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

(11) **EP 4 403 660 A1**

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

(43) Date of publication:
24.07.2024 Bulletin 2024/30

(21) Application number: **22895236.2**

(22) Date of filing: **22.09.2022**

(51) International Patent Classification (IPC):
C22C 38/00 (2006.01) ***C21D 8/02*** (2006.01)
C22C 38/06 (2006.01) ***C22C 38/58*** (2006.01)

(52) Cooperative Patent Classification (CPC):
C21D 8/02; C22C 38/00; C22C 38/06; C22C 38/58

(86) International application number:
PCT/JP2022/035522

(87) International publication number:
WO 2023/089950 (25.05.2023 Gazette 2023/21)

(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: **19.11.2021 JP 2021189013**

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(54) THICK STEEL SHEET AND MANUFACTURING METHOD THEREFOR

(57) Provided is a steel plate having excellent internal properties and capable of being produced at low cost with no need for special equipment. The steel plate comprises a predetermined chemical composition, and an area ratio of void defects at a thickness center position of the steel plate is 0.5 % or less.

EP 4 403 660 A1

Description

TECHNICAL FIELD

[0001] The present disclosure relates to a steel plate and a production method therefor.

BACKGROUND

[0002] In recent years, structures are increasing in size in fields such as ships, line pipes, buildings, bridges, marine structures, wind power generators, construction machinery, and pressure vessels. Accordingly, steel plates used in these fields are also increasing in thickness.

[0003] As techniques related to such thick steel plates (hereafter also referred to as "steel plates") and production methods therefor, for example, JP S58-167045 A (PTL 1) discloses "A steel material hot forging method of performing extend forging on an axisymmetric steel material between an upper anvil and a lower anvil, comprising a step of forming a shape of a cross section perpendicular to an extend forging direction of the steel material into a rectangle or substantially rectangle whose ratio of a length of a long side and a length of a short side is at least 1.4, between start of the extend forging and end of the extend forging."

[0004] JP 6137080 B2 (PTL 2) discloses "A slab forging method comprising continuously subjecting a slab to reduction in a width direction and thereafter in a thickness direction using asymmetric anvils that are upper and lower anvils with different widths, wherein the reduction in the width direction is performed from one end in a longitudinal direction of the slab, at which time a ratio $\Delta L/B$ is limited to 0.20 or less where ΔL is an amount of deviation between end positions of the upper and lower anvils at the other end in the longitudinal direction of the slab and B is a shorter contact length out of respective contact lengths of the upper and lower anvils with the slab."

[0005] JP 6156321 B2 (PTL 3) discloses "A slab hot forging method comprising continuously subjecting a slab produced by continuous casting to reduction in a width direction and thereafter in a thickness direction using asymmetric upper and lower anvils, wherein the reduction of the slab in the width direction is performed in two stages of a first and second stages between which the slab is reversed and in each of which reduction is performed at least twice, the reduction of the slab in the width direction in each stage is performed using an anvil of 400 mm to 1200 mm in width as a short side anvil and an anvil of 800 mm to 1500 mm in width as a long side anvil while shifting a reduction phase at a reduction position by the short side anvil so that $\Delta L \leq 0.20B$ where ΔL is a deviation between a slab feed margin boundary during first reduction of the slab and a center of an anvil contact length (B) during next reduction, and each reduction ratio in the reduction of the slab in the width direction is 4 % or more and a total reduction ratio in the reduction of the slab in the thickness direction is 10 % or more".

[0006] JP H6-69569 B2 (PTL 4) discloses "A production method for an ultra-thick steel plate having excellent internal properties, comprising subjecting cast steel produced by continuous casting to broad side pass rolling in a rough rolling step and further performing rolling to a product thickness in a finish rolling step, wherein in the finish rolling step, rolling is performed in a plurality of passes at a rolling rate of 200 mm/sec to 350 mm/sec".

[0007] JP S59-74220 A (PTL 5) discloses "A production method for a high-toughness steel plate with excellent internal quality through continuous casting, comprising a sequential combination of: immediately after cutting a continuous cast strand of aluminum killed steel containing Al: 0.07 wt% or less into a hot slab with a certain length, hot charging the hot slab into a blooming soaking furnace, soaking the hot slab to a temperature of 1050 °C to 1150 °C, and performing slab rolling so that a value of a shape ratio R according to the following formula will be 0.5 or more; thereafter subjecting the slab to dehydrogenation treatment to reduce diffusible hydrogen contained in a thickness center part of the slab to 1.2 ppm or less; thereafter reheating the slab to 950 °C to 1050 °C and subjecting the slab to plate rolling to obtain a plate with a finished thickness planned to be a required thickness of 50 mm or more; and, after the plate rolling ends, performing accelerated cooling from Ar_3 or a temperature not lower than Ar_3 by 40 °C or more to 500 °C to 350 °C at a heat releasing rate of 15 °C or more per minute.

CITATION LIST

Patent Literature

[0008]

PTL 1: JP S58-167045 A

PTL 2: JP 6137080 B2

PTL 3: JP 6156321 B2

PTL 4: JP H6-69569 B2

PTL 5: JP S59-74220 A

SUMMARY

(Technical Problem)

[0009] Steel plates are thick, and therefore have a high risk of fractures such as ductile fractures, brittle fractures, and fatigue fractures. Hence, a steel plate having excellent internal properties with a reduced risk of such fractures is needed. With steel plates produced using the techniques in PTL 1 to PTL 5, however, the risk of such fractures cannot always be reduced sufficiently and excellent internal properties cannot be obtained in some cases.

[0010] The techniques in PTL 1 to PTL 3 involve hot forging a slab. The production efficiency of hot forging is much lower than the production efficiency of hot rolling. Thus, the production capacity is low and the production costs are high.

[0011] The techniques in PTL 4 and PTL 5 involve hot rolling a slab instead of hot forging, but require reduction by rolling (hereinafter referred to as rolling reduction) with a high rolling shape ratio. In order to apply rolling reduction with a high rolling shape ratio in a stage in which the slab is thick, the rolling reduction amount per pass needs to be increased. This requires introducing an expensive rolling line with a high upper limit of load capacity and a high upper limit of torque.

[0012] It could therefore be helpful to provide a steel plate having excellent internal properties and capable of being produced at low cost (i.e. with high productivity) with no need for special equipment. It could also be helpful to provide a production method for the steel plate.

(Solution to Problem)

[0013] Upon careful examination, we discovered the following:

- A slab, which is a rolling or forging material of a steel plate, is typically produced by continuous casting, ingot casting, or the like. Therefore, the final solidification position is usually near the thickness center position of the slab. When molten steel solidifies, volumetric shrinkage occurs. This inevitably causes void defects near the thickness center position of the slab. Such void defects serve as initiation points for fractures such as ductile fractures, brittle fractures, and fatigue fractures. When the amount of void defects is greater, fractures occur more frequently.
- An effective way of reducing the amount of void defects that form near the thickness center position of the slab is to increase the amount of strain introduced near the position during hot rolling. However, the distribution of strain in the thickness direction introduced into the slab by hot rolling is greatest near the surface of the slab that is in contact with the rolling rolls, and decreases toward the thickness center. Thus, the amount of strain is smallest and the void defect annihilation ability is lowest at the thickness center position of the slab.

[0014] We conducted various studies in order to increase the amount of strain near the thickness center position of the slab during hot rolling without using special equipment.

[0015] We consequently discovered the following:

- By performing rolling reduction with at least a certain temperature difference between the surface and the thickness center position of the slab, it is possible to increase the deformation resistance near the surface of the slab relative to the thickness center position of the slab and reduce the amount of strain applied near the surface of the slab. The amount of strain applied near the thickness center position of the slab can be increased by this reduction in the amount of strain applied near the surface of the slab.
- By performing rolling reduction in a state in which the temperature at the thickness center position of the slab is at least a certain level, specifically 700 °C or more, it is possible to close void defects by rolling strain and annihilate them through metal bonding more advantageously.

[0016] We conducted further studies based on these discoveries, and discovered that the amount of void defects that form near the thickness center position of the slab can be significantly reduced particularly by increasing the rolling reduction ratio in the rolling passes that satisfy the following (a) and (b):

(a) the temperature at the thickness center position of the slab: 700 °C or more, and
(b) the temperature difference between the surface and the thickness center position of the slab: 100 °C or more.

[0017] We conducted further studies, and discovered the following:

- By limiting the area ratio of void defects at the thickness center position of the steel plate to 0.5 % or less, it is possible to obtain excellent internal properties with a sufficiently reduced risk of fractures.
- An effective way of limiting the area ratio of void defects at the thickness center position of the steel plate to 0.5 % or less is to set the total rolling reduction ratio in the rolling passes that satisfy the foregoing (a) and (b) in the hot rolling step to more than 30 %.

[0018] The present disclosure is based on these discoveries and further studies.
[0019] We thus provide the following.

[1] A steel plate comprising a chemical composition containing (consisting of), in mass%, C: 0.03 % to 0.18 %, Si: 0.03 % to 0.70 %, Mn: 0.30 % to 2.50 %, P: 0.030 % or less, S: 0.0200 % or less, Al: 0.001 % to 0.100 %, O: 0.0100 % or less, and N: 0.0100 % or less with a balance consisting of Fe and inevitable impurities, wherein an area ratio of void defects at a thickness center position of the steel plate is 0.5 % or less.
[2] The steel plate according to [1], wherein the chemical composition further contains, in mass%, one or more selected from the group consisting of Cu: 2.00 % or less, Ni: 2.50 % or less, Cr: 1.50 % or less, Mo: 1.00 % or less, Nb: 0.100 % or less, Ti: 0.100 % or less, V: 0.30 % or less, B: 0.0100 % or less, W: 0.50 % or less, Ca: 0.0200 % or less, Mg: 0.0200 % or less, and REM: 0.0500 % or less.
[3] A production method for the steel plate according to [1] or [2], the production method comprising: preparing a slab having the chemical composition according to [1] or [2]; and hot rolling the slab, wherein a total rolling reduction ratio in rolling passes that satisfy the following (a) and (b) in the hot rolling is more than 30 %: (a) a temperature at a thickness center position of the slab: 700 °C or more, and (b) a temperature difference between a surface and the thickness center position of the slab: 100 °C or more.

(Advantageous Effect)

[0020] It is thus possible to obtain a steel plate having excellent internal properties and capable of being produced at low cost with no need for special equipment.
[0021] A steel plate according to the present disclosure is not limited to any particular use, and can be used in a wide range of fields in which steel plates are typically used, such as ships, line pipes, buildings, bridges, marine structures, wind power generators, construction machinery, and pressure vessels.

DETAILED DESCRIPTION

[0022] A steel plate according to the present disclosure will be described below by way of embodiments.
[0023] First, the chemical composition of a steel plate according to one embodiment of the present disclosure will be described. While the unit of the content of each element in the chemical composition is "mass%", the content is expressed simply in "%" unless otherwise specified.

C: 0.03 % to 0.18 %

[0024] C is an element that can improve the strength of the steel at the lowest cost. C also contributes to strengthening austenite grain boundaries. If the C content is less than 0.03 %, the grain boundary strength of austenite decreases and the slab undergoes hot cracking. This significantly decreases productivity. Moreover, sufficient strength cannot be obtained. If the C content is more than 0.18 %, weldability decreases, and also toughness decreases. The C content is therefore 0.03 % to 0.18 %. The C content is preferably 0.05 % or more. The C content is preferably 0.17 % or less.

Si: 0.03 % to 0.70 %

[0025] Si is an element effective for deoxidation. If the Si content is less than 0.03 %, the effect is insufficient. If the Si content is more than 0.70 %, weldability decreases. The Si content is therefore 0.03 % to 0.70 %. The Si content is preferably 0.04 % or more. The Si content is preferably 0.60 % or less.

Mn: 0.30 % to 2.50 %

[0026] Mn is an element that improves the quench hardenability of the steel and improves the strength of the steel at low cost. In order to achieve such an effect, the Mn content is 0.30 % or more. If the Mn content is more than 2.50 %, weldability decreases. The Mn content is therefore 0.30 % to 2.50 %. The Mn content is preferably 0.50 % or more. The Mn content is preferably 2.20 % or less.

P: 0.030 % or less

[0027] P is an element that has a strong effect of embrittling grain boundaries. If the P content is high, the toughness of the steel decreases. The P content is therefore 0.030 % or less. The P content is preferably 0.025 % or less. Since a lower P content is more desirable, no lower limit is placed on the P content, and the P content may be 0 %. However, P is an element that is inevitably contained in steel as impurities, and an excessively low P content leads to longer refining time and higher cost. Accordingly, the P content is preferably 0.001 % or more.

S: 0.0200 % or less

[0028] S decreases the toughness of the steel. The S content is therefore 0.0200 % or less. The S content is preferably 0.0100 % or less. Since a lower S content is more desirable, no lower limit is placed on the S content, and the S content may be 0 %. However, S is an element that is inevitably contained in steel as impurities, and an excessively low S content leads to longer refining time and higher cost. Accordingly, the S content is preferably 0.0001 % or more.

Al: 0.001 % to 0.100 %

[0029] Al is an element effective for deoxidation. Al also has the effect of reducing the austenite grain size by forming nitrides. In order to achieve these effects, the Al content is 0.001 % or more. If the Al content is more than 0.100 %, the cleanliness of the steel decreases. This results in decreases in ductility and toughness. The Al content is therefore 0.001 % to 0.100 %. The Al content is preferably 0.005 % or more. The Al content is preferably 0.080 % or less.

O: 0.0100 % or less

[0030] O is an element that decreases ductility and toughness. The O content is therefore 0.0100 % or less. Since a lower O content is more desirable, no lower limit is placed on the O content, and the O content may be 0 %. However, O is an element that is inevitably contained in steel as impurities, and an excessively low O content leads to longer refining time and higher cost. Accordingly, the O content is preferably 0.0005 % or more.

N: 0.0100 % or less

[0031] N is an element that decreases ductility and toughness. The N content is therefore 0.0100 % or less. Since a lower N content is more desirable, no lower limit is placed on the N content, and the N content may be 0 %. However, N is an element that is inevitably contained in steel as impurities, and the N content may be more than 0 % industrially. An excessively low N content leads to longer refining time and higher cost. Accordingly, the N content is preferably 0.0005 % or more.

[0032] While the basic chemical composition of the steel plate according to one embodiment of the present disclosure has been described above, the chemical composition may optionally further contain one or more of the following elements as optional components from the viewpoint of further improving strength and weldability (such as weld toughness and welding activity):

Cu: 2.00 % or less,
Ni: 2.50 % or less,
Cr: 1.50 % or less,
Mo: 1.00 % or less,
Nb: 0.100 % or less,
Ti: 0.100 % or less,
V: 0.30 % or less,
B: 0.0100 % or less,
W: 0.50 % or less,
Ca: 0.0200 % or less,
Mg: 0.0200 % or less, and
REM: 0.0500 % or less.

Cu: 2.00 % or less

[0033] Cu is an element that improves the strength of the steel without greatly degrading toughness. If the Cu content is more than 2.00 %, hot cracking is caused by a Cu-enriched layer formed directly below scale. Accordingly, in the case where Cu is contained, the Cu content is preferably 2.00 % or less. The Cu content is more preferably 0.01 % or more. The Cu content is more preferably 1.50 % or less.

Ni: 2.50 % or less

[0034] Ni is an element that enhances the quench hardenability of the steel. Ni also has the effect of improving toughness. If the Ni content is more than 2.50 %, the production costs increase. Accordingly, in the case where Ni is contained, the Ni content is preferably 2.50 % or less. The Ni content is more preferably 0.01 % or more. The Ni content is more preferably 2.00 % or less.

Cr: 1.50 % or less

[0035] Cr is an element that improves the strength of the steel by improving the quench hardenability of the steel. If the Cr content is more than 1.50 %, weldability decreases. Accordingly, in the case where Cr is contained, the Cr content is preferably 1.50 % or less. The Cr content is more preferably 0.01 % or more. The Cr content is more preferably 1.20 % or less.

Mo: 1.00 % or less

[0036] Mo is an element that improves the strength of the steel by improving the quench hardenability of the steel. If the Mo content is more than 1.00 %, weldability decreases. Accordingly, in the case where Mo is contained, the Mo content is preferably 1.00 % or less. The Mo content is more preferably 0.01 % or more. The Mo content is more preferably 0.80 % or less.

Nb: 0.100 % or less

[0037] Nb is an element that suppresses recrystallization when strain is applied to austenite microstructure, by solute Nb or finely precipitated NbC. Nb also has the effect of raising the non-recrystallization temperature range. If the Nb content is more than 0.100 %, weldability decreases. Accordingly, in the case where Nb is contained, the Nb content is preferably 0.100 % or less. The Nb content is more preferably 0.001 % or more, and further preferably 0.005 % or more. The Nb content is more preferably 0.075 % or less, and further preferably 0.050 % or less.

Ti: 0.100 % or less

[0038] Ti is an element that has the effect of, by precipitating as TiN, pinning crystal grain boundaries and inhibiting grain growth. If the Ti content is more than 0.100 %, the cleanliness of the steel decreases. This results in decreases in ductility and toughness. Accordingly, in the case where Ti is contained, the Ti content is preferably 0.100 % or less. The Ti content is more preferably 0.001 % or more. The Ti content is more preferably 0.080 % or less.

V: 0.30 % or less

[0039] V is an element that improves the strength of the steel by improving the quench hardenability of the steel and forming carbonitrides. If the V content is more than 0.30 %, weldability decreases. Accordingly, in the case where V is contained, the V content is preferably 0.30 % or less. The V content is more preferably 0.01 % or more. The V content is more preferably 0.25 % or less.

B: 0.0100 % or less

[0040] B is an element that improves the strength of the steel by improving the quench hardenability of the steel. If the B content is more than 0.0100 %, weldability decreases. Accordingly, in the case where B is contained, the B content is preferably 0.0100 % or less. The B content is more preferably 0.0001 % or more. The B content is more preferably 0.0070 % or less.

W: 0.50 % or less

[0041] W is an element that improves the strength of the steel by improving the quench hardenability of the steel. If the W content is more than 0.50 %, weldability decreases. Accordingly, in the case where W is contained, the W content is preferably 0.50 % or less. The W content is more preferably 0.01 % or more. The W content is more preferably 0.40 % or less.

Ca: 0.0200 % or less

[0042] Ca is an element that improves weldability by forming oxysulfides having high stability at high temperature. If the Ca content is more than 0.0200 %, the cleanliness of the steel decreases and the toughness of the steel decreases. Accordingly, in the case where Ca is contained, the Ca content is preferably 0.0200 % or less. The Ca content is more preferably 0.0001 % or more. The Ca content is more preferably 0.0180 % or less.

Mg: 0.0200 % or less

[0043] Mg is an element that improves weldability by forming oxysulfides having high stability at high temperature. If the Mg content is more than 0.0200 %, the Mg addition effect is saturated and the effect appropriate to the content cannot be expected, which is economically disadvantageous. Accordingly, in the case where Mg is contained, the Mg content is preferably 0.0200 % or less. The Mg content is more preferably 0.0001 % or more. The Mg content is more preferably 0.0180 % or less.

REM: 0.0500 % or less

[0044] REM (rare earth metal) is an element that improves weldability by forming oxysulfides having high stability at high temperature. If the REM content is more than 0.0500 %, the REM addition effect is saturated and the effect appropriate to the content cannot be expected, which is economically disadvantageous. Accordingly, in the case where REM is contained, the REM content is preferably 0.0500 % or less. The REM content is more preferably 0.0001 % or more. The REM content is more preferably 0.0450 % or less.

[0045] The balance other than the foregoing elements in the chemical composition of the steel plate according to one embodiment of the present disclosure consists of Fe and inevitable impurities. If the content of any of the foregoing elements as optional components is less than the preferable lower limit, the element is treated as inevitable impurities.

[0046] It is very important that, in the steel plate according to one embodiment of the present disclosure, the area ratio of void defects at the thickness center position is 0.5 % or less.

Area ratio of void defects at thickness center position: 0.5 % or less

[0047] Void defects inside a steel plate serve as initiation points for fractures such as ductile fractures, brittle fractures, and fatigue fractures. In particular, if a large amount of void defects remain at the thickness center position of the steel plate, specifically, if the area ratio of void defects at the thickness center position is more than 0.5 %, the frequency of such fractures is high, and a steel plate having excellent internal properties cannot be obtained. The area ratio of void defects at the thickness center position is therefore 0.5 % or less. The area ratio of void defects at the thickness center position is preferably 0.3 % or less. No lower limit is placed on the area ratio of void defects at the thickness center position, and the area ratio of void defects at the thickness center position may be 0 %.

[0048] The area ratio of void defects at the thickness center position is measured in the manner described in the EXAMPLES section below. Herein, the expression "excellent internal properties" means that the area reduction ratio in the thickness direction of the steel plate measured in a tensile test in accordance with ASTM A370 (2010) is 35 % or more. Detailed test conditions are as described in [Tensile test in thickness direction] in the EXAMPLES section below.

[0049] The thickness of the steel plate according to one embodiment of the present disclosure is preferably 30 mm to 240 mm. The thickness of the steel plate according to one embodiment of the present disclosure is more preferably 50 mm or more, and further preferably 101 mm or more. The thickness of the steel plate according to one embodiment of the present disclosure is more preferably 230 mm or less.

[0050] Next, a production method for the steel plate according to one embodiment of the present disclosure will be described.

[0051] The production method for the steel plate according to one embodiment of the present disclosure comprises: preparing a slab (steel material) having the foregoing chemical composition (preparation step); and hot rolling the slab (hot rolling step), wherein a total rolling reduction ratio in rolling passes that satisfy the following (a) and (b) in the hot rolling is more than 30 %:

(a) the temperature at the thickness center position of the slab: 700 °C or more, and
(b) the temperature difference between the surface and the thickness center position of the slab: 100 °C or more.

[0052] Thus, the steel plate according to one embodiment of the present disclosure can be produced favorably. Each step will be described below.
[0053] The surface temperature of the slab can be measured using a radiation thermometer, for example. The temperature at the thickness center position of the slab can be measured, for example, by attaching a thermocouple at the thickness center position of the slab, or by calculating the temperature distribution in the cross section of the slab by thermal analysis and correcting the result using the surface temperature of the slab. Hereafter, the temperature of the slab and steel plate denotes the surface temperature unless otherwise specified. Moreover, the material to be rolled during the hot rolling step is hereafter referred to as "slab" and not "steel plate" (hot-rolled steel plate), for the sake of convenience.

[Preparation step]

[0054] In the preparation step, a slab having the foregoing chemical composition is prepared. The preparation method is not limited. For example, molten steel is obtained by a known steelmaking method such as a converter, an electric furnace, or a vacuum melting furnace. Secondary refining such as ladle refining may be optionally performed. The obtained molten steel is then made into a slab by continuous casting, ingot casting, or the like, and thus a slab having the foregoing chemical composition is prepared. Conditions may be according to conventional methods.

[Hot rolling step]

[0055] Following this, the slab prepared in the preparation step is optionally heated, and subjected to hot rolling to obtain a steel plate (hot-rolled steel plate). It is very important to satisfy the following conditions in the hot rolling.
[0056] Total rolling reduction ratio in rolling passes that satisfy (a) and (b) (hereafter also referred to as "rolling passes under the predetermined conditions"): more than 30 %

(a) the temperature at the thickness center position of the slab: 700 °C or more, and
(b) the temperature difference between the surface and the thickness center position of the slab: 100 °C or more

[0057] An effective way of closing void defects present near the thickness center position of the slab and annihilating them through metal bonding is to apply strain in a state in which the temperature at the thickness center position of the slab is 700 °C or more. In order to increase the amount of strain applied near the thickness center position of the slab, it is necessary to perform rolling in a state in which the temperature difference between the surface and the thickness center position of the slab is 100 °C or more. From the viewpoint of ensuring the amount of strain necessary for closing and annihilating void defects present near the thickness center position of the slab, the total rolling reduction ratio in the rolling passes under the predetermined conditions is more than 30 %. The total rolling reduction ratio in the rolling passes under the predetermined conditions is preferably 40 % or more. Although no upper limit is placed on the total rolling reduction ratio in the rolling passes under the predetermined conditions, the total rolling reduction ratio in the rolling passes under the predetermined conditions is preferably 65 % or less.
[0058] The total rolling reduction ratio in the rolling passes under the predetermined conditions is calculated using the following formula (1):

$$r_t = 100 \times \{(t_{i1} - t_{f1})/t_{i1} + (t_{i2} - t_{f2})/t_{i2} + (t_{i3} - t_{f3})/t_{i3} + \dots + (t_{iN} - t_{fN})/t_{iN}\} \quad \dots (1),$$

where r_t is the total rolling reduction ratio (%) in the rolling passes under the predetermined conditions, t_{iN} is the thickness (mm) of the slab at the start of rolling in the Nth rolling pass among the rolling passes under the predetermined conditions, t_{fN} is the thickness (mm) of the slab at the end of rolling in the Nth rolling pass among the rolling passes under the predetermined conditions, and N is the number of rolling passes under the predetermined conditions.
[0059] Whether the temperature conditions (a) and (b) are satisfied is determined based on the surface temperature of the slab and the temperature at the thickness center position of the slab at the start of rolling in each rolling pass.
[0060] The method of adjusting the temperature difference between the surface and the thickness center position of the slab is not limited. For example, the temperature difference between the surface and the thickness center position of the slab can be adjusted to the foregoing range by forced-cooling the surface of the slab through air cooling, water cooling, or the like.

[0061] Conditions other than the above are not limited and may be according to conventional methods.

[0062] For example, the slab heating temperature is preferably 950 °C to 1300 °C. The total number of rolling passes in the hot rolling is preferably 5 passes to 60 passes. N (the number of rolling passes under the predetermined conditions) is preferably 5 passes to 50 passes. The rolling reduction ratio in the hot rolling (= [the thickness (mm) of the slab at the start of the hot rolling (i.e. the start of the first rolling pass)]/[the thickness (mm) of the steel plate obtained after the end of the hot rolling (i.e. the end of the final rolling pass)]) is preferably 1.6 to 16. The rolling finish temperature (i.e. the delivery temperature in the final pass) is preferably 650 °C to 1000 °C.

[0063] After the hot rolling step, optional cooling treatment may be further performed. Furthermore, optional heat treatment such as quenching, annealing, and tempering may be performed. Cooling treatment conditions and heat treatment conditions are not limited and may be according to conventional methods.

EXAMPLES

[0064] Molten steels having the chemical compositions shown in Table 1 were obtained by steelmaking, and slabs of 260 mm to 600 mm in thickness were prepared by continuous casting, ingot casting, or the like. Each blank space in the element columns in Table 1 indicates that the element is not intentionally added, including not only the case where the element is not contained (0 %) but also the case where the element is inevitably contained.

[0065] Each prepared slab was then subjected to hot rolling under the conditions shown in Table 2 to obtain a steel plate having the thickness (mm) shown in Table 2. The rolling reduction ratio in the hot rolling was in the range of 2.5 to 3.5, and N (the number of rolling passes under the predetermined conditions) was 5 passes to 37 passes. The surface temperature of the slab was measured using a radiation thermometer, and the temperature of the thickness center of the slab was measured using a thermocouple. The temperature difference between the surface and the thickness center position of the slab was adjusted by forced-cooling the surface of the slab through air cooling, water cooling, or the like. Conditions other than the above were according to conventional methods.

[0066] For each obtained steel plate, the area ratio of void defects at the thickness center position was measured in the following manner. The measurement results are shown in Table 2.

[Measurement of area ratio of void defects at thickness center position]

[0067] From each obtained steel plate, a sample for the entire width of the steel plate was collected at the center position in the longitudinal direction (i.e. the rolling direction) of the steel plate so that the cross section in the width direction (i.e. the direction orthogonal to the rolling direction) of the steel plate at the thickness center position of the steel plate would be the evaluation plane. The obtained sample was then mirror polished through alumina buffing for finish. Setting the evaluation region in the sample to the thickness center position ± 3 mm in the thickness direction and the entire plate width in the width direction, the area ratio of void defects in the evaluation region was measured through image analysis. The measured value was taken to be the area ratio of void defects at the thickness center position.

[0068] Moreover, for each obtained steel plate, a tensile test in the thickness direction was conducted to evaluate the internal properties in the following manner. The evaluation results are shown in Table 2.

[Tensile test in thickness direction]

[0069] From each obtained steel plate, a tensile test piece was collected at the center position in the longitudinal direction (i.e. the rolling direction) of the steel plate so that the longitudinal direction of the tensile test piece would be parallel to the thickness direction of the steel plate. Here, the tensile test piece was collected so that the longitudinal center position of the tensile test piece would be the thickness center position (i.e. the position of 1/2 of the thickness) of the steel plate. Such tensile test pieces were collected over the entire width of the steel plate with a collection pitch of 100 mm in the width direction of the steel plate. The shape of the tensile test piece was Type 3 shape in ASTM A770 (2007). Next, a tensile test in accordance with ASTM A370 (2010) was conducted using each collected tensile test piece, and the area reduction ratio was measured. The minimum value from among the reductions of area measured for the respective tensile test pieces collected over the entire width of the steel plate was taken to be the area reduction ratio of the steel plate. In the case where this value was 35 % or more, the steel plate was evaluated as having excellent internal properties.

[Table 1]

Table 1

Steel sample ID	Chemical composition (mass%) *1,2																				Remarks
	C	Si	Mn	P	S	Al	O	N	Cu	Ni	Cr	Mo	Nb	Ti	V	B	W	Ca	Mg	REM	
A	0.04	0.26	1.75	0.022	0.0106	0.055	0.0026	0.0041													Conforming steel
B	0.11	0.09	1.32	0.012	0.0184	0.021	0.0009	0.0061													Conforming steel
C	0.18	0.64	0.47	0.009	0.0054	0.013	0.0051	0.0026													Conforming steel
D	0.08	0.46	2.43	0.003	0.0009	0.034	0.0029	0.0030													Conforming steel
E	0.09	0.31	0.89	0.008	0.0022	0.009	0.0046	0.0013	0.65												Conforming steel
F	0.13	0.52	1.64	0.026	0.0035	0.029	0.0027	0.0032		1.21											Conforming steel
G	0.04	0.68	2.16	0.008	0.0016	0.025	0.0016	0.0022			0.73										Conforming steel
H	0.06	0.25	1.37	0.016	0.0074	0.033	0.0031	0.0046				0.48									Conforming steel
I	0.12	0.46	1.28	0.009	0.0022	0.039	0.0021	0.0038					0.038								Conforming steel
J	0.16	0.22	0.64	0.015	0.0034	0.028	0.0034	0.0078						0.035							Conforming steel
K	0.11	0.34	0.92	0.011	0.0008	0.018	0.0025	0.0061							0.07						Conforming steel
L	0.12	0.22	1.52	0.013	0.0066	0.061	0.0071	0.0026									0.32				Conforming steel
M	0.07	0.18	1.55	0.008	0.0029	0.042	0.0031	0.0019								0.0022					Conforming steel
N	0.08	0.26	1.31	0.018	0.0026	0.024	0.0018	0.0030										0.0064			Conforming steel
O	0.03	0.08	2.38	0.027	0.0062	0.033	0.0008	0.0056											0.0084		Conforming steel
P	0.15	0.63	2.15	0.016	0.0038	0.041	0.0051	0.0024												0.0115	Conforming steel
Q	0.09	0.24	1.39	0.007	0.0015	0.029	0.0026	0.0021	0.26	0.67								0.0016			Conforming steel
R	0.08	0.39	1.53	0.003	0.0008	0.019	0.0035	0.0036			0.21		0.011	0.008		0.0007			0.0022		Conforming steel
S	0.06	0.09	0.95	0.004	0.0012	0.031	0.0027	0.0041				0.13			0.02					0.0036	Conforming steel
T	0.05	0.17	0.78	0.011	0.0028	0.024	0.0017	0.0035		0.35	0.12			0.024				0.0035			Conforming steel

*1: Balance consists of Fe and inevitable impurities.

*2: Blank space indicates that the element is not intentionally added, including not only the case where the element is not contained (0 %) but also the case where the element is inevitably contained.

[Table 2]

[0070]

Table 2

No.	Steel sample ID	Thickness (mm)	Hot rolling conditions: Total rolling reduction ratio r_t in rolling passes under predetermined conditions (%)	Area ratio of void defects at thickness center position (%)	Area reduction ratio (%)	Remarks
1	A	85	55	0	69	Example
2	B	120	38	0.2	58	Example
3	C	185	53	0.1	66	Example
4	D	151	63	0.1	67	Example
5	E	113	35	0.2	54	Example
6	F	227	60	0.1	63	Example
7	G	93	49	0.1	66	Example
8	H	180	59	0.1	67	Example
9	I	210	53	0.1	61	Example
10	J	165	39	0.2	58	Example
11	K	126	61	0.1	66	Example
12	L	76	53	0	63	Example
13	M	113	66	0.1	74	Example
14	N	142	54	0.1	66	Example
15	O	178	64	0.1	67	Example

(continued)

No.	Steel sample ID	Thickness (mm)	Hot rolling conditions Total rolling reduction ratio r_t in rolling passes under predetermined conditions (%)	Area ratio of void defects at thickness center position (%)	Area reduction ratio (%)	Remarks
16	P	32	50	0	65	Example
17	Q	240	66	0.1	72	Example
18	R	167	58	0.1	65	Example
19	S	105	62	0.1	69	Example
20	T	50	57	0	63	Example
21	E	101	51	0.1	68	Example
22	B	151	22	0.6	31	Comparative Example
23	C	196	16	0.6	22	Comparative Example
24	F	84	6	0.8	18	Comparative Example
25	H	138	13	0.7	21	Comparative Example
26	J	216	23	0.6	29	Comparative Example
27	M	155	17	0.7	24	Comparative Example
28	Q	101	20	0.6	23	Comparative Example
29	T	230	18	0.6	20	Comparative Example
Underline indicates outside the appropriate range.						

[0071] As shown in Table 2, the steel plate of each Example had excellent internal properties. Moreover, the steel plate of each Example was capable of being produced using a usual hot rolling line at low cost (i.e. with high productivity) with no need for special equipment.

[0072] On the other hand, the steel plate of each Comparative Example did not have sufficient internal properties.

Claims

1. A steel plate comprising

a chemical composition containing, in mass%,
C: 0.03 % to 0.18 %,
Si: 0.03 % to 0.70 %,
Mn: 0.30 % to 2.50 %,
P: 0.030 % or less,
S: 0.0200 % or less,
Al: 0.001 % to 0.100 %,
O: 0.0100 % or less, and
N: 0.0100 % or less
with a balance consisting of Fe and inevitable impurities,

wherein an area ratio of void defects at a thickness center position of the steel plate is 0.5 % or less.

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

Cu: 2.00 % or less,
Ni: 2.50 % or less,
Cr: 1.50 % or less,
Mo: 1.00 % or less,
Nb: 0.100 % or less,
Ti: 0.100 % or less,
V: 0.30 % or less,
B: 0.0100 % or less,
W: 0.50 % or less,
Ca: 0.0200 % or less,
Mg: 0.0200 % or less, and
REM: 0.0500 % or less.

3. A production method for the steel plate according to claim 1 or 2, the production method comprising:

preparing a slab having the chemical composition according to claim 1 or 2; and
hot rolling the slab,
wherein a total rolling reduction ratio in rolling passes that satisfy the following (a) and (b) in the hot rolling is more than 30 %:

(a) a temperature at a thickness center position of the slab: 700 °C or more, and
(b) a temperature difference between a surface and the thickness center position of the slab: 100 °C or more.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/035522

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 8/02***(2006.01)i; ***C22C 38/06***(2006.01)i; ***C22C 38/58***(2006.01)i
FI: C22C38/00 301A; C22C38/06; C22C38/58; C21D8/02 A

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60; C21D8/02

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	JP 2007-302908 A (SUMITOMO METAL IND LTD) 22 November 2007 (2007-11-22) claims 1-4, paragraphs [0042]-[0071], [0104]-[0107]	1-2
A		3
X	WO 2021/182618 A1 (NIPPON STEEL CORPORATION) 16 September 2021 (2021-09-16) claims 1-5, paragraphs [0018]-[0042], [0056]-[0078]	2
A		1, 3

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 October 2022	**08 November 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.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/035522

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2007-302908 A	22 November 2007	(Family: none)	
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		KR 10-2022-0133985 A	

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

REFERENCES CITED IN THE DESCRIPTION

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- JP 6137080 B **[0004] [0008]**
- JP 6156321 B **[0005] [0008]**
- JP H669569 B **[0006] [0008]**
- JP S5974220 A **[0007] [0008]**