(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 317 504 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
07.02.2024 Bulletin 2024/06

(21) Application number: **22780434.1**

(22) Date of filing: **23.03.2022**

(51) International Patent Classification (IPC):
C22C 38/00 (2006.01) ***C21D 8/02*** (2006.01)
C21D 9/46 (2006.01) ***C22C 38/06*** (2006.01)
C22C 38/60 (2006.01)

(52) Cooperative Patent Classification (CPC):
C21D 8/02; C21D 9/46; C22C 38/00; C22C 38/06; C22C 38/60

(86) International application number:
PCT/JP2022/013740

(87) International publication number:
WO 2022/210220 (06.10.2022 Gazette 2022/40)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **30.03.2021 JP 2021056688**

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(54) **HOT-ROLLED STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) There is provided a hot-rolled steel sheet having excellent stretch flangeability.

A hot-rolled steel sheet has a chemical composition containing, by mass%, C: 0.10% or less, Si: 2.0% or less, Mn: 2.0% or less, P: 0.100% or less, S: 0.02% or less, Al: 1.5% or less, and O: 0.0025% or less, the balance being Fe and incidental impurities, in which a main phase is ferrite, and a maximum orientation density of grains is 2.1 or less.

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Description

Technical Field

[0001] The present invention relates to a hot-rolled steel sheet and a method for manufacturing the same, and in particular, to a hot-rolled steel sheet suitable as a material for automotive parts and a method for manufacturing the same.

Background Art

[0002] Techniques have been developed to increase the strength of steel sheets used for automotive parts and to optimize the structure from the viewpoints of improving crash safety and fuel economy of automobiles. Shape optimization requires the elaboration of three-dimensional shapes; thus, more severe processing may be used than in the past. Thus, steel sheets for automobiles are required to have better workability. In particular, a part composed of a hot-rolled steel sheet of a low-strength grade of less than 780 MPa is required to have excellent flangeability that withstands severe stretch flanging. Various hot-rolled steel sheets have been developed to meet such needs.

[0003] Patent Literature 1 discloses a technique related to a hot-rolled steel sheet having excellent fatigue properties and flangeability obtained by adjusting the amounts of C, Si, Mn, P, S, and Al added to appropriate ranges, forming a microstructure composed of fine polygonal ferrite and bainite, and controlling the length and grain boundary coverage of cementite. Patent Literature 2 discloses a technique related to a hot-rolled steel sheet having a further improved strength-elongation balance, endurance ratio, and stretch flanging properties obtained by adjusting the amounts of C, Si, Mn, Al, and Nb added to appropriate ranges and forming a microstructure that is composed of retained austenite and polygonal ferrite and that has fine grains. Patent Literature 3 discloses a technique related to a hot-rolled steel sheet having excellent stretch flangeability and ductility obtained by controlling C, Si, Mn, P, S, Al, N, Mg, Nb, and Ti to appropriate ranges, using ferrite as a main phase, and controlling oxides such as MgO, Al_2O_3, Ti_2O_3, SiO_2, and MnO.

Citation List

Patent Literature

[0004]

PTL 1: Japanese Unexamined Patent Application Publication No. 9-170048
PTL 2: Japanese Unexamined Patent Application Publication No. 11-1747
PTL 3: Japanese Unexamined Patent Application Publication No. 2001-342543

Summary of Invention

Technical Problem

[0005] However, in the technique of Patent Literature 1, the hole expansion ratio remains less than 100%, and there is no finding or suggestion to further improve the hole expansion ratio. Moreover, the amount of O in steel and the crystallographic orientation are not studied. In Patent Literature 2, 5% to 20% of retained austenite is introduced in order to improve toughness and fatigue properties. However, retained austenite becomes martensite at the time of punching to reduce stretch flangeability, and thus flangeability sufficient to withstand severe stretch flanging is not obtained. Moreover, there is no disclosure of a technique related to the amount of O in steel or the crystallographic orientation. Although the oxides are controlled in Patent Literature 3, there is no knowledge suggesting that the flangeability is improved by controlling the amount of oxygen itself, and the crystallographic orientation is not taken into consideration.

[0006] The present invention has been made to solve the above problems, and it is an object of the present invention to provide a hot-rolled steel sheet having excellent stretch flangeability.

[0007] It is another object of the present invention to provide a method for manufacturing the hot-rolled steel sheet described above.

Solution to Problem

[0008] The inventors have conducted intensive studies focusing on O in steel and the crystallographic orientation and have found that stretch flangeability can be markedly improved by randomizing the crystallographic orientation while controlling the amount of O in steel to a certain level or less, leading to the completion of the present invention.

[0009] In the present invention, excellent stretch flangeability indicates that the hole expansion ratio is 100% or more.

[0010] The present invention has the following configurations.

[1] A hot-rolled steel sheet has a chemical composition containing, by mass%:

C: 0.10% or less,
Si: 2.0% or less,
Mn: 2.0% or less,
P: 0.100% or less,
S: 0.02% or less,
Al: 1.5% or less, and
O: 0.0025% or less, the balance being Fe and incidental impurities, in which the main phase is ferrite, and the maximum orientation density of grains is 2.1 or less.

[2] In the hot-rolled steel sheet described in [1], the maximum orientation density of grains is 1.5 or less in a plane inclined in the thickness direction at an angle of 45° with respect to a surface of the sheet from a direction perpendicular to the rolling direction.
[3] In the hot-rolled steel sheet described in [1] or [2], the chemical composition further contains one or two or more selected from, by mass%:

Cr: 0.005% to 2.0%,
Ti: 0.005% to 0.20%,
Nb: 0.005% to 0.20%,
Mo: 0.01% to 2.0%,
V: 0.01% to 1.0%,
Cu: 0.01% to 4.0%,
Ni: 0.005% to 2.0%,
B: 0.0001% to 0.01%,
Ca: 0.0001% to 0.0050%,
REM: 0.0001% to 0.0050%,
Sb: 0.0010% to 0.10%, and
Sn: 0.0010% to 0.10%.

[4] A method for manufacturing a hot-rolled steel sheet includes:

heating a slab to 1,100°C or higher, the slab having the chemical composition described in [1] or [3];
performing rolling in 6 passes or more at a rolling reduction of 15% or more per pass in a temperature range of 1,000°C or higher;
then performing rolling under conditions in which the rolling is performed in 3 passes or more in a temperature range of lower than 1,000°C at a rolling reduction of 15% or more per pass, a rolling time is 2.0 seconds or less in a temperature range of lower than 1,000°C, and a final pass rolling temperature is 850°C to 940°C; and subsequently performing cooling to 700°C at an average cooling rate of 50 °C/s or more, and performing coiling at 580°C to 700°C.

Advantageous Effects of Invention

[0011] According to the present invention, a hot-rolled steel sheet having excellent stretch flangeability is provided.
[0012] According to the present invention, there is provided a hot-rolled steel sheet that is suitable as a material for automotive parts and that has excellent stretch flangeability. The use of the hot-rolled steel sheet of the present invention enables the production of, for example, automotive parts with high yields.

Description of Embodiments

[0013] A hot-rolled steel sheet and a method for manufacturing the hot-rolled steel sheet according to the present invention will be described in detail below. The present invention is not limited to the following embodiments.

<Hot-Rolled Steel Sheet>

[0014] The hot-rolled steel sheet of the present invention may be a non-pickled hot-rolled steel sheet, which is as hot rolled, or a pickled hot-rolled steel sheet, which has been further pickled after hot rolling. The hot-rolled steel sheet of the present invention preferably has a thickness of 0.6 mm or more. The hot-rolled steel sheet of the present invention preferably has a thickness of 10.0 mm or less. When the hot-rolled steel sheet of the present invention is used as a material for automotive parts, the thickness is more preferably 1.0 mm or more. When the hot-rolled steel sheet of the present invention is used as a material for automotive parts, the thickness is more preferably 6.0 mm or less. The hot-rolled steel sheet of the present invention preferably has a width of 500 mm or more, more preferably 700 mm or more. The hot-rolled steel sheet of the present invention preferably has a width of 1,800 mm or less, more preferably 1,400 mm or less.

[0015] The hot-rolled steel sheet of the present invention has a specific chemical composition and a specific steel microstructure. Here, the chemical composition and the steel microstructure will be described in this order.

[0016] First, the chemical composition of the hot-rolled steel sheet of the present invention will be described. Here, "%" representing the component content of the chemical composition refers to "mass%".

[0017] The hot-rolled steel sheet of the present invention has a chemical composition containing, by mass%, C: 0.10% or less, Si: 2.0% or less, Mn: 2.0% or less, P: 0.100% or less, S: 0.02% or less, Al: 1.5% or less, and O: 0.0025% or less, the balance being Fe and incidental impurities.

C: 0.10% or Less

[0018] C is preferably minimized as much as possible in order to obtain ferrite. In the present invention, a C content of up to 0.10% is allowable. A C content of more than 0.10% results in increases of, for example, pearlite and bainite, thereby failing to obtain the microstructure of the present invention. Accordingly, the C content is 0.10% or less. The C content is preferably 0.08% or less, more preferably 0.05% or less. Although the lower limit is not particularly specified, a C content of 0.0001% or more is preferred because a C content of less than 0.0001% leads to a decrease in production efficiency.

Si: 2.0% or Less

[0019] Si is an element effective in increasing the strength of steel through solid solution strengthening to increase the tensile strength (TS). Si is an element also effective in promoting the formation of ferrite. In the present invention, Si can be appropriately added in consideration of the strength and microstructure. On the other hand, an excessive addition of Si leads to embrittlement of the steel and the accumulation of the crystallographic orientation, thereby deteriorating the stretch flangeability. For this reason, the amount of Si added needs to be 2.0% or less. Accordingly, the Si content is 2.0% or less (including 0%). The Si content is preferably 1.0% or less, more preferably 0.6% or less. Although the lower limit is not particularly specified, a Si content of 0.001% or more is preferred because a Si content of less than 0.001% leads to a decrease in production efficiency.

Mn: 2.0% or Less

[0020] Mn is preferably minimized as much as possible in order to obtain ferrite. A Mn content of up to 2.0% is allowable in the present invention. A Mn content of more than 2.0% does not sufficiently result in the effect. Martensite, bainite, and so forth may be formed, failing to obtain the microstructure of the present invention. In addition, a large amount of MnS is formed, failing to obtain the desired stretch flangeability. Accordingly, the Mn content is 2.0% or less. The Mn content is preferably 1.6% or less, more preferably 1.0% or less. Although the lower limit is not particularly specified, a Mn content of 0.01% or more is preferred because a Mn content of less than 0.01% may lead to a decrease in production efficiency.

P: 0.100% or Less

[0021] P causes embrittlement of the steel, deteriorating the stretch flangeability. Thus, the amount thereof is desirably minimized as much as possible. A P content of up to 0.100% is allowable in the present invention. Accordingly, the P content is 0.100% or less. The P content is preferably 0.050% or less. Although the lower limit is not particularly specified, a P content of 0.001% or more is preferred because a P content of less than 0.001% leads to a decrease in production efficiency.

S: 0.02% or Less

[0022] S causes embrittlement of the steel, deteriorating the stretch flangeability. Thus, the amount thereof is desirably minimized as much as possible. A S content of up to 0.02% is allowable in the present invention. Accordingly, the S content is 0.02% or less. The S content is preferably 0.010% or less, more preferably 0.0080% or less. Although the lower limit is not particularly specified, a S content of 0.0002% or more is preferred because a S content of less than 0.0002% leads to a decrease in production efficiency.

Al: 1.5% or Less

[0023] Regarding Al, a large amount of Al contained results in the development of the texture, failing to obtain the steel microstructure of the present invention. An Al content of up to 1.5% is allowable in the present invention. Accordingly, the Al content is 1.5% or less. The Al content is preferably 0.50% or less. Although the lower limit is not particularly specified, an Al content of 0.001% or more is preferred because an Al content of less than 0.001% may lead to a decrease in production efficiency.

O: 0.0025% or Less

[0024] O is an important element of the present invention and is desirably minimized as much as possible because O leads to embrittlement of the steel, promotion of the accumulation of the crystallographic orientation, and the increase of inclusions to deteriorate stretch flangeability. To provide the desired stretch flangeability, the O content needs to be 0.0025% or less. Accordingly, the O content is 0.0025% or less. The O content is preferably 0.0020% or less. Although the lower limit is not particularly specified, an O content of 0.0001% or more is preferred because an O content of less than 0.0001% leads to a decrease in production efficiency.

[0025] The balance is Fe and incidental impurities. Examples of the incidental impurities include N, Na, Mg, Zr, Hf, Ta, and W. The total amount thereof is 0.020% or less. The total amount is more preferably 0.010% or less.

[0026] The above components are the basic chemical composition of the hot-rolled steel sheet of the present invention. In the present invention, the following elements may be further contained as appropriate.

[0027] One or two or more Selected from, by mass%, Cr: 0.005% to 2.0%, Ti: 0.005% to 0.20%, Nb: 0.005% to 0.20%, Mo: 0.01% to 2.0%, V: 0.01% to 1.0%, Cu: 0.01% to 4.0%, Ni: 0.005% to 2.0%, B: 0.0001% to 0.01%, Ca: 0.0001% to 0.0050%, REM: 0.0001% to 0.0050%, Sb: 0.0010% to 0.10%, and Sn: 0.0010% to 0.10%

[0028] Cr, Ti, Nb, Mo, and V are elements effective in forming carbides to increase the strength of steel. To provide the effect, when Cr, Ti, Nb, Mo, and V are contained, the amounts of individual elements contained are preferably equal to or higher than their respective lower limits described above. When the amounts of individual elements contained are more than the respective upper limits described above, the increases of bainite and martensite and the development of the texture may be caused, failing to obtain the microstructure of the present invention. Accordingly, when Cr, Ti, Nb, Mo, and V are contained, the amounts of elements contained are preferably Cr: 0.005% to 2.0%, Ti: 0.005% to 0.20%, Nb: 0.005% to 0.20%, Mo: 0.01% to 2.0%, and V: 0.01% to 1.0%. The Cr content is more preferably 0.05% or more. The Cr content is more preferably 1.0% or less. The Ti content is more preferably 0.01% or more. The Ti content is more preferably 0.15% or less. The Nb content is more preferably 0.01% or more. The Nb content is more preferably 0.10% or less. The Mo content is more preferably 0.05% or more. The Mo content is more preferably 1.0% or less. The V content is more preferably 0.05% or more. The V content is more preferably 0.5% or less.

[0029] Cu and Ni are elements effective in increasing the strength of steel through solid solution strengthening. To provide the effect, when Cu and Ni are contained, the amounts of individual elements contained are preferably equal to or higher than their respective lower limits described above. When the amount of each of Cu and Ni contained is more than the corresponding upper limit described above, large amounts of bainite and martensite may be formed, failing to obtain the steel microstructure of the present invention. Accordingly, when Cu and Ni are contained, the amounts of individual elements contained are preferably Cu: 0.01 to 4.0% and Ni: 0.005 to 2.0%. The Cu content is more preferably 0.05% or more. The Cu content is more preferably 1.0% or less. The Ni content is more preferably 0.05% or more. The Ni content is more preferably 1.0% or less.

[0030] B is an element effective in strengthening grain boundaries to increase the strength of steel. To obtain the effect, when B is contained, the B content is preferably 0.0001% or more. On the other hand, a B content of more than 0.01% may result in the increase of a B-containing compound to deteriorate the stretch flangeability. Accordingly, when B is contained, the B content is preferably 0.0001% to 0.01%. The B content is more preferably 0.0005% or more. The B content is more preferably 0.0040% or less.

[0031] Ca and REM are elements effective in improving stretch flangeability due to their contribution to the shape control of inclusions. To provide the effect, when Ca and REM are contained, the amount of each element contained is preferably 0.0001% or more. On the other hand, when each of the Ca content and the REM content is more than the corresponding upper limit described above, the amount of inclusions may increase to deteriorate the stretch flangeability. Accordingly, when Ca and REM are contained, their individual contents are preferably Ca: 0.0001% to 0.0050% and REM: 0.0001% to 0.0050%. The Ca content is more preferably 0.0005% or more. The Ca content is more preferably 0.0030% or less. The REM content is more preferably 0.0005% or more. The REM content is more preferably 0.0030%

or less. REM is a general term for Sc, Y, and 15 elements ranging from lanthanum (La) with atomic number 57 to lutetium (Lu) with atomic number 71, and the REM content used here refers to the total amount of these elements contained.

[0032] Sb and Sn are elements effective in suppressing denitrification, deboronization, and so forth to inhibit a decrease in the strength of steel. To provide the effect, when Sb and Sn are contained, the amount of each element contained is preferably 0.0010% or more. On the other hand, when each of the Sb content and the Sn content is more than the corresponding upper limit described above, the steel may embrittle to deteriorate stretch flangeability. Accordingly, when Sb and Sn are contained, their individual contents are preferably Sb: 0.0010% to 0.10% and Sn: 0.0010 to 0.10%. The Sb content is more preferably 0.005% or more. The Sb content is more preferably 0.015% or less. The Sn content is more preferably 0.005% or more. The Sn content is more preferably 0.015% or less.

[0033] Even if the amounts of individual Cr, Ti, Nb, Mo, V, Cu, Ni, B, Ca, REM, Sb, and Sn contained are less than the respective lower limits described above, the effects of the present invention are not impaired. Accordingly, when the amounts of these elements contained are less than the respective lower limits described above, these elements are treated as being contained as incidental impurities.

[0034] The steel microstructure of the hot-rolled steel sheet of the present invention will be described below.

[0035] The steel microstructure of the hot-rolled steel sheet according to the present invention is characterized in that the main phase is ferrite and the maximum orientation density of grains is 2.1 or less.

Main Phase: Ferrite

[0036] The use of ferrite as the main phase makes it possible to achieve excellent stretch flangeability in the present invention. If the main phase is bainite or pearlite, the desired stretch flangeability is not provided. Accordingly, the main phase is ferrite. Here, the main phase refers to a phase having an area fraction of more than 50%. The area fraction of ferrite is preferably 90% or more, more preferably 95% or more. The balance other than ferrite is one or more of martensite, bainite, pearlite, and retained austenite. The area fraction of the balance is preferably 10% or less, more preferably 5% or less. The area fraction of each phase (microstructure) can be determined by a method described in Examples.

Maximum Orientation Density of Grains: 2.1 or Less

[0037] An insufficient randomization of the crystallographic orientation deteriorates the stretch flangeability. At a maximum orientation density of grains of more than 2.1, the desired stretch flangeability is not obtained. Accordingly, the maximum orientation density of the grains is 2.1 or less. The maximum orientation density of the grains is preferably 2.0 or less, more preferably 1.9 or less. Although the lower limit is not particularly specified, the maximum orientation density of the grains is preferably 1.0 or more. The maximum orientation density of the grains can be determined by a method described in Examples.

Maximum Orientation Density of Grains in Plane Inclined in Thickness Direction at Angle of 45° with Respect to Surface of Sheet from Direction Perpendicular to Rolling Direction: 1.5 or Less

[0038] The stretch flangeability can be further improved by promoting randomization of the crystallographic orientation. The effect can be provided by setting the maximum orientation density of grains to 1.5 or less in a plane inclined in the thickness direction at an angle of 45° with respect to a surface of the sheet from a direction perpendicular to the rolling direction. Accordingly, the maximum orientation density of the grains is preferably 1.5 or less in the plane inclined in the thickness direction at an angle of 45° with respect to the surface of the sheet from the direction perpendicular to the rolling direction. The maximum orientation density of the grains is more preferably 1.4 or less, still more preferably 1.3 or less, in the plane inclined in the thickness direction at an angle of 45° with respect to the surface of the sheet from the direction perpendicular to the rolling direction. Although the lower limit is not particularly specified, the maximum orientation density of the grains is preferably 1.0 or more in the plane inclined in the thickness direction at an angle of 45° with respect to the surface of the sheet from the direction perpendicular to the rolling direction. The maximum orientation density of the grains in the plane inclined in the thickness direction at an angle of 45° with respect to the surface of the sheet from the direction perpendicular to the rolling direction can be determined by a method described in Examples.

<Method for Manufacturing Hot-Rolled Steel Sheet>

[0039] The hot-rolled steel sheet of the present invention is manufactured by heating a slab to 1,100°C or higher, the slab having the chemical composition described above, performing rolling in 6 passes or more at a rolling reduction of 15% or more per pass in a temperature range of 1,000°C or higher, then performing rolling under conditions in which the rolling is performed in 3 passes or more in a temperature range of lower than 1,000°C at a rolling reduction of 15%

or more per pass, a rolling time is 2.0 seconds or less in a temperature range of lower than 1,000°C, and a final pass rolling temperature is 850°C to 940°C, and subsequently performing cooling to 700°C at an average cooling rate of 50 °C/s or more, and performing coiling at 580°C to 700°C.

[0040] A detailed description will be given below. The temperature described above is the surface temperature of the central portion of the width of the steel sheet, and the average cooling rate described above is the average cooling rate at the surface of the central portion of the width of the steel sheet. The average cooling rate is [(cooling start temperature - finish cooling temperature)/cooling time from the cooling start temperature to the finish cooling temperature] unless otherwise specified.

[0041] A steel having the above-described chemical composition is obtained by a known steelmaking method using, for example, a converter, an electric arc furnace, or a vacuum melting furnace, and is cast by a known method, such as a continuous casting method or an ingot making-slabbing method to form a cast slab (slab).

Slab Heating Temperature: 1,100°C or Higher

[0042] Heating the slab to 1,100°C or higher enables carbide and so forth to enter into solid solution, thereby promoting the randomization of the crystallographic orientation. At a slab heating temperature of less than 1,100°C, the effect is not sufficiently provided, and the maximum orientation density of the grains of the present invention is not obtained. Accordingly, the slab heating temperature is 1,100°C or higher. The slab heating temperature is preferably 1,150°C or higher. Although the upper limit is not particularly specified, the slab heating temperature is preferably 1,350°C or lower because of an increase in electric power cost or the like at higher than 1,350°C.

Number of Rolling Passes in Temperature Range of 1,000°C or Higher: 6 Passes or More

[0043] When the number of rolling passes (the number of rolling times) in a temperature range of 1,000°C or higher in the hot rolling is less than 6 passes (6 times), recrystallization is insufficient; thus, the randomization of the crystallographic orientation is inhibited, failing to obtain the maximum orientation density of the grains of the present invention. Accordingly, the number of rolling passes in the temperature range of 1,000°C or higher is 6 passes or more. The number of rolling passes is preferably 8 passes or more, more preferably 10 passes or more. Although the upper limit is not particularly specified, the number of rolling passes is preferably 20 passes or less because an increase in the number of rolling passes may lead to a decrease in production efficiency or the like. The rolling in the temperature range of 1,000°C or higher includes rolling in any process as long as the rolling is performed in the temperature range of 1,000°C or higher regardless of the process of rough rolling or finish rolling. The same applies to rolling in a temperature range of lower than 1,000°C described below.

Rolling Reduction per Pass of Rolling in Temperature Range of 1,000°C or higher: 15% or More

[0044] When the rolling reduction per pass (one time) of the hot rolling in the temperature range of 1,000°C or higher is less than 15%, recrystallization is insufficient; thus, the randomization of the crystallographic orientation is inhibited, failing to obtain the maximum orientation density of the grains of the present invention. Accordingly, the rolling reduction per pass of rolling in the temperature range of 1,000°C or higher is 15% or more. The rolling reduction is preferably 18% or more, more preferably 20% or more. Although the upper limit is not particularly specified, the rolling reduction is preferably 80% or less because a rolling reduction of more than 80% may lead to a problem such as an increase in equipment load.

Number of Rolling Passes in Temperature Range of Lower than 1,000°C: 3 Passes or More

[0045] When the number of rolling passes (the number of times of rolling) in the temperature region of lower than 1,000°C in the hot rolling is less than 3 passes (3 times), insufficient strain accumulation decreases ferrite with random orientations during subsequent ferrite transformation, failing to obtain the maximum orientation density of the grains of the present invention. Accordingly, the number of rolling passes in the temperature range of lower than 1,000°C is 3 passes or more. The number of rolling passes is preferably 4 passes or more. Although the upper limit is not particularly specified, the number of rolling passes is preferably 8 passes or less because an increase in the number of rolling passes leads to a decrease in rolling temperature in the final rolling pass (final finish rolling pass).

Rolling Reduction per Pass of Rolling in Temperature Range of Lower than 1,000°C: 15% or More

[0046] When the rolling reduction per pass (one time) of the hot rolling in the temperature range of lower than 1,000°C is less than 15%, insufficient strain accumulation decreases ferrite with random orientations during subsequent ferrite transformation, failing to obtain the maximum orientation density of the grains of the present invention. Accordingly, the rolling reduction per pass in the temperature range of lower than 1,000°C is 15% or more. The rolling reduction is preferably 170 or more, more preferably 20% or more. Although the upper limit is not specified, the rolling reduction is preferably 50% or less because an increase in rolling reduction may lead to a decrease in shape stability or the like.

Rolling Time in Temperature Range of Lower than 1,000°C: 2.0 Seconds or Less

[0047] When the rolling time in the temperature range of lower than 1,000°C is more than 2.0 seconds, insufficient strain accumulation decreases ferrite with random orientations during subsequent ferrite transformation, failing to obtain the maximum orientation density of the grains of the present invention. Accordingly, the rolling time in the temperature range of lower than 1,000°C is 2.0 seconds or less. Here, the rolling time in the temperature range of lower than 1,000°C indicates the time from when the same portion of the material to be rolled reaches a temperature of lower than 1,000°C and comes into contact with the rolling rolls of the first rolling pass to when the portion leaves (passes through) the rolling rolls of the final rolling pass. The rolling time is preferably 1.7 seconds or less, more preferably 1.4 seconds or less. Although the lower limit is not particularly specified, the rolling time is preferably 0.2 seconds or more because rolling at an excessively high speed causes a decrease in operational stability.

Final Pass Rolling Temperature: 850°C to 940°C

[0048] When the final pass rolling temperature (finishing delivery temperature) is lower than 850°C, excessive strain accumulation decreases ferrite with random orientations during subsequent ferrite transformation, failing to obtain the maximum orientation density of the grains of the present invention. On the other hand, when the rolling temperature is higher than 940°C, insufficient strain accumulation decreases ferrite with random orientations during subsequent ferrite transformation, failing to obtain the maximum orientation density of grains of the present invention. Accordingly, the final pass rolling temperature is 850°C to 940°C. The rolling temperature is preferably 860°C or higher, more preferably 870°C or higher. The rolling temperature is preferably 920°C or lower, more preferably 910°C or lower.

Average Cooling Rate to 700°C: 50 °C/s or More

[0049] When the average cooling rate from the final pass rolling temperature (finishing delivery temperature) to 700°C is less than 50 °C/s, the rolling strain is partially released to lead to insufficient strain accumulation; thus, ferrite with random orientations decreases during subsequent ferrite transformation, failing to obtain the maximum orientation density of grains of the present invention. Accordingly, the average cooling rate from the final pass rolling temperature to 700°C is 50 °C/s or more. The average cooling rate is preferably 80 °C/s or more. Although the upper limit is not particularly specified, the average cooling rate is preferably 1,000 °C/s or less from the viewpoint of the shape stability of the steel sheet and so forth.

Coiling Temperature: 580°C to 700°C

[0050] A coiling temperature of lower than 580°C results in the increases of bainite and martensite, failing to obtain the steel microstructure of the present invention. On the other hand, a coiling temperature of higher than 700°C results in a low degree of undercooling of ferrite transformation; thus, ferrite with random orientations decreases during the ferrite transformation, failing to obtain the maximum orientation density of the grains of the present invention. Accordingly, the coiling temperature is 580°C to 700°C. The coiling temperature is preferably 590°C or higher. The coiling temperature is preferably 680°C or lower. After the coiling, the sheet is cooled to room temperature, for example.

[0051] There are no particular limitations other than the conditions of the manufacturing method described above.

[0052] The tensile strength (TS) of the hot-rolled steel sheet of the present invention is preferably, but not particularly limited to, 200 MPa or more, more preferably 270 MPa or more. The tensile strength (TS) of the hot-rolled steel sheet of the present invention is preferably, but not particularly limited to, 780 MPa or less, more preferably 650 MPa or less. The hot-rolled steel sheet of the present invention has excellent stretch flangeability with a hole expansion ratio of 100% or more. The hole expansion ratio is preferably 110% or more, more preferably 120% or more. TS and the hole expansion ratio are each determined by a method described in Examples.

EXAMPLES

[0053] Steels having respective chemical compositions given in Table 1 were obtained by steelmaking in a vacuum melting furnace and formed into slabs. The slabs were heated and hot-rolled under the conditions given in Table 2. The resulting hot-rolled steel sheets were used to make evaluation on microstructure observation, tensile properties, and a hole expansion test according to the following test methods.

Microstructure Observation

[0054] The area fraction of ferrite was determined as follows: A sample was cut out from the resulting hot-rolled steel sheet. A cross section in the thickness direction and parallel to the rolling direction was polished and then etched in 3% nital. A position 1/4 of the thickness was photographed in three visual fields at a magnification of ×1,500 with a scanning electron microscope (SEM). The area fraction of each microstructure was determined from the image data of the obtained secondary electron image using Image-Pro available from Media Cybernetics, Inc., and the average area fraction of the three visual fields was defined as the area fraction of each microstructure. In the image data, ferrite is black or dark gray and has smooth grain boundaries. Carbides appear white dots or lines. A lamellar microstructure composed of ferrite and a carbide is distinguished as pearlite. Microstructures other than the above were distinguished as others.

[0055] The results are presented in Table 3. In Table 3, "F" indicates ferrite, "P" indicates pearlite, and "O" indicates other microstructures (one or more of martensite and bainite). The main phase indicates that the phase (microstructure) has an area fraction of more than 50%.

Crystallographic Orientation (Maximum Orientation Density of Grains)

[0056] With respect to the same sample used for the microstructure observation, the crystal orientation was determined by electron backscatter diffraction (EBSD) in a 500 pm × 500 pm region centered at a position 1/4 of the thickness of a cross section in the thickness direction and parallel to the rolling direction. The range of each of Φ1, Φ2, and Φ was set to 0 to 90, the resolution of each was set to 5, and the orientation distribution function (ODF) was calculated to determine the maximum orientation density of grains in the field of view. This was performed for similar five points, and the average thereof was used as the maximum orientation density of the grains. The above-described crystallographic orientation data was subjected to coordinate transformation in such a manner that the normal direction (ND) plane was a plane inclined in the thickness direction at an angle of 45° with respect to a surface of the sheet from a direction perpendicular to the rolling direction. The range of each of Φ1, Φ2, and Φ was set to 0 to 90, the resolution of each was set to 5, and the orientation distribution function (ODF) was calculated to determine the maximum orientation density of grains in the field of view. This was performed for similar five points, and the average thereof was used as the maximum orientation density of the grains in the plane inclined in the thickness direction at an angle of 45° with respect to the surface of the sheet from the direction perpendicular to the rolling direction. The EBSD measurement was performed at an accelerating voltage of 30 kV and a step size of 0.5 pm.

Tensile Test

[0057] A JIS No. 5 test piece for a tensile test (JIS Z 2201) was sampled from the resulting hot-rolled steel sheet in a direction parallel to the rolling direction. The tensile test was performed in accordance with JIS Z 2241 at a strain rate of 10^{-3}/s to determine tensile strength (TS).

Hole Expansion Test

[0058] Test pieces each having a width of 100 mm and a length of 100 mm were collected from the resulting hot-rolled steel sheets. A hole expansion test was performed five times in accordance with JFST1001 (The Japan Iron and Steel Federation Standard). The average hole expansion ratio λ

[0059] (%) was determined to evaluate the stretch flangeability. When λ was 100% or more, the stretch flangeability was evaluated to be excellent and was regarded as acceptable.

[Table 1]

Steel	Chemical composition (mass%)								Remarks
	C	Si	Mn	P	S	Al	O	Others	
A	0.010	0.12	0.2	0.014	0.0012	0.001	0.0013	-	Acceptable steel
B	0.072	0.00	1.1	0.022	0.0049	0.031	0.0024	Cr: 0.3, REM: 0.0020	Acceptable steel
C	0.095	0.01	0.5	0.018	0.0032	0.061	0.0019	Ti: 0.03	Acceptable steel
D	0.032	0.33	0.1	0.005	0.0017	0.002	0.0015	Nb: 0.01	Acceptable steel

(continued)

Steel	Chemical composition (mass%)								Remarks
	C	Si	Mn	P	S	Al	O	Others	
E	0.002	0.59	1.9	0.009	0.0003	0.027	0.0022	Mo: 0.05	Acceptable steel
F	0.047	0.95	1.3	0.013	0.0064	0.044	0.0010	V: 0.1, Ca: 0.0010	Acceptable steel
G	0.028	1.70	1.8	0.018	0.0029	0.350	0.0018	Cu: 0.1, Ni: 0.2	Acceptable steel
H	0.026	0.09	1.3	0.025	0.0008	0.037	0.0020	B: 0.0011, Sn: 0.010	Acceptable steel
I	0.024	0.10	0.7	0.012	0.0022	0.001	0.0016	Sb: 0.015	Acceptable steel
J	<u>0.108</u>	0.24	1.5	0.023	0.0027	0.020	0.0017	-	Comparative steel
K	0.055	<u>2.20</u>	0.2	0.009	0.0013	0.003	0.0020	-	Comparative steel
L	0.063	0.37	<u>2.1</u>	0.010	0.0019	0.028	0.0021	-	Comparative steel
M	0.039	0.05	0.5	0.017	0.0035	0.036	0.0026	-	Comparative steel
N	0.051	0.46	1.1	0.006	0.0031	0.029	0.0035	-	Comparative steel

* Underlined portions indicate that the values are outside the scope of the present invention.

[Table 2]

Steel sheet No.	Steel	Slab heating temperature (°C)	Rolling in temperature range of 1,000°C or higher		Rolling in temperature range of lower than 1,000°C				Average cooling rate to 700°C*2 (°C/s)	Coiling temperature (°C)	Remarks
			Number of passes (times)	Rolling reduction per pass (%)	Number of passes (times)	Rolling reduction per pass (%)	Rolling time*1 (s)	Final pass rolling temperature (°C)			
1	A	1150	7	20	4	30	1.2	850	100	650	Inventive example
2		1050	7	20	3	30	1.2	850	100	650	Comparative example
3	B	1200	7	18	3	18	0.9	900	100	600	Inventive example
4		1200	5	18	4	18	0.9	900	60	600	Comparative example
5	C	1250	6	25	4	20	1.0	940	60	580	Inventive example
6		1250	6	14	4	20	1.0	940	60	580	Comparative example
7	0	1200	8	16	5	20	0.6	900	60	680	Inventive example
8		1200	8	16	5	20	0.6	900	60	560	Comparative example
9		1200	8	16	5	20	0.6	900	60	720	Comparative example
10	E	1200	10	25	5	15	1.8	900	50	630	Inventive example
11		1200	10	25	5	12	1.8	900	50	630	Comparative example

(continued)

Steel sheet No.	Steel	Slab heating temperature (°C)	Rolling in temperature range of 1,000°C or higher		Rolling in temperature range of lower than 1,000°C				Average cooling rate to 700°C*2 (°C/s)	Coiling temperature (°C)	Remarks
			Number of passes (times)	Rolling reduction per pass (%)	Number of passes (times)	Rolling reduction per pass (%)	Rolling time*1 (s)	Final pass rolling temperature (°C)			
12	F	1200	9	30	4	25	1.5	900	120	600	Inventive example
13	F	1200	9	30	4	25	2.2	900	120	600	Comparative example
14	G	1200	9	20	3	25	1.2	900	150	600	Inventive example
15	G	1200	9	20	3	25	1.2	970	150	600	Comparative example
16	G	1200	9	20	3	25	1.2	830	150	600	Comparative example
17	H	1200	9	20	4	25	1.2	900	200	650	Inventive example
18	H	1200	9	20	4	25	1.2	900	40	650	Comparative example
19	I	1200	9	20	4	25	1.2	900	80	650	Inventive example
20	I	1200	9	20	2	25	1.2	900	80	650	Comparative example
21	J	1200	9	20	4	25	1.2	900	80	600	Comparative example
22	K	1200	9	20	4	25	1.2	900	80	650	Comparative example
23	L	1200	9	20	4	25	1.2	900	80	590	Comparative example

(continued)

Steel sheet No.	Steel	Slab heating temperature (°C)	Rolling in temperature range of 1,000°C or higher		Rolling in temperature range of lower than 1,000°C				Average cooling rate to 700°C*2 (°C/s)	Coiling temperature (°C)	Remarks
			Number of passes (times)	Rolling reduction per pass (%)	Number of passes (times)	Rolling reduction per pass (%)	Rolling time*1 (s)	Final pass rolling temperature (°C)			
24	M	1200	9	20	4	25	1.2	900	80	650	Comparative example
25	N	1200	9	20	4	25	1.2	900	80	650	Comparative example

* Underlined portions indicate that the values are outside the scope of the present invention.
*1 The time from when the same portion of the material to be rolled reaches a temperature of lower than 1,000°C and comes into contact with the first pass to when the portion passes through the final pass.
*2 Average cooling rate from the final pass rolling temperature to 700°C.

[Table 3]

Steel sheet No.	Steel microstructure				Mechanical properties		Remarks
	Main phase	Others	Maximum orientation density of grains in plane inclined in the thickness direction at angle of 45° from direction perpendicular to rolling direction	Maximum orientation density of grains	TS (MPa)	λ (%)	
1	F	-	1.1	1.5	298	180	Inventive example
2	F	-	1.7	2.2	302	93	Comparative example
3	F	P	1.5	1.8	389	140	Inventive example
4	F	P	1.8	2.2	391	96	Comparative example
5	F	P, O	1.2	1.5	425	132	Inventive example
6	F	P, O	1.8	2.3	436	90	Comparative example
7	F	P	1.3	1.6	366	190	Inventive example
8	O	F, P	1.9	2.4	408	93	Comparative example
9	F	P	2.0	2.4	369	93	Comparative example
10	F	-	1.4	1.7	411	144	Inventive example
11	F	-	1.7	2.2	410	98	Comparative example
12	F	P	1.5	1.8	512	135	Inventive example
13	F	P	1.6	2.2	518	95	Comparative example
14	F	P, O	1.5	1.9	635	125	Inventive example
15	F	P, O	1.8	2.2	639	98	Comparative example
16	F	P	2.1	2.5	657	88	Comparative example
17	F	-	1.2	1.7	350	172	Inventive example
18	F	-	1.6	2.2	354	98	Comparative example
19	F	-	1.3	1.6	336	188	Inventive example

(continued)

Steel sheet No.	Steel microstructure				Mechanical properties		Remarks
	Main phase	Others	Maximum orientation density of grains in plane inclined in the thickness direction at angle of 45° from direction perpendicular to rolling direction	Maximum orientation density of grains	TS (MPa)	λ (%)	
20	F	-	1.9	2.3	329	93	Comparative example
21	O	F, P	1.5	2.1	491	95	Comparative example
22	F	-	1.5	2.1	655	88	Comparative example
23	O	F, P	1.4	1.9	483	93	Comparative example
24	F	P	1.7	2.2	338	91	Comparative example
25	F	P	1.9	2.4	420	85	Comparative example
* Underlined portions indicate that the values are outside the scope of the present invention.							

[0060] The hot-rolled steel sheets obtained in all inventive examples have excellent stretch flangeability. In contrast, in comparative examples, which are outside the scope of the present invention, desired stretch flangeability is not obtained.

Industrial Applicability

[0061] According to the present invention, a hot-rolled steel sheet having excellent stretch flangeability can be stably obtained. When the steel sheet of the present invention is used for automotive parts, the steel sheet can greatly contribute to the improvements of the crash safety and fuel economy of automobiles.

Claims

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

C: 0.10% or less,
Si: 2.0% or less,
Mn: 2.0% or less,
P: 0.100% or less,
S: 0.02% or less,
Al: 1.5% or less, and
O: 0.0025% or less, the balance being Fe and incidental impurities,
wherein a main phase is ferrite, and a maximum orientation density of grains is 2.1 or less.

2. The hot-rolled steel sheet according to Claim 1, wherein a maximum orientation density of grains is 1.5 or less in a plane inclined in a thickness direction at an angle of 45° with respect to a surface of the sheet from a direction perpendicular to a rolling direction.

3. The hot-rolled steel sheet according to Claim 1 or 2, wherein the chemical composition further contains one or two or more selected from, by mass%:

Cr: 0.005% to 2.0%,
Ti: 0.005% to 0.20%,
Nb: 0.005% to 0.20%,
Mo: 0.01% to 2.0%,
V: 0.01% to 1.0%,
Cu: 0.01% to 4.0%,
Ni: 0.005% to 2.0%,
B: 0.0001% to 0.01%,
Ca: 0.0001% to 0.0050%,
REM: 0.0001% to 0.0050%,
Sb: 0.0010% to 0.10%, and
Sn: 0.0010% to 0.10%.

4. A method for manufacturing a hot-rolled steel sheet, comprising:

heating a slab to 1,100°C or higher, the slab having the chemical composition according to Claim 1 or 3;
performing rolling in 6 passes or more at a rolling reduction of 15% or more per pass in a temperature range of 1,000°C or higher;
then performing rolling under conditions in which the rolling is performed in 3 passes or more in a temperature range of lower than 1,000°C at a rolling reduction of 15% or more per pass, a rolling time is 2.0 seconds or less in a temperature range of lower than 1,000°C, and a final pass rolling temperature is 850°C to 940°C; and
subsequently performing cooling to 700°C at an average cooling rate of 50 °C/s or more, and performing coiling at 580°C to 700°C.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/013740

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 8/02***(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/06***(2006.01)i; ***C22C 38/60***(2006.01)i
FI: C22C38/00 301W; C21D8/02 A; C21D9/46 T; C22C38/06; C22C38/60

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2012/128206 A1 (NIPPON STEEL CORP.) 27 September 2012 (2012-09-27) claims, paragraphs [0022], [0067]-[0093]	1-3 4
X A	JP 2015-199987 A (NIPPON STEEL & SUMITOMO METAL CORP.) 12 November 2015 (2015-11-12) claims, paragraphs [0047]-[0068]	3 1-2, 4
X A	CN 107746939 A (SHOUGANG GROUP) 02 March 2018 (2018-03-02) claims, paragraphs [0058]-[0086]	3 1-2, 4
A	JP 2005-298956 A (SUMITOMO METAL IND., LTD.) 27 October 2005 (2005-10-27)	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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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 May 2022	**07 June 2022**

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/JP2022/013740

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2012/128206 A1	27 September 2012	US 2014/0000766 A1 claims, paragraphs [0088], [0153]-[0183] CN 103328671 A KR 10-2013-0116329 A	
JP 2015-199987 A	12 November 2015	(Family: none)	
CN 107746939 A	02 March 2018	(Family: none)	
JP 2005-298956 A	27 October 2005	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 9170048 A **[0004]**
- JP 11001747 A **[0004]**
- JP 2001342543 A **[0004]**