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(54) **HOT-ROLLED STEEL SHEET**

(57) In a hot rolled steel sheet, a value A represented by Expression (1) is 0.0150 mass% or more, a value M represented by Expression (2) is 930 or less, a microstructure in a 1/4 position of a sheet thickness from a surface includes, by area%, ferrite: 50% or more

and less than 80%, bainite: more than 20% and 50% or less, pearlite: 0% to 5%, and MA: 0% to 2%, an average grain size is 10 μm or less, a BH amount is 45 MPa or more, and a tensile strength is 780 MPa or more.

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Description

TECHNICAL FIELD

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

[0002] Priority is claimed on Japanese Patent Application No. 2023-201058, filed November 28, 2023, the content of which is incorporated herein by reference.

BACKGROUND ART

[0003] In recent years, vehicle manufacturers have made efforts to reduce the weight of vehicle bodies by reducing the number of components and reducing the thickness, in order to reduce the amount of greenhouse gases emitted. On the other hand, since vehicle bodies are also required to have collision safety, the use of high strength steel sheets for components for a vehicle is being accelerated.

[0004] High-strength hot rolled steel sheets used for vehicles or the like are required to have excellent press formability. In order to improve the press formability of high-strength hot rolled steel sheets, for example, a technique for achieving both a high strength and formability by setting a ratio of ferrite to 80% or more in a microstructure with a remainder of bainite and pearlite, and by precipitating fine carbides in ferrite grains, thereby achieving both a high strength and ductility has been known. In this technique, Ti having low unit cost for strength is mainly used.

[0005] The press formability can be improved by adding Ti. However, in a case where high-strength hot rolled steel sheets to which Ti is added are cut into a blank shape (subjected to punching), a problem is likely to occur in which a sheared end surface is peeled into two layers. The peeling may lead to cracking in a direction perpendicular to the sheet thickness direction. The peeling of the end surface occurring during punching is called "peeling-off".

[0006] In high-strength hot rolled steel sheets, it is required to prevent peeling-off occurring during punching.

[0007] For example, Patent Document 1 discloses a technique for strengthening grain boundaries and improving punching workability by causing solid solution carbon to remain in a steel sheet.

[0008] Patent Document 2 shows a method for strengthening grain boundaries and improving punching workability by adding and segregating B at the grain boundaries.

Citation List

Patent Documents

[0009]

Patent Document 1: Japanese Unexamined Patent Application, First Publication No. 2003-342684

Patent Document 2: Japanese Unexamined Patent Application, First Publication No. 2004-315857

SUMMARY OF INVENTION

Technical Problem

[0010] However, there is also room for improvement in the steel sheet in which the amount of solid solution carbon is caused to remain in Patent Document 1, from the viewpoint of suppressing slight peeling-off during punching. In a working process in which a sheared end surface receives a plastic strain after punching, the slight peeling-off becomes the origin of cracking.

[0011] In addition, in a case where B is added as in the technique described in Patent Document 2, the grain boundary strength increases, but there is room for improvement from the viewpoint of controlling the microstructure and the surface properties of the steel sheet associated with an improvement in hardenability.

[0012] The present invention has been contrived in view of the above circumstances. An object of the present invention is to provide a hot rolled steel sheet having a high strength and excellent press formability and punching workability.

Solution to Problem

[0013] The inventors of the present invention have found that the amount of solid solution carbon can be increased by increasing a calculated amount of unprecipitated carbon, which is calculated from a C content, a Ti content, an N content, an Nb content, and a V content in the chemical composition, and it is thus possible to suppress the occur-

rence of slight peeling-off during punching.

[0014] Regarding the amount of solid solution carbon, Patent Document 1 describes that, in a case where the amount of unfixed carbon ($C - Ti/4 + N/1.17$) is more than 0.015%, the ferrite is not sufficiently strengthened, the hardness difference between the bainite and the ferrite increases due to an increase in the amount of carbon in the bainite, and thus the press formability deteriorates. Furthermore, Patent Document 1 describes that the ductility decreases in a case in which the area ratio of ferrite is less than 80%. Therefore, the inventors of the present invention have found that, by increasing the area ratio of bainite in the microstructure, an increase in the amount of carbon in the bainite is suppressed, an increase in hardness is suppressed, and the press formability can thus be improved.

[0015] The gist of the present invention made based on the above-described findings is as follows.

[1] A hot rolled steel sheet including, as a chemical composition, by mass%:

C: 0.04% to 0.10%;

Si: 0.11 % to 0.30%;

Mn: 1.40% to 2.50%;

P: 0.05% or less;

S: 0.05% or less;

N: 0.010% or less;

O: 0.010% or less;

Al: 0.001% to 0.050%;

Ti: 0.060% to 0.150%;

Nb: 0.020% to 0.100%;

V: 0% to 0.200%;

Mo: 0% to 1.000%;

Ca: 0% to 0.0100%;

REM: 0% to 0.0100%;

Cu: 0% to 2.00%;

Ni: 0% to 1.50%;

Cr: 0% to 2.00%;

Mg: 0% to 0.0200%;

Bi: 0% to 0.0200%;

Zr: 0% to 0.500%;

Co: 0% to 1.000%;

Zn: 0% to 0.200%;

W: 0% to 0.200%;

Sb: 0% to 0.200%;

As: 0% to 0.050%;

Sn: 0% to 0.050%;

B: less than 0.0005%; and

a remainder: Fe and impurities,

in which a value A represented by Expression (1) is 0.0150 mass% or more,

a value M represented by Expression (2) is 930 or less,

a microstructure in a 1/4 position of a sheet thickness from a surface consists of, by area%,

ferrite: 50% or more and less than 80%,

bainite: more than 20% and 50% or less,

pearlite: 0% to 5%, and

MA: 0% to 2%,

an average grain size is 10 μm or less,

a BH amount is 45 MPa or more, and

a tensile strength is 780 MPa or more,

$$\text{value A} = C - Ti/4 + N/1.17 - Nb/7.75 - V/4.25 \quad (1),$$

$$\text{value M} = 937 - 436.5 \times C + 56 \times Si - 19.7 \times Mn - 16.3 \times Cu - 26.6 \times Ni - 4.9 \times Cr + 38.1 \times Mo + 124.8 \times V + 136.3 \times Ti - 19.1 \times Nb + 198.4 \times Al \quad (2),$$

where each element symbol in Expressions (1) and (2) represents a corresponding element content by mass%, and 0% is substituted in a case where the corresponding element is not contained.

[2] The hot rolled steel sheet according to [1], including, as the chemical composition, by mass%, one or more of the group consisting of:

V: 0.001% to 0.200%,
 Mo: 0.001% to 1.000%,
 Ca: 0.0001% to 0.0100%,
 REM: 0.0001% to 0.0100%,
 Cu: 0.01% to 2.00%,
 Ni: 0.01% to 1.50%,
 Cr: 0.01% to 2.00%,
 Mg: 0.0001% to 0.0200%,
 Bi: 0.001 % to 0.0200%,
 Zr: 0.001% to 0.500%,
 Co: 0.001% to 1.000%,
 Zn: 0.001% to 0.200%,
 W: 0.001 % to 0.200%,
 Sb: 0.001 % to 0.200%,
 As: 0.001% to 0.050%, and
 Sn: 0.001 % to 0.050%.

[3] The hot rolled steel sheet according to [1] or [2], in which in a microstructure from the surface to a depth of 500 μm from the surface, a maximum value of pole densities of an orientation group expressed by Euler angles of $\Phi = 0^\circ$ to 90° , $\varphi_1 = 0^\circ$ to 90° , and $\varphi_2 = 45^\circ$ is 7.0 or less.

[4] The hot rolled steel sheet according to any one of [1] to [3], including, as the chemical composition, by mass%, B: 0.0002% or less.

Advantageous Effects of Invention

[0016] According to the aspect of the present invention, it is possible to provide a hot rolled steel sheet having a high strength and excellent press formability and punching workability.

DESCRIPTION OF EMBODIMENTS

[0017] A hot rolled steel sheet according to an embodiment of the present invention (hereinafter, may be referred to as the hot rolled steel sheet according to the present embodiment) will be described below. However, the present invention is not limited to the configuration disclosed in the present embodiment, and various modifications can be made without departing from the gist of the present disclosure.

[0018] Hereinafter, individual configuration requirements of the present invention will be described. First, the reasons for limiting the chemical composition of the hot rolled steel sheet according to the present embodiment will be described.

[0019] The numerical limit range described below with "to" in between 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, % related to the chemical composition is mass% unless otherwise specified.

[0020] A hot rolled steel sheet according to the present embodiment contains, as a chemical composition, by mass%: C: 0.04% to 0.10%; Si: 0.11% to 0.30%; Mn: 1.40% to 2.50%; P: 0.05% or less; S: 0.05% or less, N: 0.010% or less, O: 0.010% or less, Al: 0.001% to 0.050%, Ti: 0.060% to 0.150%, Nb: 0.020% to 0.100%, V: 0% to 0.200%, Mo: 0% to 1.000%, Ca: 0% to 0.0100%, REM: 0% to 0.0100%, Cu: 0% to 2.00%, Ni: 0% to 1.50%, Cr: 0% to 2.00%, Mg: 0% to 0.0200%, Bi: 0% to 0.0200%, Zr: 0% to 0.500%, Co: 0% to 1.000%, Zn: 0% to 0.200%, W: 0% to 0.200%, Sb: 0% to 0.200%, As: 0% to 0.050%, Sn: 0% to 0.050%, B: less than 0.0005%, and a remainder: Fe and impurities. Each element will be described in detail below.

C: 0.04% to 0.10%

[0021] C is an element necessary for obtaining an effect of suppressing peeling-off at an end surface formed in

shearing or punching by being present at grain boundaries as solid solution C, and for obtaining a strength of the hot rolled steel sheet by being precipitated as a carbide. In a case where the C content is less than 0.04%, it becomes difficult to obtain punching workability and a desired strength. Therefore, the C content is set to 0.04% or more. The C content is preferably 0.05% or more, or 0.06% or more.

[0022] On the other hand, in a case where the C content is more than 0.10%, the ductility decreases, and thus the press formability of the hot rolled steel sheet deteriorates. Therefore, the C content is set to 0.10% or less. The C content is preferably 0.09% or less, or 0.08% or less.

Si: 0.11 % to 0.30%

[0023] Si is an effective element as a deoxidizing material, and is an effective element for increasing the strength as a solid solution strengthening element. In a case where the Si content is less than 0.11%, it becomes difficult to obtain a desired strength in the hot rolled steel sheet. Therefore, the Si content is set to 0.11 % or more. The Si content is preferably 0.15% or more.

[0024] On the other hand, in a case where the Si content is more than 0.30%, striped Si scale is generated on the surface of the steel sheet, and the surface properties are impaired. Furthermore, the chemical convertibility of the hot rolled steel sheet deteriorates. Therefore, the Si content is set to 0.30% or less. The Si content is preferably 0.25% or less.

Mn: 1.40% to 2.50%

[0025] Mn is an effective element for the strength as a solid solution strengthening element. In a case where the Mn content is less than 1.40%, it becomes difficult to obtain a desired strength in the hot rolled steel sheet. Therefore, the Mn content is set to 1.40% or more. The Mn content is preferably set to 1.60% or more, or 1.80% or more.

[0026] On the other hand, in a case where the Mn content is more than 2.50%, the ductility decreases, and thus the press formability of the hot rolled steel sheet deteriorates. Therefore, the Mn content is set to 2.50% or less. The Mn content is preferably 2.30% or less, or 2.00% or less.

P: 0.05% or less

[0027] P is an element that is segregated at grain boundaries and decreases the ductility, thereby deteriorating the press formability of the hot rolled steel sheet. Since this action is significant in a case where the P content is more than 0.05%, the P content is set to 0.05% or less.

[0028] The P content is preferably as low as possible, and may thus be set to 0%. However, from the viewpoint of suppressing refining costs, the P content may be set to 0.001 % or more.

S: 0.05% or less

[0029] S is an element that forms MnS and acts as the origin of fracture, which deteriorates hole expansibility, and thus deteriorates the press formability of the hot rolled steel sheet. Since this action is significant in a case where the S content is more than 0.05%, the S content is set to 0.05% or less.

[0030] The S content is preferably as low as possible, and may thus be set to 0%. However, from the viewpoint of suppressing refining costs, the S content may be set to 0.001 % or more.

N: 0.010% or less

[0031] N is an element that forms a nitride with Ti and reduces the amount of Ti that can bond with C, thereby decreasing the strength of the hot rolled steel sheet. In addition, N is an element that forms coarse TiN and deteriorates punching workability. Since these actions are significant in a case where the N content is more than 0.010%, the N content is set to 0.010% or less.

[0032] The N content is preferably as low as possible, and may thus be set to 0%. However, from the viewpoint of suppressing refining costs, the N content may be set to 0.001 % or more.

O: 0.010% or less

[0033] O is an element that forms a coarse oxide serving as the origin of fracture when contained in a large amount in the steel, and deteriorates press formability. Since this action is significant in a case where the O content is more than 0.010%, the O content is set to 0.010% or less. The O content is preferably 0.008% or less, or 0.006% or less.

[0034] The O content is preferably as low as possible, and may thus be set to 0%. However, from the viewpoint of suppressing refining costs, the O content may be set to 0.001 % or more.

Al: 0.001 % to 0.050%

[0035] Al is an effective element as a deoxidizing material. In a case where the Al content is less than 0.001%, molten steel cannot be sufficiently deoxidized. Therefore, the Al content is set to 0.001% or more. The Al content is preferably set to 0.010% or more, or 0.020% or more.

[0036] On the other hand, in a case where the Al content is more than 0.050%, the amount of non-metallic inclusions increases and the ductility decreases, so that the press formability deteriorates. Therefore, the Al content is set to 0.050% or less. The Al content is preferably 0.040% or less.

Ti: 0.060% to 0.150%

[0037] Ti is an effective element for obtaining a strength in the hot rolled steel sheet by refining crystal grains and precipitating fine TiC. In a case where the Ti content is less than 0.060%, it becomes difficult to obtain a desired strength. Therefore, the Ti content is set to 0.060% or more. The Ti content is preferably set to 0.080% or more, or 0.100% or more.

[0038] On the other hand, in a case where the Ti content is more than 0.150%, a large amount of TiC is generated and the ductility decreases, so that the press formability of the hot rolled steel sheet deteriorates. Furthermore, a large amount of TiN is generated, and thus the punching workability decreases. Therefore, the Ti content is set to 0.150% or less. The Ti content is preferably 0.145% or less, 0.140% or less, or 0.135% or less.

Nb: 0.020% to 0.100%

[0039] Nb is an effective element for obtaining a strength by refining crystal grains and precipitating fine NbC, like Ti. In a case where the Nb content is less than 0.020%, it becomes difficult to obtain a desired strength in the hot rolled steel sheet. Therefore, the Nb content is set to 0.020% or more. The Nb content is preferably 0.030% or more, or 0.050% or more.

[0040] On the other hand, in a case where the Nb content is more than 0.100%, a large amount of NbC is generated and the ductility decreases, so that the press formability of the hot rolled steel sheet deteriorates. Therefore, the Nb content is set to 0.100% or less. The Nb content is preferably 0.090% or less, or 0.080% or less.

V: 0% to 0.200%

[0041] V is an effective element for increasing the strength of the hot rolled steel sheet by precipitating fine VC. The V content may be 0%. However, in order to sufficiently obtain the effect, the V content is preferably set to 0.001% or more. The V content is more preferably 0.005% or more, or 0.010% or more.

[0042] On the other hand, in a case where the V content is more than 0.200%, a large amount of VC may be generated, and the amount of solid solution carbon may be reduced. Therefore, the V content is set to 0.200% or less. The V content is preferably 0.150% or less, or 0.100% or less.

Mo: 0% to 1.000%

[0043] Mo is an effective element for increasing the strength of the hot rolled steel sheet by increasing the hardenability of the steel. The Mo content may be 0%. However, in order to sufficiently obtain the effect, the Mo content is preferably set to 0.001% or more. The Mo content is more preferably 0.005% or more, or 0.010% or more.

[0044] On the other hand, in a case where the Mo content is set to more than 1.000%, the above effect is saturated, which is not preferable economically. Therefore, the Mo content is set to 1.000% or less. The Mo content is preferably 0.800% or less, or 0.600% or less.

Ca: 0% to 0.0100%

[0045] Ca is an effective element for increasing the press formability by controlling the morphology of non-metallic inclusions that serve as the origin of fracture and cause a deterioration in workability. The Ca content may be 0%. However, in order to sufficiently obtain the effect, the Ca content is preferably set to 0.0001% or more. The Ca content is more preferably 0.0005% or more, or 0.0010% or more.

[0046] On the other hand, in a case where the Ca content is set to more than 0.0100%, the above effect is saturated,

which is not preferable economically. Therefore, the Ca content is set to 0.0100% or less. The Ca content is preferably 0.0080% or less, or 0.0060% or less.

REM: 0% to 0.0100%

[0047] REM is an effective element for increasing the press formability by controlling the morphology of non-metallic inclusions that serve as the origin of fracture and cause a deterioration in workability, like Ca. The REM content may be 0%. However, in order to sufficiently obtain the effect, the REM content is preferably set to 0.0001 % or more. The REM content is more preferably 0.0005% or more, or 0.0010% or more.

[0048] On the other hand, in a case where the REM content is set to more than 0.0100%, the above effect is saturated, which is not preferable economically. Therefore, the REM content is set to 0.0100% or less. The REM content is preferably 0.0080% or less, or 0.0060% or less.

[0049] 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 industrially added in the form of misch metal.

Cu: 0% to 2.00%

[0050] Cu is an effective element for increasing the strength of the hot rolled steel sheet by increasing the hardenability of the steel. The Cu content may be 0%. However, in order to sufficiently obtain the effect, the Cu content is preferably set to 0.01% or more. The Cu content is more preferably 0.05% or more, or 0.10% or more.

[0051] On the other hand, in a case where the Cu content is set to more than 2.00%, the above effect is saturated, which is not preferable economically. Therefore, the Cu content is set to 2.00% or less. The Cu content is preferably 1.80% or less, or 1.60% or less.

Ni: 0% to 1.50%

[0052] Ni is an effective element for increasing the strength of the hot rolled steel sheet by increasing the hardenability. The Ni content may be 0%. However, in order to sufficiently obtain the effect, the Ni content is preferably set to 0.01% or more. The Ni content is more preferably 0.05% or more, or 0.10% or more.

[0053] On the other hand, in a case where the Ni content is set to more than 1.50%, the above effect is saturated, which is not preferable economically. Therefore, the Ni content is set to 1.50% or less. The Ni content is preferably 1.30% or less, or 1.10% or less.

Cr: 0% to 2.00%

[0054] Cr is an effective element for increasing the strength of the hot rolled steel sheet by increasing the hardenability. The Cr content may be 0%. However, in order to sufficiently obtain the effect, the Cr content is preferably set to 0.01% or more. The Cr content is more preferably 0.05% or more, or 0.10% or more.

[0055] On the other hand, in a case where the Cr content is set to more than 2.00%, the above effect is saturated, which is not preferable economically. Therefore, the Cr content is set to 2.00% or less. The Cr content is preferably 1.80% or less, or 1.60% or less.

Mg: 0% to 0.0200%

[0056] Mg is an element that increases the yield ratio of the hot rolled steel sheet by controlling the shape of inclusions in the steel to a preferable shape. The Mg content may be 0%. However, in order to sufficiently obtain the effect, the Mg content is preferably set to 0.0001% or more. The Mg content is more preferably 0.0005% or more, or 0.0010% or more.

[0057] On the other hand, in a case where the Mg content is more than 0.0200%, inclusions are excessively generated in the steel, and the yield ratio of the hot-rolled steel sheet decreases. Therefore, the Mg content is set to 0.0200% or less. The Mg content is preferably 0.0150% or less, or 0.0100% or less.

Bi: 0% to 0.0200%

[0058] Bi is an element that increases the yield ratio of the hot rolled steel sheet by refining the solidification structure. The Bi content may be 0%. However, in order to sufficiently obtain the effect, the Bi content is preferably set to 0.001% or more. The Bi content is more preferably 0.0005% or more, or 0.0010% or more.

[0059] On the other hand, in a case where the Bi content is more than 0.0200%, the effect obtained by the action is

saturated, which is not preferable economically. Therefore, the Bi content is set to 0.0200% or less. The Bi content is preferably 0.0150% or less, or 0.0100% or less.

Zr: 0% to 0.500%

[0060] Zr is an element that increases the strength of the hot rolled steel sheet by solid solution strengthening. The Zr content may be 0%. However, in order to sufficiently obtain the effect, the Zr content is preferably set to 0.001% or more. The Zr content is more preferably 0.005% or more, or 0.010% or more.

[0061] On the other hand, in a case where the Zr content is more than 0.500%, the hole expansibility of the hot rolled steel sheet deteriorates, and thus the press formability deteriorates. Therefore, the Zr content is set to 0.500% or less. The Zr content is preferably 0.400% or less, or 0.300% or less.

Co: 0% to 1.000%

[0062] Co is an element that increases the strength of the hot rolled steel sheet by solid solution strengthening. The Co content may be 0%. However, in order to sufficiently obtain the effect, the Co content is preferably set to 0.001% or more. The Co content is more preferably 0.005% or more, or 0.010% or more.

[0063] On the other hand, in a case where the Co content is more than 1.000%, the hole expansibility of the hot rolled steel sheet deteriorates, and thus the press formability deteriorates. Therefore, the Co content is set to 1.000% or less. The Co content is preferably 0.800% or less, or 0.600% or less.

Zn: 0% to 0.200%

[0064] Zn is an element that increases the strength of the hot rolled steel sheet by solid solution strengthening. The Zn content may be 0%. However, in order to sufficiently obtain the effect, the Zn content is preferably set to 0.001% or more. The Zn content is more preferably 0.005% or more, or 0.010% or more.

[0065] On the other hand, in a case where the Zn content is more than 0.200%, the hole expansibility of the hot rolled steel sheet deteriorates, and thus the press formability deteriorates. Therefore, the Zn content is set to 0.200% or less. The Zn content is preferably 0.150% or less, or 0.100% or less.

W: 0% to 0.200%

[0066] W is an element that increases the strength of the hot rolled steel sheet by solid solution strengthening. The W content may be 0%. However, in order to sufficiently obtain the effect, the W content is preferably set to 0.001% or more. The W content is more preferably 0.005% or more, or 0.010% or more.

[0067] On the other hand, in a case where the W content is more than 0.200%, the hole expansibility of the hot rolled steel sheet deteriorates, and thus the press formability deteriorates. Therefore, the W content is set to 0.200% or less. The W content is preferably 0.150% or less, or 0.100% or less.

Sb: 0% to 0.200%

[0068] Sb is an element that increases the hole expansibility of the hot rolled steel sheet by suppressing the generation of an oxide that serves as the origin of fracture. The Sb content may be 0%. However, in order to sufficiently obtain the effect, the Sb content is preferably set to 0.001% or more. The Sb content is more preferably 0.005% or more, or 0.010% or more.

[0069] On the other hand, the effect is saturated even in a case where a large amount of Sb is contained. Therefore, the Sb content is set to 0.200% or less. The Sb content is preferably 0.150% or less, or 0.100% or less.

As: 0% to 0.050%

[0070] As is an element that increases the hole expansibility of the hot rolled steel sheet by refining prior austenite grains by lowering an austenitizing temperature. The As content may be 0%. However, in order to sufficiently obtain the effect, the As content is preferably set to 0.001% or more. The As content is more preferably 0.005% or more, or 0.010% or more.

[0071] On the other hand, the effect is saturated even in a case where a large amount of As is contained. Therefore, the As content is set to 0.050% or less. The As content is preferably 0.030% or less, or 0.020% or less.

Sn: 0% to 0.050%

[0072] Sn is an element that increases the hole expansibility of the hot rolled steel sheet by suppressing the generation of an oxide that serves as the origin of fracture. The Sn content may be 0%. However, in order to sufficiently obtain the effect, the Sn content is preferably set to 0.001% or more. The Sn content is more preferably 0.005% or more, or 0.010% or more.

[0073] On the other hand, the effect is saturated even in a case where a large amount of Sn is contained. Therefore, the Sn content is set to 0.050% or less. The Sn content is preferably 0.030% or less, or 0.020% or less.

B: less than 0.0005%

[0074] In the chemical composition of the hot rolled steel sheet according to the present embodiment, B is not substantially contained, and thus the B content is set to less than 0.0005%. Since the B content is preferably as low as possible from the viewpoint of ensuring the strength of the hot rolled steel sheet, the B content is preferably set to 0.0004% or less, less than 0.0004%, 0.0003% or less, 0.0002% or less, or less than 0.0002%.

Value A: 0.0150 mass% or more

[0075] In the chemical composition, in a case where a value A (calculated amount of unprecipitated carbon) represented by Expression (1) is less than 0.0150 mass%, the amount of solid solution carbon is insufficient, a BH amount cannot be sufficiently increased, and desired press formability cannot be obtained in the hot rolled steel sheet. Therefore, the value A is set to 0.0150 mass% or more. The value A is preferably set to 0.0200 mass% or more, 0.0250 mass% or more, or 0.0300 mass% or more.

[0076] The upper limit of the value A is not particularly limited, and may be set to 1.0000 mass% or less, 0.0800 mass% or less, or 0.0750 mass% or less.

$$\text{Value A} = \text{C} - \text{Ti}/4 + \text{N}/1.17 - \text{Nb}/7.75 - \text{V}/4.25 \quad (1)$$

[0077] Each element symbol in Expression (1) represents the corresponding element content by mass%, and 0% is substituted in a case where the corresponding element is not contained.

Value M: 930 or less

[0078] In a case where a value M represented by Expression (2) is more than 930, the ferrite generating ability increases, and thus it is not possible to obtain a desired amount of bainite. As a result, the hole expansibility deteriorates, and thus the press formability of the hot rolled steel sheet deteriorates. Therefore, the value M is set to 930 or less. The value M is preferably 920 or less, 910 or less, or 900 or less.

$$\text{Value M} = 937 - 436.5 \times \text{C} + 56 \times \text{Si} - 19.7 \times \text{Mn} - 16.3 \times \text{Cu} - 26.6 \times \text{Ni} - 4.9 \times \text{Cr} + 38.1 \times \text{Mo} + 124.8 \times \text{V} + 136.3 \times \text{Ti} - 19.1 \times \text{Nb} + 198.4 \times \text{Al} \quad (2)$$

[0079] Each element symbol in Expression (2) represents the corresponding element content by mass%, and 0% is substituted in a case where the corresponding element is not contained.

[0080] In a case where the chemical composition of the hot rolled steel sheet contains 0.0005% or more of B, Expression (2') with a term for B is preferably used instead of Expression (2). If necessary, Expression (2') may be used instead of Expression (2) in a case where B is contained in an amount of 0.0001% or more, 0.0002% or more, 0.0003% or more, or 0.0004% or more.

$$\text{Value M} = 937 - 436.5 \times \text{C} + 56 \times \text{Si} - 19.7 \times \text{Mn} - 16.3 \times \text{Cu} - 26.6 \times \text{Ni} - 4.9 \times \text{Cr} + 38.1 \times \text{Mo} + 124.8 \times \text{V} + 136.3 \times \text{Ti} - 19.1 \times \text{Nb} + 198.4 \times \text{Al} + 3315 \times \text{B} \quad (2')$$

[0081] Each element symbol in Expression (2') represents the corresponding element content by mass%, and 0% is substituted in a case where the corresponding element is not contained.

[0082] The hot rolled steel sheet according to the present embodiment may contain the above elements, and a remainder of Fe and impurities. In the present embodiment, the impurities mean substances incorporated from ore as a raw material, scrap, production environment, or the like and/or substances permitted to an extent that the properties (strength, press formability, and punching workability) of the hot rolled steel sheet according to the present embodi-

ment are not adversely affected.

[0083] The above-described chemical composition of the hot rolled steel sheet may be analyzed using a spark discharge emission spectrophotometer or the like. For C and S, values identified by burning the hot rolled steel sheet in an oxygen stream using a gas component analyzer or the like and measuring C and S by an infrared absorption method are adopted. In addition, for N, a value identified by melting a test piece collected from the steel sheet in a helium stream and measuring N by a thermal conductivity method is adopted. In addition, for O, a value identified by dissolving a test piece collected from the steel sheet and put in a graphite crucible in a helium stream and measuring O by an infrared absorption method is adopted.

[0084] In a case where the hot rolled steel sheet has a plating layer, a coating film, or the like on the surface thereof, the chemical composition is analyzed after removing the plating layer, the coating film, or the like by mechanical grinding or the like, if necessary.

[0085] Next, a microstructure of the hot rolled steel sheet according to the present embodiment will be described.

[0086] In the hot rolled steel sheet according to the present embodiment, a microstructure in a 1/4 position of the sheet thickness from the surface consists of, by area%, ferrite: 50% or more and less than 80%, bainite: more than 20% and 50% or less, pearlite: 0% to 5%, and MA: 0% to 2%, and an average grain size is 10 μm or less.

[0087] Hereinafter, each requirement will be described.

[0088] In this embodiment, a microstructure in a 1/4 position of the sheet thickness from the surface (a region from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) is specified. In other words, the position is a region which starts from the depth of 1/8 of the sheet thickness from the surface, and ends at the depth of 3/8 of the sheet thickness from the surface.

[0089] The reason for specifying the microstructure at the position is that the above microstructure at the position indicates a representative microstructure of the steel sheet.

[0090] In a case where the hot rolled steel sheet has a plating layer, a coating film, or the like on the surface thereof, the surface mentioned here means an interface between the steel sheet and the plating layer, coating film, or the like.

Ferrite: 50% or more and less than 80%

[0091] In the hot rolled steel sheet according to the present embodiment, fine TiC is precipitated in ferrite grains to obtain a desired strength. In order to obtain the effect, the area ratio of ferrite is set to 50% or more. The area ratio of ferrite is preferably 55% or more, 60% or more, or 65% or more.

[0092] On the other hand, in a case where the area ratio of ferrite is 80% or more, the area ratio of bainite is reduced, the amount of carbon in bainite increases, the hardness of bainite increases, the hole expansibility deteriorates, and the press formability of the hot rolled steel sheet deteriorates. Therefore, the area ratio of ferrite is set to less than 80%. The area ratio of ferrite is preferably 75% or less, or 70% or less.

Bainite: more than 20% and 50% or less

[0093] In a case where the area ratio of bainite is 20% or less, the amount of carbon in bainite increases, the hardness of bainite increases, and the hole expansibility deteriorates. Therefore, desired press formability cannot be obtained in the hot rolled steel sheet. Therefore, the area ratio of bainite is set to more than 20%. The area ratio of bainite is preferably 25% or more, or 30% or more.

[0094] In addition, the area ratio of bainite is set to 50% or less in relation to the area ratio of ferrite. The area ratio of bainite is preferably 45% or less, 40% or less, or 35% or less.

Pearlite: 0% to 5%

[0095] Pearlite is a structure having an inferior strength. In a case where the area ratio of pearlite is more than 5%, the strength of the hot rolled steel sheet decreases. Therefore, the area ratio of pearlite is set to 5% or less. The area ratio of pearlite is preferably 4% or less, 3% or less, 2% or less, or 1% or less.

[0096] The area ratio of pearlite is preferably as small as possible, and is thus preferably 0%.

MA: 0% to 2%

[0097] MA represents a structure including martensite and austenite. MA has high hardness. Therefore, in a case where the area ratio of MA is more than 2%, the hole expansibility deteriorates, and thus the press formability of the hot rolled steel sheet deteriorates. Therefore, the area ratio of MA is set to 2% or less. The area ratio of MA is preferably 1% or less.

[0098] Since MA does not have to be contained, the area ratio of MA may be 0%.

[0099] The area ratio of each structure is measured by the following method.

Method for Measuring Area Ratio of Ferrite

[0100] A test piece is collected from the hot rolled steel sheet so that a cross section perpendicular to the sheet width direction can be observed. The collected test piece is subjected to wet polishing to finish an observation surface to a mirror surface, and the observation surface is polished for 8 minutes at room temperature using colloidal silica containing no alkaline solution to remove the strain introduced into the observation surface. Next, the structure is observed at a 1/4 position of the sheet thickness from the surface (a region from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) using an SEM-EBSD device. As the SEM-EBSD device, a device including a field emission type 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, the degree of vacuum in the device 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.

[0101] A region of $500 \mu\text{m} \times 500 \mu\text{m}$ is set as an observation region, and a step size is set to $0.3 \mu\text{m}$ to obtain crystal orientation information. At least three regions are set as the observation regions. A crystal misorientation is obtained between adjacent measurement points using the obtained crystal orientation information and OIM data analysis, and a region surrounded by a boundary with a crystal misorientation of 15° or more is regarded as a crystal grain. Next, an average value (grain average misorientation, GAM) of the misorientations between the adjacent measurement points is calculated for each crystal grain. Crystal grains with a GAM of 1.0° or less are defined as ferrite, and the area ratio of the crystal grains is obtained to obtain the area ratio of ferrite.

[0102] The ferrite defined by this method does not include ferrite in pearlite.

Method for Measuring Area Ratio of Pearlite

[0103] A test piece is collected in the same manner as in the above-described method, and an observation surface is corroded with Nital so that a microstructure appears. Using an optical microscope, a microstructure photograph is taken. As a photographing position, a 1/4 position of the sheet thickness from the surface (a region from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) is set. As a photographing region, a region of $500 \mu\text{m} \times 500 \mu\text{m}$ is set, and at least three regions are set. Image analysis is performed on the obtained microstructure photograph, and crystal grains etched in black are defined as pearlite. The area ratio of the crystal grains is calculated to obtain the area ratio of pearlite.

[0104] The pearlite etched in black by the above method does not include the ferrite defined using the above-described SEM-EBSD device.

Method for Measuring Area Ratio of MA

[0105] A test piece is collected in the same manner as in the above-described method, and an observation surface is subjected to LePera corrosion so that a microstructure appears. Using an optical microscope, a microstructure photograph is taken. A photographing position and a photographing region are the same as those in the above-described method. Image analysis is performed on the obtained microstructure photograph, and crystal grains etched in white are defined as MA. The area ratio of the crystal grains is calculated to obtain the area ratio of MA.

Method for Measuring Area Ratio of Bainite

[0106] The area ratio of bainite is obtained by subtracting the area ratios of ferrite, pearlite, and MA from 100%.

Average Grain Size: $10 \mu\text{m}$ or less

[0107] In the present embodiment, a desired tensile strength is obtained by utilizing not only precipitation hardening by precipitation of fine TiC but also high-strengthening by refining crystal grains. In a case where the average grain size is more than $10 \mu\text{m}$, the amount of strengthening due to the refinement of crystal grains is reduced, and a desired strength cannot be obtained. Therefore, the average grain size is set to $10 \mu\text{m}$ or less. The average grain size is preferably $8 \mu\text{m}$ or less, $7 \mu\text{m}$ or less, or $6 \mu\text{m}$ or less.

[0108] The lower limit of the average grain size is not particularly limited, and may be set to $2 \mu\text{m}$ or more, or $3 \mu\text{m}$ or more.

[0109] The average grain size of the microstructure is measured by the following method.

[0110] The analysis is performed using crystal orientation information obtained when the area ratio of ferrite is

measured. A region surrounded by a boundary with a crystal misorientation of 15° or more is defined as a crystal grain, and an equivalent circle diameter of the crystal grain is calculated. Equivalent circle diameters of all the crystal grains in an observation region are calculated, and an average value thereof is calculated to obtain the average grain size.

- 5 **[0111]** The equivalent circle diameter is a diameter of a circle having the same area as the area of the specified crystal grain.

BH Amount: 45 MPa or more

- 10 **[0112]** In the present embodiment, carbon generates precipitates necessary to obtain a desired strength, and also has a role of increasing the punching workability by being present in a solid solution state in the steel. The inventors of the present invention found that the amount of solid solution carbon and a BH amount (amount of bake hardening) have a correlation, so that in a case where the BH amount is less than 45 MPa, the amount of solid solution carbon is reduced and desired punching workability cannot be obtained. Therefore, the BH amount is set to 45 MPa or more.

- 15 The BH amount is preferably 55 MPa or more, 60 MPa or more, or 70 MPa or more.

- [0113]** The hot rolled steel sheet according to the present embodiment is a steel sheet related to precipitation-hardening steel, which has a tensile strength of 780 MPa or more. In the present embodiment, the strength is exhibited by dispersing a Ti-based carbide in the steel. In a case where the amount of solid solution carbon in the steel is increased, the BH amount is improved, but the amount of Ti-based carbide precipitated is reduced, and the strength is reduced simultaneously. The inventors of the present invention conducted intensive studies, and as a result, found that the strength of the hot rolled steel sheet is further improved by setting the BH amount to less than 100 MPa. Therefore, the BH amount may be set to less than 100 MPa. The BH amount may be set to 95 MPa or less, 90 MPa or less, 80 MPa or less, or 75 MPa or less.

[0114] The BH amount is measured by the following method.

- 25 **[0115]** A No. 5 test piece is collected from the hot rolled steel sheet in accordance with JIS Z 2241: 2022. The BH amount (amount of bake hardening) is evaluated using the No. 5 test piece collected, in accordance with Annex A of JIS G 3135: 2018.

[0116] More specifically, the BH amount (σ_{BH}) is obtained by the following expression.

30

$$\sigma_{BH} = R_{SA} - R_{WH}$$

- [0117]** Here, R_{SA} represents a value (N/mm²) obtained by dividing a test force at a yield point of a test piece heat-treated under the following conditions after giving 2% total elongation by an original cross-section area of a parallel portion of the test piece before pre-strain.

Heat treatment conditions: heating to 170°C for 20 minutes, and then air cooling

- 40 **[0118]** In addition, R_{WH} represents a value (N/mm²) obtained by dividing a test force when a total elongation is 2% in the tensile test by an original cross-section area of a parallel portion of the test piece before pre-strain. The tensile test is performed in accordance with JIS Z 2241: 2022.

[0119] Maximum Value of Pole Density of Orientation Group Expressed by Euler Angles of $\Phi = 0^\circ$ to 90° , $\phi_1 = 0^\circ$ to 90° , and $\phi_2 = 45^\circ$ in Microstructure from Surface to Depth of 500 μm from Surface: 7.0 or less

- 45 **[0120]** The inventors of the present invention performed punching on a high strength hot rolled steel sheet having a tensile strength of 780 MPa or more, and observed an end surface of a punching hole. As a result, they found that the end surface properties were more inferior in a surface (L cross section) parallel to the rolling direction and the sheet thickness direction than in a surface (C cross section) perpendicular to the rolling direction. The inventors of the present invention thought that this is due to the anisotropy of the crystal orientation of the hot rolled steel sheet, and intensively studied the relationship between the texture during hot rolling and the end surface properties. As a result, they found that, in a case where the maximum value of a pole density of an orientation group expressed by the Euler angles of $\Phi = 0^\circ$ to 90° , $\phi_1 = 0^\circ$ to 90° , and $\phi_2 = 45^\circ$ is set to 7.0 or less in a microstructure from a surface to a depth of 500 μm from the surface, the deterioration of the end surface properties of the punching can be suppressed. Therefore, in order to further improve the punching workability, the maximum value of the pole density is preferably set to 7.0 or less. The maximum value of the pole density is more preferably 6.7 or less, or 6.5 or less. The lower limit of the maximum value of the pole density is not particularly limited, and may be set to 5.5 or more, or 6.0 or more.

- 55 **[0121]** The maximum value of the pole density is measured by the following method.

[0122] A sample is collected so that a microstructure can be observed in a cross section (sheet thickness direction $\times$

rolling direction) where the sheet width direction of the hot rolled steel sheet is a normal direction. The sample size depends on the measurement device, but for example, the sample may be a rectangular parallelepiped of full thickness in the sheet thickness direction, 15 mm in the rolling direction, and 10 mm in the width direction. Next, an observation surface of the sample is mirror-polished, and then polished for 8 minutes at room temperature using colloidal silica containing no alkaline solution to remove the strain introduced into the observation surface of the sample. A region from the surface (surface of the steel sheet) of the sample after the polishing to a depth of 500 μm in the sheet thickness direction and a region of 2000 μm or more at any position in the rolling direction are measured at a measurement interval of 5.0 μm .

[0123] For the measurement, an EBSD device in which a scanning electron microscope and an EBSD analyzer are combined and OIM Analysis (registered trademark) manufactured by TSL Solutions are used. The sample is analyzed by an electron back scattering diffraction (EBSD) method. A crystal orientation distribution function (ODF) is calculated from the obtained data. From the obtained crystal orientation distribution function, the maximum value of the pole density of the orientation group expressed by the Euler angles of $\Phi = 0^\circ$ to 90° , $\varphi_1 = 0^\circ$ to 90° , and $\varphi_2 = 45^\circ$ is obtained.

Tensile Strength (TS): 780 MPa or more

[0124] The hot rolled steel sheet according to the present embodiment has a tensile strength of 780 MPa or more. In a case where the tensile strength is less than 780 MPa, the effect of reducing the weight of a vehicle body is small, and the steel sheet cannot be suitably applied to a suspension component of a vehicle. The tensile strength is more preferably 800 MPa or more, or 820 MPa or more.

[0125] The upper limit of the tensile strength does not need to be particularly limited, and may be set to 1000 MPa or less, or 900 MPa or less.

[0126]

Total Elongation (EI): 14% or more

Hole Expansion Ratio (λ): 40% or more

[0127] The total elongation may be 14% or more, and the hole expansion ratio may be 40% or more. In a case where the total elongation is 14% or more and the hole expansion ratio is 40% or more, it can be determined that the press formability is excellent.

[0128] The total elongation is a "percentage total extension at fracture" described in JIS Z 2241: 2022.

[0129] In addition, the yield point (YP) may be set to 700 MPa or more.

[0130] The tensile strength, the total elongation, and the yield point are obtained by collecting a No. 5 test piece in accordance with JIS Z 2241: 2022 and performing a tensile test in accordance with JIS Z 2241: 2022. In the tensile test piece, a direction perpendicular to the rolling direction is set as a longitudinal direction.

[0131] In the present embodiment, the rolling direction is determined by the following method, except in a case where the rolling direction is known in advance.

[0132] A test piece is collected from any position 50 mm or more away from an end portion of the hot rolled steel sheet so that a sheet thickness cross section can be observed. The sheet thickness cross section of the collected test piece is finished by mirror polishing, and then observed at magnifications of 100 times, 200 times, 500 times, and 1000 times using an optical microscope. An observation result at an appropriate magnification at which the dimensions of inclusions can be measured is selected according to the dimensions of the inclusions. As an observation range, a range having a width of 500 μm or more in the overall sheet thickness is set, and a region having a low luminance is determined as an inclusion. During the observation, the observation may be performed in a plurality of visual fields. Next, using the sheet thickness cross section initially observed by the above-described method as a reference, a cross section parallel to a surface rotated in increments of 5° in a range of 0° to 180° about the sheet thickness direction as an axis is observed in the same manner as in the above description. An average value of the lengths of the major axes of a plurality of inclusions in each cross section is calculated for each cross section. A cross section where the obtained average value of the lengths of the major axes of the inclusions is maximum is specified. A direction parallel to the long axis direction of the inclusions in the cross section is determined as the rolling direction.

[0133] The hole expansion ratio is measured by performing a hole expansion test according to JIS Z 2256: 2020. More specifically, first, a hole is punched at the center of a test piece by a 10 mm-diameter punch, and a 60° -conical punch is pressed into the hole. The 60° -conical punch is pressed until a crack generated at the edge of the hole of the test piece penetrates through the thickness direction. The hole expansion ratio is obtained by calculating a ratio of the amount of expansion of the hole diameter when the crack penetrates through the thickness direction to the initial hole diameter (10 mm-diameter punched hole).

Punching Workability

[0134] The hot rolled steel sheet according to the present embodiment is preferably excellent in punching workability to be evaluated below.

[0135] A test piece collected from the hot rolled steel sheet is punched at three points using a 12 mm ϕ -punch under a condition of a clearance of 20%. The length of a crack (peeling-off) generated in a direction perpendicular to the sheet thickness direction is measured around the whole circumference of each punching hole. As for the three punching holes, the sum of the lengths of cracks exceeding 2 mm (total length of cracks) is obtained. In a case where a value (total length of cracks/sum of whole circumferences $\times$ 100) obtained by dividing the above sum by the sum (113 mm) of the whole circumferences of the three punching holes is 20% or less, it can be determined that the punching workability is excellent.

[0136] The sheet thickness of the hot rolled steel sheet according to the present embodiment is not particularly limited, and may be set to 2.0 to 8.0 mm. By setting the sheet thickness of the hot rolled steel sheet to 2.0 mm or more, it is possible to suppress the rolling force becoming excessive and to suppress the difficulty in performing hot rolling.

[0137] In addition, by setting the sheet thickness to 8.0 mm or less, the above-described microstructure can be stably obtained after hot rolling.

[0138] The hot rolled steel sheet according to the present embodiment may be a surface-treated steel sheet having 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 aluminizing, hot-dip Zn-Al alloy plating, hot-dip Zn-Al-Mg alloy plating, and hot-dip Zn-Al-Mg-Si alloy plating. The plating adhesion amount is not particularly limited, and may be the same as before.

[0139] In addition, it is also possible to further increase the corrosion resistance by performing an appropriate chemical conversion treatment (for example, application and drying of a silicate-based chromium-free chemical conversion treatment liquid) after plating.

[0140] Next, a preferable producing method of the hot rolled steel sheet according to the present embodiment will be described. According to the producing method to be described below, the hot rolled steel sheet according to the present embodiment can be stably produced. The temperature of a slab and the temperature of a steel sheet in the present embodiment refer to the surface temperature of the slab and the surface temperature of the steel sheet.

[0141] A preferable producing method of the hot rolled steel sheet according to the present embodiment includes:

heating a slab having the above-described chemical composition in a temperature range of 1230°C or higher;
performing hot rolling so that a finish rolling finishing temperature is in a temperature range of 880°C to 980°C;
performing cooling to a temperature range of 650°C to 750°C at an average cooling rate of 50 °C/s or faster;
performing air cooling in the temperature range of 650°C to 750°C for 3.0 to 10.0 seconds after the cooling;
performing cooling to a temperature range of 470°C to 530°C at an average cooling rate of 50 °C/s or faster after the air cooling; and
performing coiling in a temperature range of 470°C to 530°C after the cooling.

[0142] Hereinafter, each step will be described.

[0143] The slab is preferably heated in a temperature range of 1,230°C or higher to solutionize the coarse TiC precipitated in the casting step. In a case where the heating temperature is lower than 1,230°C, the amount of coarse TiC may be increased, a sufficient amount of fine TiC may not be obtained, and the strength of the hot rolled steel sheet may decrease.

[0144] The slab to be heated is not particularly limited except that the slab has the above-described chemical composition. For example, a slab produced by melting molten steel having the above chemical composition using a converter or an electric furnace and performing a continuous casting method thereon can be used. Instead of the continuous casting method, an ingot-making method, a thin slab casting method, or the like may be adopted.

[0145] In order to obtain a desired average grain size and a desired area ratio of ferrite and to obtain a desired strength, the finish rolling finishing temperature (exit-side temperature in the final stage of finish rolling) is preferably in a temperature range of 880°C to 980°C. In a case where the finish rolling finishing temperature is lower than 880°C, the ferrite generating ability excessively increases, and coarse ferrite is generated in a high temperature range. Therefore, a desired average grain size may not be obtained, and the strength of the hot rolled steel sheet may decrease.

[0146] On the other hand, in a case where the finish rolling finishing temperature is higher than 980°C, the ferrite generating ability decreases, and the generation of ferrite during air cooling is suppressed. Therefore, the strength of the hot rolled steel sheet may decrease.

[0147] In a microstructure from a surface to a depth of 500 μ m from the surface, in order to preferably control the

maximum value of the pole density, the start temperature and the finish temperature of finish rolling, the total rolling reduction at the true strain in a temperature range of 930°C or higher, and the total rolling reduction at the true strain in all stages of the finish rolling are preferably strictly controlled. More specifically, it is preferable that the start temperature (entry-side temperature in the first stage) of finish rolling is set to a temperature range of 1000°C or higher, the finish temperature (exit-side temperature in the final stage) is set to a temperature range of 880°C or higher, the total rolling reduction at the true strain in a temperature range of 930°C or higher is set to 1.5 or more, and the total rolling reduction at the true strain in all stages of the finish rolling is set to 3.0 or less.

[0148] A rolling reduction ε at the true strain is represented by the following expression. The total rolling reduction in a case where the rolling is performed in a plurality of stages can be obtained by obtaining the sum of ε in each stage.

$$\varepsilon = |\ln(h_1/h_2)|$$

[0149] In the expression, $\ln$ represents the natural logarithm to base e, h_1 represents a sheet thickness (mm) before rolling, and h_2 represents a sheet thickness (mm) after rolling.

[0150] After the finish rolling, cooling is preferably performed to a temperature range of 650°C to 750°C at an average cooling rate of 50 °C/s or faster. In a case where the average cooling rate up to the above temperature range is slower than 50 °C/s, coarse ferrite is generated during cooling, a desired average grain size may not be obtained, and the strength of the hot rolled steel sheet may decrease.

[0151] In the present embodiment, the average cooling rate is a value obtained by dividing a temperature difference between a start point and an end point in a set range by an elapsed time from the start point to the end point.

[0152] After the cooling, air cooling is preferably performed in the temperature range of 650°C to 750°C for 3.0 to 10.0 seconds. By performing the air cooling under these conditions, a desired amount of ferrite can be generated. In a case where the temperature at which the air cooling is performed is lower than 650°C, a large amount of pearlite may be generated, and the strength of the hot rolled steel sheet may decrease.

[0153] On the other hand, in a case where the temperature at which the air cooling is performed is higher than 750°C, the rate of ferrite generation may be reduced, a desired amount of ferrite may not be obtained, and the strength of the hot rolled steel sheet may decrease.

[0154] In the present embodiment, the air cooling refers to cooling at an average cooling rate of slower than 10 °C/s.

[0155] In a case where the air cooling time is shorter than 3.0 seconds, ferrite may not be sufficiently generated, and the strength of the hot rolled steel sheet may decrease.

[0156] On the other hand, in a case where the air cooling time is longer than 10.0 seconds, ferrite may be excessively generated, and a desired amount of bainite may not be obtained.

[0157] After the air cooling, cooling is preferably performed to a temperature range of 470°C to 530°C at an average cooling rate of 50 °C/s or faster. In a case where the average cooling rate after the air cooling is slower than 50 °C/s, a large amount of pearlite may be generated during cooling, and the strength of the hot rolled steel sheet may decrease.

[0158] In order to make the BH amount less than 100 MPa, the average cooling rate up to the temperature range of 470°C to 530°C after the air cooling is preferably set to 85 °C/s or slower.

[0159] The coiling temperature is preferably set to a temperature range of 470°C to 530°C in order to control the transformation and the state of precipitates after coiling and to obtain desired press formability and punching workability. In a case where the coiling temperature is lower than 470°C, MA may be generated in a large amount after coiling, and desired press formability may not be obtained.

[0160] On the other hand, in a case where the coiling temperature is higher than 530°C, the amount of solid solution carbon in the steel may be reduced due to the coarsened carbide, the BH amount may be reduced, and thus desired punching workability may not be obtained.

Examples

[0161] Next, the effects of one aspect of the present invention will be described in more detail using examples. However, conditions in the examples are merely exemplary to confirm the feasibility and the effects of the present invention, and the present invention is not limited to these condition examples. The present invention can adopt various conditions as long as the object of the present invention is achieved without departing from the gist of the present invention.

[0162] Slabs each having the chemical composition shown in Tables 1A to 2B were obtained by performing converter melting and continuous casting. Using the obtained slabs, hot rolled steel sheets having a sheet thickness of 2.6 to 3.2 mm were obtained under the conditions shown in Tables 3A and 3B.

[0163] In Tables 3A and 3B, the "total rolling reduction at 930°C or higher" is a total rolling reduction in a temperature range of 930°C or higher, expressed in true strain, and the "total rolling reduction" is a total rolling reduction in all

stages of finish rolling, expressed in true strain.

[0164] As for the obtained hot rolled steel sheets, the microstructure, the BH amount, the maximum value of a pole density, the tensile strength, the total elongation, the yield point, the hole expansion ratio, and the punching workability were evaluated by the above-described methods. In the examples, the rolling direction was known in advance, and thus the above-described determination of the rolling direction was not performed.

[0165] The obtained results are shown in Tables 4A and 4B.

[0166] In Tables 4A and 4B, the "maximum value of pole density" is the maximum value of a pole density of an orientation group expressed by the Euler angles of $\Phi = 0^\circ$ to 90° , $\varphi_1 = 0^\circ$ to 90° , and $\varphi_2 = 45^\circ$ in a microstructure from a surface to a depth of 500 μm from the surface.

[0167] In a case where the tensile strength was 780 MPa or more, the steel sheet was deemed to have a high strength and determined to be acceptable. On the other hand, in a case where the tensile strength was less than 780 MPa, the steel sheet was deemed to have no high strength and determined to be unacceptable.

[0168] In a case where the total elongation was 14% or more and the hole expansion ratio was 40% or more, the steel sheet was deemed to have excellent press formability and determined to be acceptable. On the other hand, in a case where any one of both was not satisfied, the steel sheet was deemed to have no excellent press formability and determined to be unacceptable.

[0169] In the above-described punching workability evaluation, the evaluation was performed based on the following criteria according to the value of total length of cracks/whole circumference length $\times 100$. In a case where the evaluation result was Fair or higher, that is, the value was 20% or less, the steel sheet was deemed to have excellent punching workability and determined to be acceptable. In a case where the evaluation result was Poor, the steel sheet was deemed to have no excellent punching workability and determined to be unacceptable.

Less than 1%: Excellent

1% or more and less than 10%: Good

More than 10% and 20% or less: Fair

More than 20%: Poor

[Table 1A]

Steel Type	Chemical Composition (mass%), Remainder being Fe and Impurities												
	C	Si	Mn	P	S	N	O	Al	Ti	Nb	B	Value A	Value M
A	0.09	0.20	1.80	0.03	0.03	0.004	0.003	0.025	0.102	0.042	0.0002	0.0625	892
B	0.04	0.15	2.00	0.02	0.04	0.010	0.001	0.050	0.081	0.021	0.0002	0.0256	909
C	0.06	0.30	2.30	0.02	0.03	0.001	0.005	0.010	0.133	0.083		0.0189	900
D	0.10	0.11	1.40	0.05	0.01	0.006	0.004	0.022	0.150	0.100	0.0001	0.0547	895
E	0.07	0.25	1.60	0.01	0.05	0.008	0.005	0.040	0.066	0.066	0.0003	0.0478	906
F	0.09	0.25	1.50	0.03	0.03	0.003	0.008	0.010	0.124	0.088	0.0002	0.0502	899
G	0.05	0.15	1.60	0.02	0.04	0.005	0.006	0.024	0.113	0.033	0.0003	0.0218	912
H	0.07	0.20	1.96	0.02	0.03	0.003	0.003	0.036	0.124	0.041		0.0363	902
I	0.08	0.13	1.84	0.05	0.04	0.004	0.007	0.010	0.071	0.052	0.0001	0.0590	884
J	0.07	0.18	1.75	0.01	0.03	0.005	0.004	0.032	0.066	0.023	0.0003	0.0508	899
K	0.05	0.18	1.60	0.03	0.01	0.007	0.004	0.040	0.102	0.036		0.0258	915
L	0.04	0.29	2.50	0.04	0.05	0.004	0.002	0.050	0.083	0.055	0.0002	0.0156	907
M	0.04	0.20	2.43	0.03	0.02	0.009	0.005	0.020	0.063	0.091	0.0001	0.0202	894
N	0.10	0.30	1.90	0.01	0.05	0.010	0.005	0.030	0.096	0.098	0.0002	0.0248	915
O	0.08	0.15	2.50	0.05	0.01	0.005	0.006	0.010	0.141	0.033	0.0002	0.0418	921
P	0.05	0.20	2.02	0.02	0.03	0.008	0.004	0.030	0.147	0.021	0.0002	0.0184	912

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(continued)

Steel Type	Chemical Composition (mass%), Remainder being Fe and Impurities												
	C	Si	Mn	P	S	N	O	Al	Ti	Nb	B	Value A	Value M
Q	0.07	0.30	2.20	0.05	0.02	0.010	0.006	0.046	0.133	0.027		0.0368	909
R	0.09	0.23	1.40	0.01	0.04	0.002	0.005	0.050	0.084	0.087	0.0003	0.0565	871
S	0.10	0.25	1.70	0.03	0.03	0.006	0.003	0.040	0.075	0.096	0.0002	0.0700	852
T	0.04	0.11	1.40	0.04	0.01	0.001	0.010	0.001	0.066	0.021	0.0003	0.0236	896

[Table 1B]

Steel Type	Chemical Composition (mass%), Remainder being Fe and Impurities												
	C	Si	Mn	P	S	N	O	Al	Ti	Nb	B	Value A	Value M
a	<u>0.03</u>	0.12	2.30	0.02	0.03	0.008	0.006	0.025	0.063	0.023	0.0001	0.0181	898
b	<u>0.12</u>	0.15	2.40	0.03	0.01	0.005	0.006	0.040	0.091	0.035	0.0002	0.0970	865
c	0.05	<u>0.09</u>	2.00	0.02	0.04	0.008	0.003	0.050	0.102	0.044		0.0257	904
d	0.09	0.25	<u>1.00</u>	0.02	0.05	0.002	0.007	0.026	0.077	0.086	0.0003	0.0614	906
e	0.07	0.24	<u>2.80</u>	0.03	0.03	0.003	0.002	0.032	0.132	0.061		0.0317	888
f	0.10	0.16	1.93	<u>0.10</u>	0.05	0.010	0.004	0.030	0.096	0.096	0.0003	0.0722	881
g	0.08	0.24	1.64	0.02	<u>0.10</u>	0.008	0.005	0.044	0.061	0.072	0.0003	0.0623	899
h	0.07	0.16	1.79	0.02	0.04	0.006	0.001	<u>0.060</u>	0.092	0.031	0.0003	0.0481	904
i	0.08	0.26	1.43	0.01	0.05	0.007	0.008	0.026	<u>0.053</u>	0.043		0.0672	900
j	0.08	0.21	1.56	0.02	0.02	0.002	0.004	0.038	<u>0.160</u>	0.094		0.0316	910
k	0.06	0.14	2.45	0.03	0.03	0.006	0.005	0.042	0.088	<u>0.012</u>	0.0002	0.0366	893
l	0.09	0.23	2.31	0.04	0.01	0.008	0.009	0.015	0.121	<u>0.123</u>	0.0003	0.0487	883
m	0.05	0.28	2.15	0.03	0.01	<u>0.020</u>	0.005	0.031	0.123	0.081	0.0003	0.0219	912
n	0.05	0.15	1.60	0.02	0.04	0.002	0.006	0.020	0.134	0.033	0.0002	<u>0.0110</u>	915
o	0.04	0.29	1.41	0.01	0.01	0.008	0.003	0.050	0.125	0.020	0.0001	0.0150	<u>934</u>
p	0.05	0.20	1.60	0.05	0.04	0.005	0.005	0.046	0.086	0.057	0.0003	0.0254	915
q	0.05	0.23	1.50	0.01	0.03	0.007	0.006	0.050	0.113	0.021	0.0001	0.0250	923
r	0.10	0.18	2.30	0.03	0.01	0.004	0.005	0.015	0.062	0.095	0.0003	0.0707	870
s	0.07	0.18	1.96	0.04	0.05	0.009	0.010	0.001	0.141	0.056	0.0001	0.0312	898
t	0.08	0.29	1.84	0.03	0.02	0.010	0.008	0.025	0.146	0.091	0.0002	0.0373	907
u	0.10	0.11	2.49	0.03	0.03	0.006	0.006	0.021	0.077	0.020	0.0002	0.0793	866
v	0.10	0.16	2.30	0.03	0.01	0.004	0.007	0.015	0.066	0.100	0.0003	0.0690	869
w	0.05	0.23	1.59	0.02	0.03	0.006	0.003	0.042	0.071	0.023	0.0002	0.0294	916
x	0.05	0.25	1.43	0.05	0.02	0.007	0.006	0.015	0.091	0.091		0.0215	915
y	0.10	0.26	1.93	0.04	0.01	0.008	0.005	0.031	0.060	0.070		0.0828	883
z	0.05	0.25	1.65	0.03	0.02	0.007	0.004	0.041	0.123	0.030	0.0001	0.0164	923
aa	0.08	0.18	1.84	0.02	0.01	0.004	0.001	0.010	0.071	0.052		0.0590	887
ab	0.07	0.25	1.90	0.02	0.02	0.003	0.001	0.046	0.133	0.027		0.0308	912
ac	0.06	0.27	2.10	0.01	0.01	0.009	0.001	0.010	0.133	0.083	0.0001	0.0257	902
ad	0.04	0.23	1.96	0.03	0.02	0.004	0.006	0.015	0.123	0.057	<u>0.0007</u>	<u>0.0073</u>	912

[0170] The underline indicates that the undelined value is outside the range of the present invention.

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[Table 2A]

Steel Type	Chemical Composition (mass%), Remainder being Fe and Impurities															
	V	Mo	Ca	REM	Cu	Ni	Cr	Mg	Bi	Zr	Co	Zn	W	Sb	As	Sn
A																
B																
C																
D																
E								0.0200								
F									0.0200							
G										0.500						
H											1.000					
I												0.200				
J													0.200			
K														0.200		
L															0.050	
M																0.050
N	0.200															
O		1.000														
P			0.0100													
Q				0.0100												
R					2.00											
S			0.0050			1.50										
T				0.0030			2.00									

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[Table 2B]

Steel Type	Chemical Composition (mass%), Remainder being Fe and Impurities															
	V	Mo	Ca	REM	Cu	Ni	Cr	Mg	Bi	Zr	Co	Zn	W	Sb	As	Sn
5	a															
	b															
	c															
10	d															
	e															
	f															
	g															
15	h															
	i															
	j															
20	k															
	l															
	m															
	n															
25	o															
	p															
	q															
30	r															
	s															
	t															
	u															
35	v															
	w															
	x															
	y															
40	z															
	aa															
	ab															
45	ac															
	ad															

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[Table 3A]

No.	Steel Type	Hot Rolling									
		Heating Temperature (°C)	Finish Rolling				Average Cooling Rate Before Air Cooling (°C/s)	Air Cooling Start Temperature (°C)	Air Cooling Time (sec)	Average Cooling Rate After Air Cooling (°C/s)	Coiling Temperature (°C)
			Start Temperature (°C)	Finishing Temperature (°C)	Total Rolling Reduction at 930°C or Higher (-)	Total Rolling Reduction (-)					
1	A	1255	1006	893	1.5	3.0	62	664	5.1	53	503
2	B	1281	1011	884	1.9	2.4	51	707	3.4	56	513
3	C	1234	1014	953	1.7	2.2	83	722	6.3	74	473
4	D	1296	1017	956	2.0	2.3	76	684	5.3	63	526
5	E	1245	1003	923	2.2	2.4	71	666	4.5	68	496
6	F	1274	1021	936	1.0	2.0	68	724	5.6	65	472
7	G	1259	1009	902	2.0	2.9	80	668	8.6	82	482
8	H	1232	1012	923	1.9	2.8	62	741	7.2	59	491
9	I	1275	1011	946	1.7	2.6	56	696	3.2	85	522
10	J	1243	1010	926	2.2	2.8	85	732	7.3	72	479
11	K	1262	1001	895	1.6	2.6	53	722	3.4	79	502
12	L	1279	1012	920	2.1	2.6	64	731	6.3	53	521
13	M	1286	1024	936	1.8	2.8	89	726	5.9	64	471
14	N	1241	1002	915	2.1	2.7	72	663	6.2	83	492
15	O	1268	1012	946	1.6	2.1	59	672	8.6	56	482
16	P	1237	1015	945	1.1	1.9	53	678	8.6	61	476
17	Q	1255	1022	976	1.7	2.4	65	695	9.2	68	516
18	R	1264	1005	962	1.6	2.5	74	713	3.8	72	521
19	S	1246	1008	946	1.6	2.5	81	732	4.1	83	503
20	T	1250	1024	978	1.6	2.4	56	708	5.2	61	519

[Table 3B]

No.	Steel Type	Hot Rolling									
		Heating Temperature (°C)	Finish Rolling				Average Cooling Rate Before Air Cooling (°C/s)	Air Cooling Start Temperature (°C)	Air Cooling Time (sec)	Average Cooling Rate After Air Cooling (°C/s)	Coiling Temperature (°C)
			Start Temperature (°C)	Finishing Temperature (°C)	Total Rolling Reduction at 930°C or Higher (-)	Total Rolling Reduction (-)					
21	a	1234	1004	958	2.0	3.2	53	678	6.7	72	477
22	b	1249	1004	927	1.4	2.2	62	683	4.6	62	503
23	c	1256	1001	936	1.5	2.4	72	673	3.8	56	514
24	d	1274	1018	908	1.5	2.2	53	713	6.1	63	472
25	e	1283	1008	888	1.8	2.6	81	706	4.2	64	492
26	f	1231	1027	926	1.1	1.8	63	682	5.1	78	524
27	g	1264	1019	963	1.8	2.2	64	666	7.3	56	510
28	h	1243	1027	913	2.0	2.4	63	726	6.1	71	506
29	i	1236	1027	896	1.8	2.1	57	724	5.2	63	513
30	j	1252	1027	947	2.0	2.3	66	735	6.3	68	472
31	k	1263	1004	956	1.7	2.4	78	710	7.1	71	492
32	l	1234	1020	948	1.7	2.1	83	726	6.5	76	501
33	m	1255	1003	897	2.0	3.1	74	681	7.1	82	507
34	n	1263	1001	963	1.8	3.3	61	693	6.3	56	482
35	o	1236	1020	943	1.7	3.1	58	708	5.9	67	489
36	p	<u>1203</u>	1030	926	1.4	1.9	63	689	7.6	73	481
37	q	1238	1018	<u>868</u>	2.1	2.4	81	699	6.1	71	512
38	r	1246	1024	<u>993</u>	1.5	2.7	73	671	6.2	82	519
39	s	1252	1021	934	1.8	2.2	<u>36</u>	723	7.1	65	516
40	t	1261	1030	973	1.8	2.8	63	<u>635</u>	8.1	57	498
41	u	1274	1015	912	1.4	1.8	58	<u>776</u>	6.7	63	491
42	v	1235	1002	903	2.2	2.5	72	713	<u>2.3</u>	71	472
43	w	1239	1001	946	1.9	3.1	81	743	<u>12.3</u>	82	521
44	x	1246	1027	936	2.0	2.9	83	682	8.6	<u>37</u>	529
45	y	1263	1026	927	2.1	3.2	56	663	7.3	76	<u>453</u>
46	z	1253	1006	913	1.9	2.3	68	691	6.4	61	<u>556</u>
47	aa	1268	1021	915	1.4	2.4	62	673	3.8	62	476
48	ab	1246	1020	976	1.8	1.9	53	735	6.3	56	492
49	ac	1252	1024	963	2.2	3.0	83	689	7.1	76	482
50	ad	1252	1004	897	1.7	2.8	81	691	7.6	56	489

The underline indicates that the underlined value is outside the range of the present invention, or the producing condition is not preferable.

[Table 4A]

No.	Steel Type	Microstructure						Properties						Remarks
		Ferrite (area%)	Bainite (area%)	Pearlite (area%)	MA (area%)	Average Grain Size (μm)	Maximum Value of Pole Density (-)	YP (MPa)	TS (MPa)	EL (%)	λ (%)	BH Amount (MPa)	Punching Workability	
1	A	59	37	4	0	8	6.5	733	824	17	53	85	Good	Invention Example
2	B	67	31	1	1	8	6.7	751	834	17	50	63	Fair	Invention Example
3	C	70	28	1	1	6	6.3	738	816	17	71	58	Excellent	Invention Example
4	D	67	29	3	1	6	6.1	727	807	18	72	75	Excellent	Invention Example
5	E	65	33	2	0	7	6.5	739	823	17	62	75	Good	Invention Example
6	F	71	27	1	1	6	7.1	743	820	17	66	70	Fair	Invention Example
7	G	66	28	5	1	9	6.9	748	828	15	55	60	Fair	Invention Example
8	H	65	35	0	0	7	6.7	740	825	17	62	70	Good	Invention Example
9	I	64	34	2	0	6	6.7	731	816	18	69	80	Good	Invention Example
10	J	67	31	1	1	7	6.5	743	825	17	63	74	Good	Invention Example
11	K	66	30	3	1	8	6.9	750	831	16	53	63	Fair	Invention Example
12	L	69	30	0	1	7	6.5	745	825	17	61	58	Fair	Invention Example
13	M	69	29	1	1	7	6.4	744	823	15	66	59	Excellent	Invention Example
14	N	67	30	2	1	7	6.8	740	822	17	59	82	Good	Invention Example
15	O	72	25	1	2	6	6.4	736	811	14	69	65	Excellent	Invention Example
16	P	71	26	2	1	6	7.2	733	809	17	68	56	Fair	Invention Example
17	Q	68	30	1	1	5	6.1	725	804	18	78	67	Excellent	Invention Example
18	R	59	39	2	0	5	6.7	722	811	17	73	83	Good	Invention Example
19	S	50	49	1	0	6	6.7	711	813	17	69	99	Good	Invention Example
20	T	66	33	1	0	5	6.1	725	806	18	78	64	Excellent	Invention Example

[Table 4B]

No.	Steel Type	Microstructure						Properties						Remarks
		Ferrite (area%)	Bainite (area%)	Pearlite (area%)	MA (area%)	Average Grain Size (μm)	Maximum Value of Pole Density (-)	YP (MPa)	TS (MPa)	EL (%)	λ (%)	BH Amount (MPa)	Punching Workability	
5	21 a	67	30	2	1	5	7.1	701	<u>778</u>	18	72	46	Fair	Comparative Example
	22 b	53	45	2	0	7	7.3	715	813	<u>13</u>	63	94	Fair	Comparative Example
10	23 c	65	32	2	1	6	7.0	693	<u>772</u>	18	66	66	Good	Comparative Example
	24 d	72	26	1	1	7	6.6	700	<u>771</u>	18	57	74	Good	Comparative Example
	25 e	61	38	1	0	9	6.9	748	839	<u>12</u>	45	72	Fair	Comparative Example
	26 f	64	35	1	0	7	6.4	738	824	<u>13</u>	63	85	Fair	Comparative Example
15	27 g	64	34	2	0	5	6.1	723	807	15	<u>38</u>	81	Good	Comparative Example
	28 h	66	33	1	0	7	6.1	746	830	<u>12</u>	59	74	Good	Comparative Example
	29 i	65	33	1	1	8	6.2	689	<u>768</u>	18	54	82	Good	Comparative Example
	30 j	75	23	1	1	6	5.9	746	856	<u>13</u>	69	52	<u>Poor</u>	Comparative Example
20	31 k	62	37	1	0	6	6.7	695	<u>778</u>	18	72	74	Good	Comparative Example
	32 l	59	40	1	0	6	6.1	726	817	<u>12</u>	69	81	Good	Comparative Example
	33 m	68	31	1	0	8	7.1	756	<u>765</u>	17	50	56	<u>Poor</u>	Comparative Example
	34 n	70	27	2	1	5	7.1	728	804	18	74	<u>41</u>	<u>Poor</u>	Comparative Example
25	35 o	79	<u>17</u>	2	2	6	7.1	744	810	17	<u>36</u>	48	Fair	Comparative Example
	36 p	75	24	0	1	7	7.3	697	<u>765</u>	18	63	57	Fair	Comparative Example
	37 q	75	23	0	2	<u>13</u>	7.9	799	<u>777</u>	16	45	50	Fair	Comparative Example
	38 r	<u>43</u>	<u>51</u>	4	2	4	6.3	671	<u>768</u>	18	83	99	Excellent	Comparative Example
30	39 s	71	28	1	0	<u>14</u>	6.2	790	<u>762</u>	16	65	62	Good	Comparative Example
	40 t	65	28	<u>7</u>	0	5	6.1	687	<u>766</u>	18	77	70	Excellent	Comparative Example
	41 u	<u>42</u>	<u>51</u>	5	2	8	7.2	673	<u>772</u>	18	58	97	Fair	Comparative Example
	42 v	<u>45</u>	<u>53</u>	2	0	10	6.7	676	<u>774</u>	18	56	99	Good	Comparative Example
35	43 w	<u>82</u>	<u>16</u>	0	2	6	7.0	751	818	17	<u>34</u>	53	Fair	Comparative Example
	44 x	70	21	<u>8</u>	1	7	6.2	706	<u>777</u>	18	53	56	Fair	Comparative Example
	45 y	63	33	0	<u>4</u>	6	7.1	704	791	18	<u>37</u>	93	Fair	Comparative Example
	46 z	76	22	1	1	7	6.6	760	831	17	59	<u>42</u>	<u>Poor</u>	Comparative Example
40	47 aa	62	35	2	1	7	7.3	717	806	17	61	77	Fair	Invention Example
	48 ab	65	33	1	1	5	5.8	704	797	17	75	67	Good	Invention Example
	49 ac	64	33	2	1	5	6.1	714	807	17	69	73	Good	Invention Example
	50 ad	<u>42</u>	<u>55</u>	2	1	7	6.9	738	<u>769</u>	19	65	100	Fair	Comparative Example

45 The underline indicates that the underlined value is outside the range of the present invention, or the property value is not preferable.

[0171] In the tables, Nos. 1 to 20 and Nos. 47 to 49 are invention examples, and it is found that a hot rolled steel sheet has a high strength and excellent press formability and punching workability is provided.

50 [0172] On the other hand, Nos. 21 to 46 and 50 are comparative examples, and it is found that any one or more of the properties are inferior.

[0173] In No. 21, since the C content was low, the strength decreased.

[0174] In No. 22, since the C content was high, the total elongation decreased and the press formability deteriorated.

[0175] In No. 23, since the Si content was low, the strength decreased.

[0176] In No. 24, since the Mn content was low, the strength decreased.

55 [0177] In No. 25, since the Mn content was high, the total elongation decreased and the press formability deteriorated.

[0178] In No. 26, since the P content was high, the total elongation decreased and the press formability deteriorated.

[0179] In No. 27, since the S content was high, the hole expansion ratio decreased and the press formability

deteriorated.

[0180] In No. 28, since the Al content was high, the total elongation decreased and the press formability deteriorated.

[0181] In No. 29, since the Ti content was low, the strength decreased.

[0182] In No. 30, since the Ti content was high, the total elongation decreased, the press formability deteriorated, and the punching workability deteriorated.

[0183] In No. 31, since the Nb content was low, the strength decreased.

[0184] In No. 32, since the Nb content was high, the total elongation decreased and the press formability deteriorated.

[0185] In No. 33, since the N content was high, the strength decreased and the punching workability deteriorated due to the formation of coarse TiN.

[0186] In No. 34, since the value A (calculated amount of unprecipitated carbon) was low, the BH amount decreased and the punching workability deteriorated.

[0187] In No. 35, since the M value was high, the amount of bainite was insufficient, the hole expansion ratio decreased, and the press formability deteriorated.

[0188] In No. 36, since the heating temperature was low, the strength decreased.

[0189] In No. 37, since the finish rolling finishing temperature was low, coarse ferrite was generated and the strength decreased.

[0190] In No. 38, since the finish rolling finishing temperature was high, the amount of ferrite decreased and the strength decreased.

[0191] In No. 39, since the average cooling rate before air cooling was slow, coarse ferrite was generated and the strength decreased.

[0192] In No. 40, since the air cooling start temperature was low, the amount of pearlite increased and the strength decreased.

[0193] In No. 41, since the air cooling start temperature was high, the amount of ferrite decreased and the strength decreased.

[0194] In No. 42, since the air cooling time was short, the amount of ferrite decreased and the strength decreased.

[0195] In No. 43, since the air cooling time was long, the amount of bainite decreased, the hole expansion ratio decreased, and the press formability deteriorated.

[0196] In No. 44, since the average cooling rate after air cooling was slow, the amount of pearlite increased and the strength decreased.

[0197] In No. 45, since the coiling temperature was low, the MA amount increased, the hole expansion ratio decreased, and the press formability deteriorated.

[0198] In No. 46, since the coiling temperature was high, the BH amount decreased and the punching workability deteriorated.

[0199] In No. 50, since the B content was high, the amount of ferrite decreased and the strength decreased.

INDUSTRIAL APPLICABILITY

[0200] According to the aspect of the present invention, it is possible to provide a hot rolled steel sheet having a high strength and excellent press formability and punching workability.

Claims

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

C: 0.04% to 0.10%;

Si: 0.11% to 0.30%;

Mn: 1.40% to 2.50%;

P: 0.05% or less;

S: 0.05% or less;

N: 0.010% or less;

O: 0.010% or less;

Al: 0.001% to 0.050%;

Ti: 0.060% to 0.150%;

Nb: 0.020% to 0.100%;

V: 0% to 0.200%;

Mo: 0% to 1.000%;
 Ca: 0% to 0.0100%;
 REM: 0% to 0.0100%;
 Cu: 0% to 2.00%;
 Ni: 0% to 1.50%;
 Cr: 0% to 2.00%;
 Mg: 0% to 0.0200%;
 Bi: 0% to 0.0200%;
 Zr: 0% to 0.500%;
 Co: 0% to 1.000%;
 Zn: 0% to 0.200%;
 W: 0% to 0.200%;
 Sb: 0% to 0.200%;
 As: 0% to 0.050%;
 Sn: 0% to 0.050%;
 B: less than 0.0005%; and
 a remainder: Fe and impurities,
 wherein a value A represented by Expression (1) is 0.0150 mass% or more,
 a value M represented by Expression (2) is 930 or less,
 a microstructure in a 1/4 position of a sheet thickness from a surface consists of, by area%,

ferrite: 50% or more and less than 80%,
 bainite: more than 20% and 50% or less,
 pearlite: 0% to 5%, and
 MA: 0% to 2%,

an average grain size is 10 μm or less,
 a BH amount is 45 MPa or more, and
 a tensile strength is 780 MPa or more,

$$\text{value A} = C - \text{Ti}/4 + \text{N}/1.17 - \text{Nb}/7.75 - \text{V}/4.25 \quad (1),$$

$$\text{value M} = 937 - 436.5 \times C + 56 \times \text{Si} - 19.7 \times \text{Mn} - 16.3 \times \text{Cu} - 26.6 \times \text{Ni} - 4.9 \times \text{Cr} + 38.1 \times \text{Mo} + 124.8 \times \text{V} + 136.3 \times \text{Ti} - 19.1 \times \text{Nb} + 198.4 \times \text{Al} \quad (2),$$

where each element symbol in Expressions (1) and (2) represents a corresponding element content by mass%, and 0% is substituted in a case where the corresponding element is not contained.

2. The hot rolled steel sheet according to Claim 1, comprising, as the chemical composition, by mass%, one or more of the group consisting of:

V: 0.001% to 0.200%,
 Mo: 0.001% to 1.000%,
 Ca: 0.0001% to 0.0100%,
 REM: 0.0001% to 0.0100%,
 Cu: 0.01% to 2.00%,
 Ni: 0.01% to 1.50%,
 Cr: 0.01% to 2.00%,
 Mg: 0.0001% to 0.0200%,
 Bi: 0.001% to 0.0200%,
 Zr: 0.001% to 0.500%,
 Co: 0.001% to 1.000%,
 Zn: 0.001% to 0.200%,
 W: 0.001% to 0.200%,
 Sb: 0.001% to 0.200%,
 As: 0.001% to 0.050%, and
 Sn: 0.001% to 0.050%.

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3. The hot rolled steel sheet according to Claim 1 or 2,
wherein in a microstructure from the surface to a depth of 500 μm from the surface, a maximum value of pole
densities of an orientation group expressed by Euler angles of $\Phi = 0^\circ$ to 90° , $\varphi_1 = 0^\circ$ to 90° , and $\varphi_2 = 45^\circ$ is 7.0 or
less.
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4. The hot rolled steel sheet according to any one of Claims 1 to 3, comprising, as the chemical composition, by
mass%,
B: 0.0002% or less.
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/041617

A. CLASSIFICATION OF SUBJECT MATTER

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

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60; C21D9/46-9/48

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2025
Registered utility model specifications of Japan 1996-2025
Published registered utility model applications of Japan 1994-2025

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2020-509172 A (POSCO) 26 March 2020 (2020-03-26)	1-4
A	WO 2021/187238 A1 (NIPPON STEEL CORPORATION) 23 September 2021 (2021-09-23)	1-4
A	JP 2017-25397 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 02 February 2017 (2017-02-02)	1-4
A	KR 10-2016-0073494 A (POSCO) 27 June 2016 (2016-06-27)	1-4
A	KR 10-2013-0059651 A (HYUNDAI STEEL COMPANY) 07 June 2013 (2013-06-07)	1-4

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

* Special categories of cited documents:

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“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

24 January 2025

Date of mailing of the international search report

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Name and mailing address of the ISA/JP

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2024/041617

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Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
JP	2020-509172	A	26 March 2020	US	2020/0080167	A1	
				WO	2018/110853	A1	
				EP	3556889	A1	
				KR	10-2018-0068099	A	
				CN	110088337	A	

WO	2021/187238	A1	23 September 2021	US	2023/0140358	A1	
				EP	4123046	A1	
				CN	115298342	A	
				KR	10-2022-0138402	A	

JP	2017-25397	A	02 February 2017	(Family: none)			

KR	10-2016-0073494	A	27 June 2016	(Family: none)			

KR	10-2013-0059651	A	07 June 2013	(Family: none)			

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2023201058 A [0002]
- JP 2003342684 A [0009]
- JP 2004315857 A [0009]