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(54) **STEEL SHEET AND METHOD FOR PRODUCING SAME**

(57) Provided is a steel plate that has high strength and excellent low-temperature toughness as well as excellent manufacturability. A steel plate having a pre-determined chemical composition and a microstructure in which a volume fraction of retained austenite at a 1/4 thickness position is less than 3.0 %, the maximum prior austenite grain size at a 1/2 thickness position is 100 μm

or less, and a ratio b/a of an average value b in the top 5 % of prior austenite grain sizes to an average prior austenite grain size a at the 1/2 thickness position is 4.5 or less, with a steel plate thickness of 40 mm or less, a yield stress of 585 MPa or more, and a tensile strength of 690 MPa or more.

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Description

TECHNICAL FIELD

[0001] This disclosure relates to a steel plate, particularly to a steel plate that has high strength and excellent low-temperature toughness and is suitable for use as structural steel used in low-temperature environments, such as liquefied gas storage tanks. This disclosure also relates to a method for producing the steel plate.

BACKGROUND

[0002] In addition to strength, thick steel plates used for low-temperature structures such as liquefied gas storage tanks are required to have excellent low-temperature toughness to ensure safety against embrittlement fracture at low temperatures. For example, liquefied natural gas (LNG) is stored at low temperatures equal to or lower than -164°C , the boiling point of LNG, so thick steel plates used for LNG storage tanks must have excellent toughness at temperatures of -164°C or lower.

[0003] Therefore, thick steel plates that contain high concentrations of Ni such as 7 % and 9 % and have excellent low-temperature toughness have been conventionally used for applications such as liquefied gas storage tanks.

[0004] For example, JPH04-371520A (PTL 1) proposes a method for producing 9 % Ni steel with a thickness of 40 mm or more by sequentially applying quenching, dual-phase region quenching, and tempering treatments to a hot-rolled steel plate.

[0005] Further, JPH06-184630A (PTL 2) proposes a method for easily producing a thick 9 % Ni steel plate with excellent low-temperature toughness. In the method, by reducing the amount of Si in the steel and at the same time performing appropriate heating and rolling to control the microstructure, a large amount of stable retained austenite (y) can be generated without dual-phase region quenching, and excellent toughness can be obtained over a wide tempering temperature range.

[0006] In WO2020/136829A1 (PTL 3), a Ni-containing steel plate with excellent toughness is proposed, in which the average coarse grain size of the prior austenite measured at a 1/4t position of the steel plate is $20\text{ }\mu\text{m}$ or less.

CITATION LIST

Patent Literature

[0007]

PTL 1: JPH04-371520A

PTL 2: JPH06-184630A

PTL 3: WO2020/136829A1

SUMMARY

(Technical Problem)

[0008] In recent years, with the strengthening emission regulations for SOx and NOx, the conversion of marine fuel from heavy oil to LNG is being considered, and the application of steel plates with high Ni content, such as 7 % and 9 % Ni steel plates, to the body of marine fuel tanks is being explored. This application requires thinner plate thicknesses than conventional above-ground storage tanks. Furthermore, due to the high demand for steel material, steel plates with excellent manufacturability are required.

[0009] However, the conventional techniques such as those proposed in PTLs 1-3 have the following problems.

[0010] In detail, the method for producing 9 % Ni steel proposed in PTL 1 requires three-step heat treatment of hot-rolled steel plates: quenching, dual-phase region quenching, and tempering. This is disadvantageous in terms of manufacturing cost and productivity. The dual-phase region quenching must be performed using a furnace set to a special temperature different from that of the normal quenching. Therefore, there is a producing restriction that other products could not be produced on the production line where the aforementioned method is applied.

[0011] In addition, the method for producing a thick 9 % Ni steel plate proposed in PTL 2 requires strict control of Si content to 0.10 mass% or less, which means that there is little flexibility in component design.

[0012] Furthermore, in order to produce the Ni-containing steel plate proposed in PTL 3, it is necessary to strictly control the heating rate in a specific temperature range during reheating quenching, which poses a challenge from the standpoint of manufacturability.

[0013] It could thus be helpful to provide a steel plate having both high strength and excellent low-temperature toughness, as well as excellent manufacturability, and a method for producing the same.

(Solution to Problem)

[0014] To achieve the object, targeting the Ni-containing steel plate suitable for structural steels used in low-temperature environments, we conducted extensive study on the chemical composition and producing method of the steel plate. As a result, we made the following findings.

[1] A steel material to which Ni in an amount of 5.0 mass% to 10.0 mass% is added is hot rolled under the condition that the rolling reduction ratio is 5 or more and the number of passes where the rolling reduction per pass is 10 % or more out of the final 5 passes is 2 or more to obtain a hot-rolled steel plate having a thickness of 40 mm or less, by which austenite grains can be refined and homogenized. As a result, also in the microstructure obtained after subjecting the hot-rolled steel plate to reheating quenching and tempering, prior austenite grains are refined and homogenized, resulting in excellent low-temperature toughness.

[2] Conventionally, to achieve excellent low-temperature toughness, it was necessary to perform dual-phase region quenching to increase the content of retained austenite. In contrast, in the above process, the austenite grains can be refined and homogenized by hot rolling, reheating quenching, and tempering. Therefore, it is not necessary to increase the content of retained austenite by dual-phase region quenching, and excellent low-temperature toughness can be obtained even when the volume fraction of retained austenite is less than 3.0 %. Therefore, the steel plate obtained by the above process also has excellent manufacturability.

[0015] This disclosure is based on the aforementioned findings and further studies. We thus provide the following.

1. A steel plate comprising:

a chemical composition containing (consisting of), in mass%,

C: 0.01 % or more and 0.15 % or less,

Si: 0.01 % or more and 1.00 % or less,

Mn: 0.10 % or more and 2.00 % or less,

P: 0.010 % or less,

S: 0.0050 % or less,

Ni: 5.0 % or more and 10.0 % or less,

Al: 0.002 % or more and 0.100 % or less, and

N: 0.0080 % or less with the balance being Fe and inevitable impurities; and

a microstructure in which

a volume fraction of retained austenite at a 1/4 thickness position is less than 3.0 %,

the maximum prior austenite grain size at a 1/2 thickness position is 100 μm or less, and

a ratio b/a of an average value b in the top 5 % of prior austenite grain sizes to an average prior austenite grain size

a at the 1/2 thickness position is 4.5 or less, with

a thickness of 40 mm or less,

a yield stress of 585 MPa or more, and

a tensile strength of 690 MPa or more.

2. The steel plate according to 1., wherein the chemical composition further contains, in mass%, at least one selected from the group consisting of

Cu: 0.01 % or more and 1.00 % or less,

Cr: 0.01 % or more and 1.50 % or less,

Mo: 0.03 % or more and 1.0 % or less,

Nb: 0.001 % or more and 0.030 % or less,

V: 0.01 % or more and 0.10 % or less,

Ti: 0.003 % or more and 0.050 % or less,

B: 0.0003 % or more and 0.0050 % or less,

Sn: 0.01 % or more and 0.30 % or less,

Sb: 0.01 % or more and 0.30 % or less,

W: more than 0 % and 2.00 % or less,

Co: more than 0 % and 2.00 % or less,

Ca: 0.0005 % or more and 0.0050 % or less,
Mg: 0.0005 % or more and 0.0100 % or less,
Zr: 0.0005 % or more and 0.0050 % or less,
Ta: 0.01 % or more and 0.20 % or less,
Y: 0.001 % or more and 0.010 % or less, and
REM: 0.0010 % or more and 0.0200 % or less.

3. A method for producing a steel plate, comprising

heating a steel material having the chemical composition according to 1. or 2. to a heating temperature of 900 °C or higher and 1200 °C or lower,
hot rolling the heated steel material under the condition that a rolling reduction ratio is 5 or more and the number of passes where a rolling reduction per pass is 10 % or more out of the final 5 passes is 2 or more to obtain a hot-rolled steel plate having a thickness of 40 mm or less,
cooling the hot-rolled steel plate,
subjecting the cooled hot-rolled steel plate to reheating quenching by which the cooled hot-rolled steel plate is reheated to a reheating temperature of Ac3 point or higher and 900 °C or lower and quenched, and
tempering the reheated and quenched hot-rolled steel plate at a tempering temperature of 500 °C or higher and 650 °C or lower.

(Advantageous Effect)

[0016] The steel plate of this disclosure has both high strength and excellent low-temperature toughness. In addition, because the steel plate can be produced by performing general reheating quenching and tempering after hot rolling, other products can be produced together on the same line where the steel plate are being produced, providing excellent manufacturability.

DETAILED DESCRIPTION

[0017] The following specifically describes embodiments of this disclosure. The following description merely presents examples of preferred embodiments of this disclosure, and this disclosure is not limited to these embodiments.

[Steel plate]

[0018] The steel plate in one of the disclosed embodiments has a specific chemical composition, microstructure, thickness, tensile strength, and yield stress. The reasons for the limitations are explained below.

[Chemical composition]

[0019] The appropriate ranges of chemical composition of the steel plate and the reasons for the limitation are described. In the following description, when the unit "%" relating to the content refers to "mass%" unless otherwise stated.

C: 0.01 % or more and 0.15 % or less

[0020] C is an element that has the effect of strengthening the steel plate. To achieve the effect, the C content should be 0.01 % or more, preferably 0.03 % or more. On the other hand, when the C content is more than 0.15 %, low-temperature toughness decreases. This is due to excessive precipitation of Cr carbides and Nb, V, and Ti-based carbides in the steel plate, especially in central segregation area. Therefore, the C content is set to 0.15 % or less, preferably 0.10 % or less, more preferably 0.08 % or less.

Si: 0.01 % or more and 1.00 % or less

[0021] Si is an element that acts as a deoxidizer in the steelmaking process. Si also has the effect of strengthening the steel plate due to solid solution strengthening. To achieve the effect, the Si content should be 0.01 % or more. On the other hand, when the Si content is more than 1.00 %, the low-temperature toughness decreases due to increased inclusions and additionally, the weldability and surface characteristics deteriorate. Therefore, the C content is set to 1.00 % or less, preferably 0.5 % or less, more preferably 0.3 % or less.

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Mn: 0.10 % or more and 2.00 % or less

[0022] Mn is an element that has the effect of increasing the quench hardenability of the steel plate and strengthening it. To achieve the effect, the Mn content should be 0.10 % or more, preferably 0.40 % or more. On the other hand, when the Mn content is more than 2.00 %, it contributes to central segregation and decreases low-temperature toughness. Therefore, the Mo content is set to 2.00 % or less, preferably 1.00 % or less.

P: 0.010 % or less

[0023] When the P content exceeds 0.010 %, low-temperature toughness decreases. This is because P segregates to grain boundaries and decreases grain boundary strength, which becomes fracture origins. Therefore, the P content should be 0.010 % or less. Meanwhile, from the viewpoint of low-temperature toughness, it is desirable to reduce P as much as possible, so no lower limit is placed on the P content and the P content may be 0 %. Excessive reduction, however, leads to higher manufacturing costs and lower productivity. Therefore, from the standpoint of industrial production, it is preferable to set the P content to 0.001 % or more.

S: 0.0050 % or less

[0024] S forms MnS in the steel, which significantly degrades low-temperature toughness. Therefore, it is desirable to reduce S as much as possible, and the S content should be 0.0050 % or less, preferably 0.0020 % or less. Meanwhile, since it is desirable to reduce S as much as possible from the viewpoint of low-temperature toughness, no lower limit is placed on the S content and the S content may be 0 %. However, since excessive reduction leads to higher manufacturing costs and lower productivity, it is preferable to set the S content to 0.0001 % or more from the standpoint of industrial production.

Ni: 5.0 % or more and 10.0 % or less

[0025] Ni is an element that has the effect of increasing the strength of the steel plate. Ni is also an extremely effective element for improving the low-temperature toughness of the steel plate. When the Ni content is less than 5.0 %, the desired strength and low-temperature toughness cannot be obtained. Therefore, the Ni content should be 5.0 % or more, preferably 6.5 % or more, more preferably 6.8 % or more, and even more preferably 8.0 % or more. On the other hand, Ni is an expensive element, so a higher content increases the steel plate cost. Therefore, the Ni content is set to 10.0 % or less, preferably 9.5 % or less.

Al: 0.002 % or more and 0.100 % or less

[0026] Al is an element that acts as a deoxidizer and is commonly used in molten steel deoxidation processes. Al also reacts with N in the steel to form AlN. This reaction reduces solute N, resulting in improved low-temperature toughness. To achieve the effect, the Al content should be 0.002 % or more, preferably 0.010 % or more, more preferably 0.020 % or more. On the other hand, when the Al content is more than 0.100 %, inclusions in the steel increase and low-temperature toughness deteriorates. Therefore, the Al content is set to 0.100 % or less, preferably 0.070 % or less, more preferably 0.060 % or less.

N: 0.0080 % or less

[0027] N forms nitrides and carbonitride, thereby decreasing low-temperature toughness. When the N content is more than 0.0080 %, the desired low-temperature toughness cannot be obtained. Therefore, the N content should be 0.0080 % or less, preferably 0.0040 % or less. Meanwhile, from the viewpoint of low-temperature toughness, it is desirable to reduce N as much as possible, so no lower limit is placed on the N content and the N content may be 0 %. However, since excessive reduction leads to higher manufacturing costs and lower productivity, from the standpoint of industrial production, it is preferable to set the N content to 0.0010 % or more.

[0028] The steel plate in one of the disclosed embodiments has a chemical composition containing the above elements with the balance being Fe and inevitable impurities.

[0029] The steel plate chemical composition in another embodiment of this disclosure may optionally further contain at least one of the elements below for the purpose of further improving the properties of the steel plate.

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Cu: 0.01 % or more and 1.00 % or less

5 **[0030]** Cu is an element that has the effect of further increasing the strength of the steel plate by improving hardenability. When Cu is added, to obtain the effect, the Cu content should be 0.01 % or more. On the other hand, when the Cu content is more than 1.00 %, the low-temperature toughness of the steel plate decreases, and the surface characteristics of the steel material deteriorate. Therefore, the Cu content is set to 1.00 % or less, preferably 0.30 % or less.

Cr: 0.01 % or more and 1.50 % or less

10 **[0031]** Cr is an effective element for further improving the strength of the steel plate. When Cr is added, to obtain the effect, the Cr content should be 0.01 % or more. On the other hand, Cr may precipitate as precipitates such as nitrides, carbide, and carbonitrides during rolling, and the precipitates become initiation points for corrosion and fracture, decreasing low-temperature toughness. Therefore, the Cr content is set to 1.50 % or less, preferably 1.00 % or less.

15 Mo: 0.03 % or more and 1.0 % or less

20 **[0032]** Mo is an element that has the effect of suppressing the susceptibility of the steel plate to tempering embrittlement. Mo also has the effect of further increasing the strength of the steel plate. When Mo is added, to obtain the effect, the Mo content should be 0.03 % or more, preferably more than 0.05 %. On the other hand, when the Mo content exceeds 1.0 %, low-temperature toughness decreases. Therefore, the Mo content is set to 1.0 % or less, preferably 0.30 % or less.

Nb: 0.001 % or more and 0.030 % or less

25 **[0033]** Nb is an element that has the effect of further increasing the strength of the steel plate. When Nb is added, to obtain the effect, the Nb content should be 0.001 % or more, preferably 0.005 % or more, more preferably 0.007 % or more. On the other hand, when the Nb content is more than 0.030 %, coarse carbonitrides are formed and low-temperature toughness decreases. Therefore, the Nb content is set to 0.030 % or less, preferably 0.025 % or less, more preferably 0.022 % or less.

30 V: 0.01 % or more and 0.10 % or less

35 **[0034]** V is an element that has the effect of further increasing the strength of the steel plate. When V is added, to obtain the effect, the V content should be 0.01 % or more, preferably 0.02 % or more, more preferably 0.03 % or more. On the other hand, when the V content is more than 0.10 %, coarse carbonitrides precipitate and become initiation points of fracture. In addition, the precipitates may coarsen and degrade low-temperature toughness. Therefore, the V content is set to 0.10 % or less, preferably 0.09 % or less, more preferably 0.08 % or less.

Ti: 0.003 % or more and 0.050 % or less

40 **[0035]** Ti is an element that precipitates as nitrides or carbonitrides and has the effect of further refining the austenite grains in the steel plate microstructure. When Ti is added, to obtain the effect, the Ti content should be 0.003 % or more, preferably 0.005 % or more, more preferably 0.007 % or more. On the other hand, when the Ti content is more than 0.050 %, precipitates coarsen to decrease low-temperature toughness. Therefore, the Ti content is set to 0.050 % or less, preferably 0.035 % or less, more preferably 0.032 % or less.

45 B: 0.0003 % or more and 0.0050 % or less

50 **[0036]** B is an element that has the effect of further increasing the strength of the steel plate. When B is added, to obtain the effect, the B content should be 0.0003 % or more. On the other hand, when the B content is more than 0.0050 %, coarse precipitates are formed and decrease low-temperature toughness. Therefore, the B content is set to 0.0050 % or less, preferably 0.0030 % or less.

Sn: 0.01 % or more and 0.30 % or less

55 **[0037]** Sn is an element that has the effect of improving the corrosion resistance of the steel plate and is effective even when contained in small amounts. Therefore, when Sn is added, the Sn content should be 0.01 % or more. On the other hand, an excess of Sn decreases low-temperature toughness. Therefore, the Sn content is set to 0.30 % or less, preferably 0.25 % or less.

Sb: 0.01 % or more and 0.30 % or less

[0038] Sb, like Sn, is an element that has the effect of improving the corrosion resistance of the steel plate and is effective even when contained in small amounts. Therefore, when Sb is added, the Sb content should be 0.01 % or more. On the other hand, an excess of Sb decreases low-temperature toughness, and additionally increases costs. Therefore, the Sb content is set to 0.30 % or less, preferably 0.25 % or less.

W: more than 0 % and 2.00 % or less

[0039] W, like Sn and Sb, is an element that has the effect of improving the corrosion resistance of the steel plate and is effective even when contained in small amounts. Therefore, when W is added, the W content should be more than 0 %, preferably 0.01 % or more, more preferably 0.05 % or more. On the other hand, an excess of W decreases low-temperature toughness, and additionally increases costs. Therefore, the W content is set to 2.00 % or less, preferably 0.50 % or less.

Co: more than 0 % and 2.00 % or less

[0040] Co, like Sn, Sb, and W, is an element that has the effect of improving the corrosion resistance of the steel plate and is effective even when contained in small amounts. Therefore, when Co is added, the Co content should be more than 0 %, preferably 0.01 % or more, more preferably 0.05 % or more. On the other hand, an excess of Co increases costs. Therefore, the Co content is set to 2.00 % or less, preferably 1.50 % or less.

Ca: 0.0005 % or more and 0.0050 % or less

[0041] Ca is an effective element for morphological control of inclusions such as MnS. The morphological control of inclusions means suppressing the formation of elongated sulfide inclusions and forming granular inclusions. Through this morphological control of inclusions, the low-temperature toughness can be further improved, as well as sulfide stress corrosion cracking resistance. When Ca is added, to obtain the effect, the Ca content should be 0.0005 % or more, preferably 0.0010 % or more. On the other hand, high Ca content may increase the amount of nonmetallic inclusions and decrease low-temperature toughness. Therefore, the Ca content is set to 0.0050 % or less, preferably 0.0040 % or less.

Mg: 0.0005 % or more and 0.0100 % or less

[0042] Mg, like Ca, is an effective element for morphological control of inclusions such as MnS. Through this morphological control of inclusions, the low-temperature toughness can be further improved, as well as sulfide stress corrosion cracking resistance. When Mg is added, to obtain the effect, the Mg content should be 0.0005 % or more, preferably 0.0010 % or more. On the other hand, high Mg content may increase the amount of nonmetallic inclusions and decrease low-temperature toughness. Therefore, the Mg content is set to 0.0100 % or less, preferably 0.0050 % or less, more preferably 0.0040 % or less.

Zr: 0.0005 % or more and 0.0050 % or less

[0043] Zr, like Ca and Mg, is an effective element for morphological control of inclusions such as MnS. Through this morphological control of inclusions, the low-temperature toughness can be further improved, as well as sulfide stress corrosion cracking resistance. When Zr is added, to obtain the effect, the Zr content should be 0.0005 % or more, preferably 0.0010 % or more. On the other hand, high Zr content may increase the amount of nonmetallic inclusions and decrease low-temperature toughness. Therefore, the Zr content is set to 0.0050 % or less, preferably 0.0040 % or less.

Ta: 0.01 % or more and 0.20 % or less

[0044] Ta is an effective element for further improving the strength of the steel plate. When Ta is added, to obtain the effect, the Ta content should be 0.01 % or more. On the other hand, when the Ta content exceeds 0.20 %, low-temperature toughness decreases due to precipitate formation. Therefore, the Ta content is set to 0.20 % or less.

Y: 0.001 % or more and 0.010 % or less

[0045] Y is an effective element for the formation of oxides that are stable at high temperatures. The formation of the oxides can effectively suppress the coarsening of prior austenite grains in the heat-affected zone and improve the toughness of the welded portion. When Y is added, to obtain the effect, the Y content should be 0.001 % or more. On the

other hand, when the Y content exceeds 0.010 %, the amount of inclusions increases and low-temperature toughness decreases. Therefore, the Y content is set to 0.010 % or less.

REM: 0.0010 % or more and 0.0200 % or less

[0046] REM (rare earth metal), like Ca, Mg, and Zr, is an effective element for morphological control of inclusions such as MnS. Through this morphological control of inclusions, the low-temperature toughness can be further improved, as well as sulfide stress corrosion cracking resistance. When REM is added, to obtain the effect, the REM content should be 0.0010 % or more, preferably 0.0020 % or more. On the other hand, high REM content may increase the amount of nonmetallic inclusions and decrease low-temperature toughness. Therefore, the REM content is set to 0.0200 % or less.

[Microstructure]

[0047] Next, the microstructure of the steel plate of this disclosure will be described. The steel plate according to one of the disclosed embodiments satisfies the following conditions (1) to (3) for microstructure.

- (1) The volume fraction of retained austenite at a 1/4 thickness position is less than 3.0 %.
- (2) The maximum prior austenite grain size at a 1/2 thickness position is 100 μm or less.
- (3) The ratio b/a of an average value b in the top 5 % of prior austenite grain sizes to an average prior austenite grain size a at the 1/2 thickness position is 4.5 or less.

[0048] The term "prior austenite grain" refers to the γ grain before transformation, as seen from a steel plate in which austenite (γ) has cooled and undergone microstructure transformation to form a different microstructure.

Retained austenite (γ): less than 3.0 %

[0049] In conventional techniques, low-temperature toughness is improved by increasing the content of retained austenite. However, increasing the content of retained austenite requires dual-phase region quenching, which decreases manufacturability. Therefore, in this disclosure, the content of retained austenite at the 1/4 thickness position is set to, in volume fraction, less than 3.0 %, preferably 2.8 % or less, more preferably 2.6 % or less. On the other hand, no lower limit is placed on the volume fraction of retained austenite and the volume fraction of retained austenite may be 0 %, or 0.5 % or more.

[0050] Although there are no restrictions on the microstructure other than retained austenite, the microstructure should be composed mainly of tempered martensite and bainite. Specifically, the total area ratio of tempered martensite and bainite is preferably 90 % or more. No upper limit is placed on the total area ratio of tempered martensite and bainite, but the total area ratio may be 100 %.

[0051] The volume fraction of retained austenite can be measured by X-ray diffraction. More specifically, it can be measured by the method described in the EXAMPLES section.

Maximum prior γ grain size: 100 μm or less

[0052] The presence of coarse prior austenite grains decreases low-temperature toughness because stress is concentrated in the coarse prior austenite grains and they become initiation points for fracture. Therefore, in this disclosure, the maximum prior austenite grain size at the 1/2 thickness position is set to 100 μm or less, preferably 80 μm or less. On the other hand, no lower limit is placed on the maximum grain size but setting the maximum prior γ grain size to 20 μm or less requires very strict control of quenching conditions and the like and is therefore inferior in manufacturability. Therefore, from the standpoint of industrial production, the maximum grain size is preferably more than 20 μm , more preferably 22 μm or more, even more preferably 25 μm or more. In this disclosure, the circle equivalent diameter shall be used as the prior austenite grain size.

[0053] The maximum prior austenite grain size can be measured by optical microscopy. More specifically, it can be measured by the method described in the EXAMPLES section.

$b/a \leq 4.0$

[0054] In this disclosure, the ratio b/a of an average value b in the top 5 % of prior austenite grain sizes to an average prior austenite grain size a is set to 4.5 or less. When b/a is more than 4.5, homogenization of the prior austenite grains is insufficient, and toughness is decreased due to the presence of partially coarse crystal grains. b/a is preferably 4.0 or less, more preferably 3.5 or less, even more preferably 3.0 or less. On the other hand, no lower limit is placed on b/a , but the

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theoretical lower limit is 1. b/a closer to 1 is more preferable because it means that the formation of coarse crystal grains is suppressed and homogenization has progressed. From the standpoint of industrial production, b/a may be 1.2 or more, or 1.3 or more. For the values of a and b, the values at the 1/2 thickness position are used.

[0055] The average grain size a and average value b can be measured by optical microscopy. More specifically, they can be measured by the method described in the EXAMPLES section.

[0056] The aspect ratio of prior austenite grains at the 1/2 thickness position is not limited but is preferably 2.0 or less. When the aspect ratio is 2.0 or less, the anisotropy of mechanical properties, especially low-temperature toughness, is improved.

[0057] The aspect ratio of prior austenite grains can be measured by optical microscopy. More specifically, it can be measured by the method described in the EXAMPLES section.

[Plate thickness]

Plate thickness: 40 mm or less

[0058] When the steel plate thickness exceeds 40 mm, austenite grain refinement and homogenization are insufficient during hot rolling. And as a result, the refinement and homogenization of steel plate microstructure after reheating quenching and tempering are insufficient, resulting in a decrease in low-temperature toughness. Therefore, the steel plate thickness should be 40 mm or less. Furthermore, when the plate thickness is 40 mm or less, the heat treatment time is shorter, which can reduce the effect of tempering embrittlement during tempering. Therefore, the restriction of Si content is small in this disclosure. On the other hand, no lower limit is placed on the plate thickness, but the plate thickness is preferably 6 mm or more.

[Tensile strength]

TS: 690 MPa or more

[0059] The tensile strength (TS) of the steel plate according to this disclosure is set to 690 MPa or more. The steel plate has a high tensile strength of 690 MPa or more, and thus it can be suitably used for applications such as LNG tanks. On the other hand, no upper limit is placed on the tensile strength, but tensile strength may be, for example, 830 MPa or less, or 800 MPa or less.

[Yield stress]

YS: 585 MPa or more

[0060] The yield stress (YS) of the steel plate according to this disclosure is set to 585 MPa or more. The steel plate has a high yield stress of 585 MPa or more, and thus it can be suitably used for applications such as LNG tanks. On the other hand, no upper limit is placed on the yield stress, but yield stress may be, for example, 790 MPa or less, or 770 MPa or less.

[0061] The tensile strength and yield stress can be measured by tensile test in accordance with JIS Z 2204. More specifically, they can be measured by the method described in the EXAMPLES section.

[Low-temperature toughness]

[0062] The low-temperature toughness of the steel plate according to this disclosure preferably has an absorbed energy vE_{-196} at -196 °C of 100 J or more. The steel plate has high low-temperature toughness of a vE_{-196} of 100 J or more, making it suitable for use in LNG tanks and other applications. The absorbed energy vE_{-196} is preferably 150 J or more. On the other hand, no upper limit is placed on the absorbed energy vE_{-196} , but the absorbed energy may be, for example, 400 J or less, or 350 J or less.

[0063] The absorbed energy vE_{-196} can be measured by Charpy impact test in accordance with JIS Z 2242. More specifically, it can be measured by the method described in the EXAMPLES section.

[Manufacturing method]

[0064] The following describes a method for producing a steel plate according to one of the disclosed embodiments. The steel plate can be produced by sequentially applying the processes (1) to (5) below to a steel material having the chemical composition described above:

- (1) Heating
- (2) Hot rolling
- (3) Cooling
- (4) Reheating quenching
- (5) Tempering.

[0065] The conditions of each process are described below. In the following description, temperatures given in "°C" refer to the temperature at the 1/2 thickness position. The temperature at the 1/2 thickness position can be determined by differential calculations or other means.

(Steel material)

[0066] Any form of material can be used as the steel material. The steel material may be, for example, a steel slab. The steel material may be produced by any method, but for example, can be produced by smelting steel having the aforementioned chemical composition by a conventional method and subjecting the smelted steel to casting. The smelting can be performed by any method using a converter, an electric furnace, an induction furnace, and the like. The casting is preferably performed by continuous casting from the standpoint of productivity but may be performed by ingot casting.

(Heating)

[0067] In the heating process, the steel material is heated to a heating temperature of 900 °C or higher and 1200 °C or lower. The heating may be performed after the steel material obtained by casting or other methods has been once cooled, or the steel material obtained may be directly subjected to the heating without cooling.

[0068] The steel material is heated in order to dissolve the precipitates in the microstructure of the steel material. When the heating temperature is lower than 900 °C, the influence of undissolved precipitates becomes significant and a uniform microstructure cannot be obtained due to the formation of mixed grains, etc. Therefore, the heating temperature of the steel material is set to 900 °C or higher. On the other hand, when the heating temperature exceeds 1200 °C, reverse transformed austenite grains significantly coarsen, and the steel plate microstructure cannot be sufficiently refined even through the subsequent hot rolling and heat treatment processes. It also requires excessive energy and reduces manufacturability. Therefore, the heating temperature of the steel material is set to 1200 °C or lower, preferably 1150 °C or lower. The heating time is not limited but is preferably 2 hours or more. The heating time is preferably 8 hours or less.

(Hot rolling)

[0069] In the hot rolling process, the steel material heated in the heating process is hot rolled to make a hot-rolled steel plate with a thickness of 40 mm or less. Rolling finish temperature is not limited, but is preferably 700 °C or higher, which is austenite single phase region. No upper limit is placed on the rolling finish temperature, but the rolling finish temperature is preferably 950 °C or lower, more preferably 920 °C or lower.

Rolling reduction ratio: 5 or more

[0070] In order to achieve refinement and homogenization of the steel plate microstructure, it is necessary to apply sufficient working during the hot rolling process to promote recrystallization of austenite grains. When the rolling reduction ratio is less than 5 during the hot rolling process, the working ratio is insufficient and coarse austenite grains remain, resulting in a decrease in low-temperature toughness. When the rolling reduction ratio is less than 5, detoxification of casting defects such as internal minute voids, called porosity, is insufficient, and low-temperature toughness decreases. Therefore, the rolling reduction ratio in the hot rolling process is set to 5 or more, preferably 6 or more, more preferably 10 or more. On the other hand, no upper limit is placed on the rolling reduction ratio, but the rolling reduction ratio is preferably 50 or less. The rolling reduction ratio is defined as (thickness of steel material / thickness of hot-rolled steel plate after hot rolling).

Number of passes where rolling reduction is 10 % or more out of final 5 passes: 2 or more

[0071] For refinement and homogenization of the steel plate microstructure, recrystallization of austenite grains during the latter half of the hot rolling process is particularly effective. For this reason, the number of passes where the rolling reduction per pass is 10 % or more out of the final 5 passes of the hot rolling process is set to 2 or more. When the number of passes is less than 2, homogenization of austenite grains does not progress sufficiently. As a result, b/a in the final steel

plate becomes more than 4.0, and low-temperature toughness deteriorates. From the viewpoint of further reducing b/a, the number of passes where the rolling reduction per pass is 10 % or more out of the final 5 passes of the hot rolling process is preferably 3 or more, more preferably 4 or more, even more preferably 5.

(Cooling)

[0072] Next, the hot-rolled steel plate obtained in the hot rolling process is cooled. The cooling suppresses coarsening of precipitates and improves strength and toughness. The cooling stop temperature in the cooling process is not particularly limited, but may be, for example, room temperature (e.g., 20 °C) or higher. The cooling stop temperature is preferably 400 °C or lower.

[0073] The cooling is not limited and can be performed by any method, for example, air cooling or water cooling. Water cooling, such as spray cooling, mist cooling, or laminar cooling, may be performed to enhance required properties such as strength and low-temperature toughness. However, because of the rapid cooling in water cooling, the elongated microstructure formed during rolling tends to remain, resulting in greater anisotropy in microstructure. Therefore, from the perspective of reducing the anisotropy in microstructure, air cooling is preferred.

[Reheating quenching]

[0074] In the reheating quenching process, the cooled hot-rolled steel plate is quenched after being heated to a reheating temperature of Ac3 point or higher and 900 °C or lower. Reheating to Ac3 point or higher causes reverse transformation of the microstructure of the entire hot-rolled steel plate to austenite. As a result, the microstructure of steel plate is further refined, which improves low-temperature toughness. When the reheating temperature is lower than Ac3 point, the ferrite phase shall be included in the microstructure of the steel plate after heating, which makes the microstructure less uniform and decreases low-temperature toughness. On the other hand, when the reheating temperature exceeds 900 °C, austenite grains grow and coarsen, resulting in a decrease in low-temperature toughness.

[0075] Ac3 point is calculated by the following formula (1).

$$\text{Ac3}(^{\circ}\text{C}) = 937.2 - 436.5\text{C} + 56\text{Si} - 19.7\text{Mn} - 16.3\text{Cu} - 26.6\text{Ni} - 4.9\text{Cr} + 38.1\text{Mo} + 124.8\text{V} + 136.3\text{Ti} - 19.1\text{Nb} + 198.4\text{Al} + 3315\text{B} \quad (1)$$

where each element symbol in Formula (1) indicates a content, in mass%, of a corresponding element and is taken to be 0 when the corresponding element is not contained.

[0076] Quenching can be performed under any conditions without limitation, but preferably by water cooling.

[0077] The conditions for quenching are not limited but cooling to a cooling stop temperature of lower than 200 °C is preferred. The cooling stop temperature is more preferably 100 °C or lower, even more preferably 50 °C or lower. On the other hand, no lower limit is placed on the cooling stop temperature, but for example, the cooling stop temperature may be room temperature or higher.

(Tempering)

[0078] In the tempering process, the reheated and quenched steel plate is tempered at a tempering temperature of 500 °C or higher and 650 °C or lower. When the tempering temperature is lower than 500 °C, the yield stress is decreased. On the other hand, when the tempering temperature exceeds 650 °C, the strength is significantly decreased due to recrystallization of the steel plate microstructure. Therefore, the tempering temperature is set to 500 °C or higher and 650 °C or lower.

[0079] After the tempering process, it is preferable to cool the steel plate. The method for cooling is not limited and can be performed by any method, for example, air cooling or water cooling.

EXAMPLES

[0080] The following examples will describe the effects of this disclosure. However, this disclosure is not limited to the following examples.

[0081] Steel slabs as steel materials were prepared by smelting steels having the chemical compositions listed in Table 1. The obtained steel slabs were sequentially subjected to heating, hot rolling, cooling, reheating quenching, and tempering under the conditions listed in Table 2 to produce steel plates. In the reheating quenching, the steel plates were reheated to the reheating temperatures listed in Table 2 and then cooled to a cooling stop temperature below 200 °C.

[0082] Then, for each of the obtained steel plates, the content (volume fraction) of retained austenite, maximum prior austenite grain size, and ratio b/a, an average value b in the top 5 % of prior austenite grain sizes to an average prior

austenite grain size a , were measured by the procedures below. The measurement results are listed in Table 3.

(Content of retained austenite)

[0083] A test piece for X-ray diffraction was taken parallel to the plate surface so that the measurement surface was at the 1/4 thickness position of the obtained steel plate. The test piece was subjected to mirror polishing and electropolishing before being subjected to X-ray diffraction. The diffraction intensities of the (200) and (211) planes of α -Fe and the (200), (220), and (311) planes of γ -Fe appearing in the symmetrical reflection X-ray diffraction pattern were determined, and the content of retained austenite V_γ was calculated using the following formula.

$$V_\gamma = 100 / ((I_{\alpha}R_\gamma / I_\gamma R_\alpha) + 1)$$

where V_γ is volume fraction of retained austenite, I is diffracted X-ray intensity and R is theoretical intensity value per unit volume. The integrated intensity after background removal was used as the diffracted X-ray intensity I . Since sufficient measurement accuracy cannot be obtained when the content of retained austenite is extremely small, when the calculated retained austenite content was 0.5 % or less, the microstructure was considered to contain virtually no retained austenite (0 %), and the volume fraction column of retained austenite (γ) in Table 3 was blank (-).

[0084] Although only the content of retained austenite (γ) is listed in Table 3, the steel plates in all the examples and comparative examples had a microstructure composed mainly of tempered martensite and bainite. Specifically, the total area ratio of tempered martensite and bainite was 90 % or more.

(Crystal grain size of prior γ grains)

[0085] From the obtained steel plate, a test piece for microstructure observation was taken so that the observation position was at 1/2 thickness position. The test piece was embedded in resin so that the cross section in the rolling direction (L-direction) was the observation plane and subjected to mirror polishing. Picric acid corrosion was then performed, followed by observation under an optical microscopy at 200x magnification. The images of the 10 fields of view taken were analyzed to determine the maximum prior austenite grain size and the ratio b/a , an average value b in the top 5 % of prior austenite grain sizes to an average prior austenite grain size a . Here, the circle equivalent diameter was used as the prior austenite grain size.

[0086] The ratio obtained by dividing the major axis by the minor axis in an elliptical approximation of the prior austenite grain was calculated as aspect ratio.

[0087] Furthermore, the mechanical properties of the obtained steel plate were evaluated using the procedures below. The evaluation results are listed in Table 3.

(Strength)

[0088] A No. 5 test piece as described in JIS Z 2201 was taken so that the plate transverse direction (C direction) of the steel plate coincided with the tensile direction, and a tensile test was conducted in accordance with JIS Z 2204 to determine yield stress (YS) and tensile strength (TS).

(Low-temperature toughness)

[0089] Charpy impact test was performed to evaluate low-temperature toughness. Specifically, a test piece for Charpy impact test with a 2 mm V-notch was first taken from the steel plate so that the rolling direction (L-direction) of the steel plate was the long side. The test piece was cooled to -196 °C in liquid nitrogen, and Charpy impact test was conducted in accordance with JIS Z 2242 to measure the absorbed energy vE_{-196} at -196 °C. The same measurements were made on three test pieces, and the average of absorbed energy values vE_{-196} obtained is listed in Table 3. When the plate thickness was 12 mm or less, a sub-size test piece was used for evaluation.

[0090] When a normal test piece was used, vE_{-196} of 100 J or more was considered "passed". When a sub-size test piece was used, vE_{-196} of 50 J or more was considered "passed".

[0091] As can be seen from the results listed in Table 3, the steel plates of this disclosure satisfied the above properties and had excellent strength (tensile strength and yield stress), low-temperature toughness, and manufacturability. On the other hand, the steel plates of comparative examples that fell outside the scope of this disclosure were inferior in at least one of strength (tensile strength and yield stress), low-temperature toughness, or manufacturability.

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Table 1

5	Steel sample ID	Chemical Composition (mass%)*								Ac3 /°C	Remarks	
		C	Si	Mn	P	S	Ni	Al	N			Others
	A	0.025	0.30	1.25	0.003	0.0008	8.5	0.032	0.0026	Cu:0.15, Mo:0.1, REM:0.0078	699	Conforming steel
10	B	0.035	0.03	0.55	0.004	0.0008	9.1	0.015	0.0022	Cu:0.2, Cr:0.45, Mo:0.08, Nb:0.005, V:0.033, Y:0.004	674	Conforming steel
15	C	0.033	0.10	0.63	0.003	0.0007	7.6	0.022	0.0018	Ti0.008, B:0.0012, Zr:0.0018	723	Conforming steel
20	D	0.039	0.24	0.53	0.003	0.0010	9.2	0.020	0.0025	Mo:0.09	686	Conforming steel
	E	0.073	0.18	0.98	0.003	0.0008	5.5	0.045	0.0027	W:0.22, Co:0.3, Ca:0.002	756	Conforming steel
25	F	0.028	0.87	0.55	0.004	0.0019	9.8	0.025	0.0043	Sn:0.05, Mg:0.0025	706	Conforming steel
	G	0.052	0.25	0.61	0.004	0.0006	9.1	0.029	0.0028	-	678	Conforming steel
30	H	0.058	0.05	0.55	0.003	0.0005	9.0	0.018	0.0020	-	666	Conforming steel
	I	0.047	0.25	0.66	0.002	0.0011	8.8	0.012	0.0014	-	684	Conforming steel
35	J	0.083	0.09	0.15	0.003	0.0006	7.1	0.049	0.0018	Cr:0.4, Mo:0.1	722	Conforming steel
	K	0.138	0.20	0.73	0.005	0.0018	9.5	0.025	0.0032	Cr:0.4, V:0.025, Ta:0.05	622	Conforming steel
40	L	0.054	0.08	0.80	0.003	0.0020	7.0	0.029	0.0046	Cr:0.4, Mo:0.09	721	Conforming steel
	M	0.105	0.18	0.44	0.008	0.0011	6.8	0.078	0.0065	Sb:0.03	723	Conforming steel
45	<u>N</u>	<u>0.232</u>	0.15	0.52	0.005	0.0008	8.3	0.029	0.0041	-	610	Comparative steel
	<u>O</u>	0.063	<u>1.22</u>	0.55	0.008	0.0012	9.3	0.026	0.0024	-	722	Comparative steel
50	<u>P</u>	0.086	0.05	<u>2.40</u>	0.006	0.0016	7.9	0.032	0.0033	-	648	Comparative steel
	<u>Q</u>	0.055	0.33	0.55	<u>0.012</u>	0.0009	8.8	0.037	0.0029	-	692	Comparative steel
55	<u>R</u>	0.048	0.25	0.60	0.009	<u>0.0063</u>	8.3	0.026	0.0041	-	701	Comparative steel
	<u>S</u>	0.052	0.23	0.45	0.009	0.0013	<u>4.3</u>	0.032	0.0033	-	808	Comparative steel

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(continued)

Steel sample ID	Chemical Composition (mass%)*									Ac3 /°C	Remarks
	C	Si	Mn	P	S	Ni	Al	N	Others		
<u>I</u>	0.070	0.21	0.63	0.006	0.0006	8.4	<u>0.132</u>	0.0026	-	706	Comparative steel
<u>U</u>	0.061	0.29	0.53	0.006	0.0009	8.2	0.046	<u>0.0105</u>	-	705	Comparative steel
*The balance is Fe and inevitable impurities.											

[Table 2]

Table 2

No.	Production Conditions												Remarks
	Steel material		Heating		Hot rolling				Cooling	Reheating quenching		Tempering	
					Rolling reduction ratio	Number of passes*	Hot-rolling finish temp. /°C	Thickness /mm		Reheating temp. /°C	Quenching method		
Steel sample ID	Thickness /mm	Heating temp. /°C	Heating time /hr										
1	A	200	1200	2.0	33	2	850	6	air cooling	750	water cooling	550	Ex.
2	B	200	900	4.0	33	3	750	6	water cooling	750	water cooling	630	Ex.
3	C	260	1050	6.0	13	4	800	20	air cooling	800	water cooling	630	Ex.
4	D	250	1000	5.0	6	2	920	40	air cooling	800	water cooling	580	Ex.
5	E	250	1100	6.0	42	3	750	6	air cooling	900	water cooling	600	Ex.
6	F	310	900	5.0	10	5	850	32	air cooling	850	water cooling	630	Ex.
7	G	260	1000	4.5	13	4	800	20	air cooling	800	water cooling	600	Ex.
8	H	260	1100	4.5	13	5	850	20	air cooling	800	water cooling	550	Ex.
9	I	260	1050	5.0	7	5	900	40	air cooling	800	water cooling	600	Ex.
10	J	310	1000	8.0	8	5	930	40	air cooling	800	water cooling	650	Ex.
11	K	260	1100	6.0	13	4	800	20	air cooling	700	water cooling	600	Ex.
12	L	260	1000	6.0	8	2	850	32	water cooling	800	water cooling	500	Ex.
13	M	160	1000	3.0	5	4	800	32	air cooling	800	water cooling	600	Ex.
14	N	260	1000	6.0	13	4	800	20	air cooling	700	water cooling	600	Comp. Ex.
15	Q	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	600	Comp. Ex.
16	P	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	550	Comp. Ex.
17	Q	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	650	Comp. Ex.
18	R	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	600	Comp. Ex.
19	S	260	1000	6.0	13	4	850	20	air cooling	900	water cooling	600	Comp. Ex.
20	T	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	600	Comp. Ex.
21	U	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	600	Comp. Ex.
22	G	160	1000	6.0	4	4	850	40	air cooling	800	water cooling	600	Comp. Ex.
23	G	260	1100	7.0	5	4	900	50	air cooling	800	water cooling	600	Comp. Ex.
24	G	310	1000	6.0	5	4	900	60	air cooling	800	water cooling	600	Comp. Ex.
25	G	260	800	6.0	13	4	700	20	air cooling	800	water cooling	600	Comp. Ex.
26	G	260	1250	6.0	7	4	800	40	air cooling	800	water cooling	600	Comp. Ex.
27	G	260	1000	6.0	13	1	800	20	air cooling	800	water cooling	600	Comp. Ex.
28	G	260	1000	6.0	13	4	800	20	air cooling	950	water cooling	600	Comp. Ex.
29	G	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	400	Comp. Ex.
30	G	260	1000	6.0	13	4	800	20	air cooling	800	water cooling	700	Comp. Ex.

*Number of passes where rolling reduction per pass is 10 % or more out of final 5 passes

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Table 3

5	No.	Measurement Results							Remarks
		Microstructure				Mechanical properties			
		retained γ	prior γ grain						
		volume fraction / %	aspect ratio	maximum grain size / μm	b/a	YS / MPa	TS / MPa	vE_{-196}/J	
10	1	1.5	1.7	35	3.4	712	741	132	Ex.
	2	1.0	1.6	28	2.1	721	715	158	Ex.
	3	1.5	1.5	57	2.5	711	732	222	Ex.
	4	2.3	1.1	78	4.1	725	803	125	Ex.
15	5	0.8	1.8	24	2.0	658	730	152	Ex.
	6	2.6	1.6	58	28	598	706	332	Ex.
	7	2.5	1.5	43	2.4	699	718	310	Ex.
	8	-	1.6	36	2.0	702	730	295	Ex.
20	9	1.1	1.2	63	23	712	733	253	Ex.
	10	2.3	1.3	69	3.3	703	741	182	Ex.
	11	1.8	1.4	51	23	759	783	310	Ex.
	12	2.2	1.2	72	43	734	818	106	Ex.
25	13	1.3	1.5	75	3.0	712	743	153	Ex.
	14	2.4	1.4	53	21	791	823	15	Comp. Ex.
	15	2.2	1.5	48	2.2	723	755	10	Comp. Ex.
	16	1.5	1.3	57	1.8	716	748	15	Comp. Ex.
30	17	1.3	1.3	60	1.7	703	726	20	Comp. Ex.
	18	1.5	1.4	55	1.8	725	773	18	Comp. Ex.
	19	-	1.3	43	2.0	658	693	15	Comp. Ex.
	20	2.2	1.3	49	2.2	703	741	20	Comp. Ex.
35	21	2.1	1.3	52	2.1	655	712	15	Comp. Ex.
	22	1.8	1.7	<u>106</u>	<u>6.1</u>	678	703	35	Comp. Ex.
	23	1.6	1.8	88	<u>5.2</u>	718	743	78	Comp. Ex.
	24	1.5	1.7	92	4.4	711	725	85	Comp. Ex.
40	25	1.5	4.1	60	<u>5.3</u>	645	703	39	Comp. Ex.
	26	2.2	1.3	<u>163</u>	<u>7.3</u>	698	722	20	Comp. Ex.
	27	1.9	1.5	48	<u>8.1</u>	703	741	25	Comp. Ex.
	28	1.8	2.5	<u>115</u>	3.2	783	806	43	Comp. Ex.
45	29	2.0	1.4	59	3.1	<u>550</u>	895	185	Comp. Ex.
	30	1.7	1.5	48	3.9	605	<u>645</u>	241	Comp. Ex.

Claims

55

1. A steel plate comprising:

a chemical composition containing, in mass%,
C: 0.01 % or more and 0.15 % or less,

Si: 0.01 % or more and 1.00 % or less,
Mn: 0.10 % or more and 2.00 % or less,
P: 0.010 % or less,
S: 0.0050 % or less,
5 Ni: 5.0 % or more and 10.0 % or less,
Al: 0.002 % or more and 0.100 % or less, and
N: 0.0080 % or less
with the balance being Fe and inevitable impurities; and
a microstructure in which
10 a volume fraction of retained austenite at a 1/4 thickness position is less than 3.0 %,
the maximum prior austenite grain size at a 1/2 thickness position is 100 μm or less, and
a ratio b/a of an average value b in the top 5 % of prior austenite grain sizes to an average prior austenite grain size
a at the 1/2 thickness position is 4.5 or less, with
a thickness of 40 mm or less,
15 a yield stress of 585 MPa or more, and
a tensile strength of 690 MPa or more.

2. The steel plate according to claim 1, wherein the chemical composition further contains, in mass%, at least one
selected from the group consisting of

20 Cu: 0.01 % or more and 1.00 % or less,
Cr: 0.01 % or more and 1.50 % or less,
Mo: 0.03 % or more and 1.0 % or less,
Nb: 0.001 % or more and 0.030 % or less,
25 V: 0.01 % or more and 0.10 % or less,
Ti: 0.003 % or more and 0.050 % or less,
B: 0.0003 % or more and 0.0050 % or less,
Sn: 0.01 % or more and 0.30 % or less,
Sb: 0.01 % or more and 0.30 % or less,
30 W: more than 0 % and 2.00 % or less,
Co: more than 0 % and 2.00 % or less,
Ca: 0.0005 % or more and 0.0050 % or less,
Mg: 0.0005 % or more and 0.0100 % or less,
Zr: 0.0005 % or more and 0.0050 % or less,
35 Ta: 0.01 % or more and 0.20 % or less,
Y: 0.001 % or more and 0.010 % or less, and
REM: 0.0010 % or more and 0.0200 % or less.

3. A method for producing a steel plate, comprising

40 heating a steel material having the chemical composition according to claim 1 or 2 to a heating temperature of 900
 $^{\circ}\text{C}$ or higher and 1200 $^{\circ}\text{C}$ or lower,
hot rolling the heated steel material under the condition that a rolling reduction ratio is 5 or more and the number of
passes where a rolling reduction per pass is 10 % or more out of the final 5 passes is 2 or more to obtain a hot-rolled
45 steel plate having a thickness of 40 mm or less,
cooling the hot-rolled steel plate,
subjecting the cooled hot-rolled steel plate to reheating quenching by which the cooled hot-rolled steel plate is
reheated to a reheating temperature of Ac_3 point or higher and 900 $^{\circ}\text{C}$ or lower and quenched, and
tempering the reheated and quenched hot-rolled steel plate at a tempering temperature of 500 $^{\circ}\text{C}$ or higher and
50 650 $^{\circ}\text{C}$ or lower.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/013709

A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/02(2006.01)i; *C22C 38/00*(2006.01)i; *C22C 38/08*(2006.01)i; *C22C 38/60*(2006.01)i
 FI: C22C38/00 302Z; C22C38/08; C22C38/60; C21D8/02 B

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)

C21D8/02; C22C38/00; C22C38/08; C22C38/60

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2023
 Registered utility model specifications of Japan 1996-2023
 Published registered utility model applications of Japan 1994-2023

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2009-074123 A (NIPPON STEEL CORP) 09 April 2009 (2009-04-09)	1-3
A	CN 110129685 A (NANJING STEEL INC.) 16 August 2019 (2019-08-16)	1-3
A	WO 2020/237975 A1 (NANJING IRON AND STEEL CO., LTD.) 03 December 2020 (2020-12-03)	1-3
P, A	WO 2022/118592 A1 (JFE STEEL CORP) 09 June 2022 (2022-06-09)	1-3

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

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

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/013709

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JP	2009-074123	A	09 April 2009	(Family: none)			
CN	110129685	A	16 August 2019	(Family: none)			
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				KR	10-2022-0004220	A	
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REFERENCES CITED IN THE DESCRIPTION

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- JP H06184630 A [0005] [0007]
- WO 2020136829 A1 [0006] [0007]