930	50	575	Comparative Example
3	B	83	26	900	857	80	550	Present Invention Example
4	B	76	28	890	857	71	580	Comparative Example
5	C	81	27	930	855	75	480	Present Invention Example
6	C	79	27	900	855	80	510	Comparative Example
7	C	79	26	900	855	76	685	Comparative Example
8	D	79	28	940	861	40	530	Present Invention Example
9	D	76	28	911	861	80	550	Comparative Example
10	D	79	38	910	861	56	608	Comparative Example
11	E	80	27	910	857	55	560	Present Invention Example
12	E	78	26	888	857	70	590	Comparative Example
13	F	77	29	890	859	79	550	Present Invention Example

(continued)

Sample No.	Kind of steel	Finish rolling					Coiling	Note
		Cumulative rolling reduction %	Cumulative rolling reduction of final two stands %	Finishing temperature FT °C	T1 - 100 °C	Average cooling rate in temperature range of FT to 700°C °C/s	Coiling temperature °C	
14	F	81	27	<u>825</u>	859	68	550	Comparative Example
15	F	79	29	906	859	15	620	Comparative Example
16	G	83	27	940	847	32	580	Present Invention Example
17	G	78	29	900	847	80	530	Comparative Example
is	G	77	25	905	847	55	610	Comparative Example
19	H	87	25	950	850	80	635	Present Invention Example
20	II	81	27	925	850	75	<u>398</u>	Comparative Example
21	I	90	28	940	854	77	575	Present Invention Example
22	I	86	27	920	854	85	590	Comparative Example
23	J	85	27	955	864	85	546	Present Invention Example
24	J	<u>71</u>	27	928	864	75	585	Comparative Example
25	K	89	27	999	998	57	550	Present Invention Example
26	L	85	29	940	853	45	580	Present Invention Example

(continued)

Sample No.	Kind of steel	Finish rolling					Coiling	Note
		Cumulative rolling reduction %	Cumulative rolling reduction of final two stands %	Finishing temperature FT °C	T1 - 100 °C	Average cooling rate in temperature range of FT to 700°C °C/s	Coiling temperature °C	
27	M	90	26	890	856	69	520	Present Invention Example

The underlined indicates that the manufacturing conditions are not preferable.

[Table 3B]

Sample No.	Kind of steel	Finish rolling					Coiling	Note
		Cumulative rolling reduction %	Cumulative rolling reduction of final two stands %	Finishing temperature FT °C	T1 - 100 °C	Average cooling rate in temperature range of FT to 700°C °C/s	Coiling temperature °C	
28	N	89	27	900	855	81	495	Present Invention Example
29	O	82	28	920	846	44	520	Present Invention Example
30	P	78	29	910	854	39	500	Present Invention Example
31	Q	80	27	890	852	75	495	Present Invention Example
32	R	78	27	906	850	65	560	Present Invention Example
33	S	79	28	889	851	77	565	Present Invention Example
34	T	80	28	890	855	80	580	Present Invention Example
35	U	78	27	905	858	49	540	Present Invention Example
36	V	81	26	915	861	58	500	Present Invention Example
37	W	79	29	910	853	69	485	Present Invention Example
38	X	81	28	900	846	70	600	Present Invention Example
39	Y	77	27	896	856	84	550	Present Invention Example
40	Z	78	28	983	932	75	580	Present Invention Example

(continued)

Sample No.	Kind of steel	Finish rolling					Coiling	Note
		Cumulative rolling reduction %	Cumulative rolling reduction of final two stands %	Finishing temperature FT °C	T1 - 100 °C	Average cooling rate in temperature range of FT to 700°C °C/s	Coiling temperature °C	
41	Z	77	29	942	932	80	500	Comparative Example
42	AA	80	26	910	891	84	570	Present Invention Example
43	AB	78	28	890	853	85	550	Comparative Example
44	AC	80	27	896	853	74	610	Comparative Example
45	AD	79	28	899	858	59	490	Comparative Example
46	AE	82	27	895	855	63	500	Comparative Example
47	AF	81	28	911	879	75	630	Comparative Example
48	AG	79	28	895	842	66	500	Comparative Example
49	A	88	26	962	930	61	500	Present Invention Example
50	B	79	27	944	857	73	460	Present Invention Example
51	E	81	25	912	857	32	590	Present Invention Example
52	H	86	25	937	850	44	510	Present Invention Example
53	II	84	26	926	854	39	460	Present Invention Example

The underlined indicates that the manufacturing conditions are not preferable.

[Table 4A]

Sample No.	Kind of steel	Microstructure					Mechanical properties			Note
		Ferrite area%	Bainite area%	Martensite area%	Remainder in microstructure area%	Martensite at 30° grain boundary area%	Tensile strength TS MPa	Yield ratio-	Punching property	
1	A	15.0	72.2	12.0	0.8	6.0	1045	0.78	G	Present Invention Example
2	A	100	76.2	13.0	0.8	4.1	989	0.92	B	Comparative Example
3	B	14.0	74.8	10.0	1.2	9.0	983	0.89	E	Present Invention Example
4	B	15.0	67.7	16.0	1.3	4.1	982	0.87	B	Comparative Example
5	C	12.0	78.5	8.0	1.5	8.0	986	0.9	G	Present Invention Example
6	C	15.0	71.4	12.0	1.6	2.8	1008	0.87	B	Comparative Example
7	c	34.0	45.9	18.0	2.1	9.0	789	0.92	G	Comparative Example
8	D	16.0	66.9	16.0	1.1	12.0	1221	0.78	E	Present Invention Example
9	D	9.0	78.9	11.0	1.1	47	1001	0.91	B	Comparative Example
10	D	14.0	73.9	11.0	1.1	48	1276	0.76	B	Comparative Example
11	E	14.0	75.1	10.0	0.9	8.0	1005	0.91	G	Present Invention Example

(continued)

Sample No.	Kind of steel	Microstructure					Mechanical properties			Note
		Ferrite area%	Bainite area%	Martensite area%	Remainder in microstructure area%	Martensite at 30° grain boundary area%	Tensile strength TS MPa	Yield ratio-	Punching property	
12	E	11.0	75.9	11.0	2.1	3.9	1164	0.82	B	Comparative Example
13	F	100	81.8	7.0	1.2	6.0	991	0.87	G	Present Invention Example
14	F	18.0	72.6	8.0	1.4	3.1	990	0.89	B	Comparative Example
15	F	35.0	56.9	7.0	1.1	5.0	894	0.88	G	Comparative Example
16	G	17.0	70.2	12.0	0.8	9.0	984	0.91	E	Present Invention Example
17	G	15.0	70.9	12.0	2.1	3.5	895	0.74	B	Comparative Example
18	G	13.0	77.5	8.0	1.5	4.3	989	0.78	B	Comparative Example
19	II	12.0	72.9	14.0	1.1	11.0	1016	0.89	E	Present Invention Example
20	H	1.1	94.7	3.1	1.1	2.8	908	0.72	E	Comparative Example
21	I	15.0	71.2	12.0	1.8	9.0	1085	0.91	E	Present Invention Example
22	I	12.0	71.6	15.0	1.4	6.0	974	0.72	G	Comparative Example

(continued)

Sample No.	Kind of steel	Microstructure					Mechanical properties			Note
		Ferrite area%	Bainite area%	Martensite area%	Remainder in microstructure area%	Martensite at 30° grain boundary area%	Tensile strength TS MPa	Yield ratio-	Punching property	
23	J	12.0	70.1	17.0	0.9	13.0	1205	0.76	E	Present Invention Example
24	J	21.0	71.2	7.0	0.8	4.6	991	0.85	B	Comparative Example
25	K	11.0	76.2	11.0	1.8	6.0	994	0.92	G	Present Invention Example
26	L	16.0	74.5	8.0	1.5	12.0	987	0.88	E	Present Invention Example
27	M	12.0	75.9	10.0	2.1	13.0	981	0.87	E	Present Invention Example

The underlined indicates outside of the range of the present invention, and that the properties are not preferable.

[Table 4B]

Sample No.	Kind of steel	Microstructure					Mechanical properties			Note
		Ferrite area%	Bainite area%	Martensite area%	Remainder in microstructure area%	Martensite at 30° grain boundary area%	Tensile strength TS MPa	Yield ratio-	Punching property	
28	N	6.0	86.4	6.0	1.6	11.0	987	0.91	E	Present Invention Example
29	O	13.0	73.7	12.0	1.3	10.0	1032	0.91	E	Present Invention Example
30	P	15.0	74.1	9.0	1.9	6.0	1001	0.9	G	Present Invention Example
31	Q	13.0	69.9	15.0	2.1	11.0	1176	0.88	E	Present Invention Example
32	R	12.0	75.6	11.0	1.4	9.0	998	0.92	E	Present Invention Example
33	S	14.0	75.2	9.0	1.8	7.0	1012	0.91	G	Present Invention Example
34	T	17.0	65.7	15.0	23	11.0	1115	0.88	E	Present Invention Example
35	U	15.0	69.1	14.0	1.9	12.0	1186	0.89	E	Present Invention Example
36	V	14.0	73.7	11.0	1.3	7.0	1085	0.76	G	Present Invention Example

(continued)

Sample No.	Kind of steel	Microstructure					Mechanical properties			Note
		Ferrite area%	Bainite area%	Martensite area%	Remainder in microstructure area%	Martensite at 30° grain boundary area%	Tensile strength TS MPa	Yield ratio-	Punching property	
37	W	18.0	71.1	9.0	1.9	6.0	1006	0.91	G	Present Invention Example
38	X	16.0	630	19.0	2.0	14.0	1209	0.86	E	Present Invention Example
39	Y	13.0	74.2	11.0	1.8	7.0	1002	0.91	G	Present Invention Example
40	Z	16.0	68.9	14.0	1.1	12.0	986	0.85	E	Present Invention Example
41	Z	17.0	74.9	7.0	1.1	4.4	991	0.81	B	Comparative Example
42	AA	14.0	72.3	13.0	0.7	8.0	999	0.86	G	Present Invention Example
43	AB	13.0	78.5	7.0	1.5	5.0	809	0.86	G	Comparative Example
44	AC	14.0	74.4	11.0	0.6	7.0	860	0.89	G	Comparative Example
45	AD	1.0	72.6	250	1.4	12.0	1211	0.72	G	Comparative Example
46	AE	19.0	75.5	4.0	1.5	2.0	805	0.87	B	Comparative Example
47	AF	13.0	69.9	15.0	2.1	7.0	1015	0.92	B	Comparative Example

(continued)

Sample No.	Kind of steel	Microstructure					Mechanical properties			Note
		Ferrite area%	Bainite area%	Martensite area%	Remainder in microstructure area%	Martensite at 30° grain boundary area%	Tensile strength TS MPa	Yield ratio-	Punching property	
<u>48</u>	<u>AG</u>	12.0	76.4	10.0	1.6	7.0	<u>870</u>	<u>0.71</u>	G	Comparative Example
49	A	14.0	71.8	11.6	26	5.3	1033	0.81	G	Present Invention Example
50	B	2.1	78.1	17.1	27	9.5	1026	0.78	G	Present Invention Example
51	E	29.0	63.8	6.1	1.1	5.7	992	0.93	E	Present Invention Example
52	II	2.9	91.1	5.8	0.2	5.2	997	0.85	G	Present Invention Example
53	H	77	71.2	19.1	2.0	18.8	1005	0.78	G	Present Invention Example

The underlined indicates outside of the range of the present invention, and that the properties are not preferable.

[0124] From Table 4A and Table 4B, it can be seen that the hot-rolled steel sheets according to the present invention examples have high strength and yield ratio and excellent punching property.

[0125] On the other hand, it can be seen that the hot-rolled steel sheets according to the comparative examples do not have any one or more of the above properties.

[Industrial Applicability]

[0126] According to the aspect of the present invention, it is possible to provide a hot-rolled steel sheet having high strength and yield ratio, and excellent punching property.

Claims

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

C: 0.045% to 0.150%;
Si: 0.10% to 2.50%;
Mn: 1.50% to 3.50%;
sol. Al: 0.010% to 1.000%;
Ti: 0.050% to 0.200%;
P: 0.100% or less;
S: 0.0300% or less;
N: 0.1000% or less;
O: 0.0100% or less;
Nb: 0% to 0.050%;
V: 0% to 0.050%;
B: 0% to 0.0100%;
Cu: 0% to 2.00%;
Cr: 0% to 2.00%;
Mo: 0% to 1.000%;
Ni: 0% to 2.00%;
Ca: 0% to 0.0200%;
Mg: 0% to 0.0200%;
REM: 0% to 0.1000%;
Bi: 0% to 0.0200%;
one or two or more of Zr, Co, Zn, and W: 0% to 1.0000% in total;
Sn: 0% to 0.050%; and
a remainder comprising Fe and impurities,
wherein a microstructure at a 1/4 position from a surface includes, by area%,

ferrite: 2.0% to 30.0%,
bainite: 60.0% to 93.0%, and
martensite: 5.0% to 20.0%,

an area ratio of martensite,

which is in contact with a 30° grain boundary,
which has a relative GAIQ value of $I\alpha/3$ or less, where $I\alpha$ is a maximum value of a GAIQ value of the ferrite, and
which has a grain size of 2.0 μm or more,

is 5.0% or more, and
a tensile strength of the hot-rolled steel sheet is 980 MPa or more.

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

Nb: 0.001% to 0.050%,

V: 0.001% to 0.050%,
B: 0.0001% to 0.0100%,
Cu: 0.01% to 2.00%,
Cr: 0.01% to 2.00%,
Mo: 0.001% to 1.000%,
Ni: 0.01% to 2.00%,
Ca: 0.0005% to 0.0200%,
Mg: 0.0005% to 0.0200%,
REM: 0.0005% to 0.1000%, and
Bi: 0.0005% to 0.0200%.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/043513

A. CLASSIFICATION OF SUBJECT MATTER

C21D 9/46(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/58***(2006.01)i
FI: C22C38/00 301W; C22C38/58; C22C38/00 301T; C21D9/46 S; C21D9/46 U

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)

C21D9/46; C22C38/00-38/60

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 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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 2021/090642 A1 (NIPPON STEEL CORP.) 14 May 2021 (2021-05-14) entire text	1-2
A	WO 2017/138384 A1 (JFE STEEL CORP.) 17 August 2017 (2017-08-17) entire text	1-2

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

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Date of the actual completion of the international search	Date of mailing of the international search report
05 January 2023	**24 January 2023**

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

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/043513

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2021/090642 A1	14 May 2021	US 2022/0259692 A1 entire text EP 4056723 A1 CN 114630917 A KR 10-2022-0068250 A	
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- JP 2021191745 A **[0002]**
- JP 2009263774 A **[0006]**