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

(11) EP 4 575 008 A1

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

(43) Date of publication:
25.06.2025 Bulletin 2025/26

(21) Application number: **23854722.8**

(22) Date of filing: **27.06.2023**

(51) International Patent Classification (IPC):
C21D 8/02 (2006.01) ***C22C 38/00*** (2006.01)
C22C 38/14 (2006.01) ***C22C 38/58*** (2006.01)

(52) Cooperative Patent Classification (CPC):
C21D 8/02; C22C 38/00; C22C 38/06; C22C 38/14; C22C 38/58

(86) International application number:
PCT/JP2023/023875

(87) International publication number:
WO 2024/038684 (22.02.2024 Gazette 2024/08)

(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 ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **19.08.2022 PCT/JP2022/031459**

(71) Applicant: **JFE Steel Corporation**
Tokyo 100-0011 (JP)

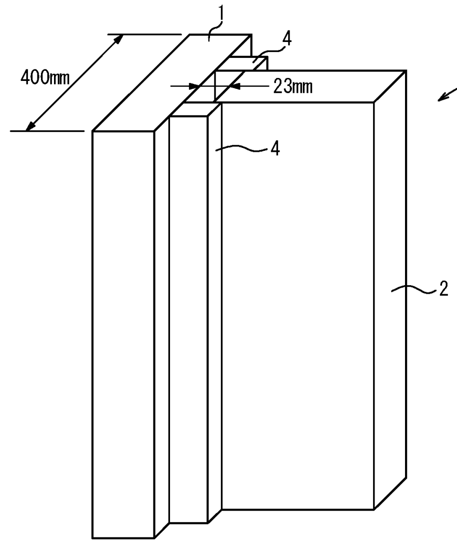
(72) Inventors:
- **YUGA, Masao**
  Tokyo 100-0011 (JP)
- **SATO, Yuya**
  Tokyo 100-0011 (JP)
- **MURAKAMI, Shunichi**
  Tokyo 100-0011 (JP)
- **MURAKAMI, Yoshiaki**
  Tokyo 100-0011 (JP)
- **SUEYOSHI, Hitoshi**
  Tokyo 100-0011 (JP)
- **HYODO, Yoshihiro**
  Tokyo 100-0011 (JP)

(74) Representative: **Haseltine Lake Kempner LLP**
One Portwall Square
Portwall Lane
Bristol BS1 6BH (GB)

(54) THICK STEEL SHEET AND METHOD FOR PRODUCING SAME

(57) It is provided a steel plate that has high strength, low yield ratio, and high toughness with excellent toughness of the joint bond portion even in large-heat input welding with an amount of welding heat input exceeding 40 kJ/mm. The steel plate has specific chemical composition and microstructure and has a Mn concentration distribution in which the area fraction of the average concentration region of Mn, defined as a region with a Mn concentration of 0.9 times to 1.1 times an average Mn content (mass%), is less than 90 %, the area fraction of a Mn-enriched region, defined as a region with a Mn concentration of 1.15 times or more the average Mn content (mass%), is 1.0 % or more, and the average equivalent circular diameter of the Mn-enriched region is 7.0 μm or less, with a Charpy absorbed energy at 0 °C: vE_0 of 70 J or more.

FIG. 1



EP 4 575 008 A1

Description

TECHNICAL FIELD

[0001] This disclosure relates to a steel plate, in particular, to a steel plate that has high strength, low yield ratio, and high toughness with excellent toughness of the bond portion at a welded joint even in large-heat input welding with an amount of welding heat input exceeding 40 kJ/mm. In addition to the above-described excellent properties, the steel plate of this disclosure is also suitable for industrial production and can be used extremely well as a construction steel material. This disclosure also relates to a method of producing the steel plate.

BACKGROUND

[0002] In recent years, as building structures have become taller and have larger spans, the steel material used has become thicker. Steel plates used as such steel material are required to have excellent mechanical properties, specifically, high tensile strength, yield stress, and toughness.

[0003] In addition, from the viewpoint of safety of steel structures, steel plates used are required to have low yield ratio (ratio of yield stress to tensile strength). A lower yield ratio improves the plastic deformation capacity, which contributes to improvement in seismic safety of the structures.

[0004] A process using multi-stage heat treatment has been put to practical use as a process of producing steel plates with reduced yield ratio. In the multi-stage heat treatment, steel plates after hot rolling are reheated to the two-phase region of ferrite and austenite and subjected to quenching and then tempering. However, in the multi-stage heat treatment, it was difficult to achieve both high strength and low yield ratio because the yield stress increases due to the recovery of the microstructure by tempering.

[0005] Furthermore, steel materials are generally welded together when building steel structures. Therefore, the steel plates used are required to have excellent toughness of the heat-affected zone as well as excellent toughness of the steel plates themselves (toughness of base metal). In particular, from the viewpoint of improving the seismic resistance of building structures, it is required that a welded joint, in particular, the bond portion at the welded joint has excellent toughness.

[0006] In addition, as the steel materials used are becoming thicker, the scope of application of large-heat input welding (welding with high heat input during welding) is expanding in order to improve construction efficiency and reduce construction costs. In particular, in recent years, the application of large-heat input welding, such as submerged arc welding and electroslag welding, where the amount of welding heat input exceeds 40 kJ/mm, has become more common. Therefore, the steel plates are required to have excellent toughness of the heat-affected zone even when large-heat input welding is applied with an amount of welding heat input exceeding 40 kJ/mm.

[0007] In general, the most serious problem when large-heat input welding is applied to the steel material is the deterioration of the toughness of the bond portion at the welded joint. In the heat-affected zone, coarsening of austenite crystal grains is most pronounced in the bond portion because of exposure to high temperatures just below the melting point during large-heat input welding. The coarsened austenite crystal grains then transform into a brittle upper bainitic microstructure due to the temperature drop after welding. Further, the toughness is reduced by the formation of coarse martensite austenite constituent (MA), which is an embrittlement microstructure. Therefore, if the toughness of the bond portion at the welded joint in large-heat input welding can be improved, the safety of steel structures can be greatly enhanced.

[0008] Thus, in addition to excellent mechanical properties such as strength, yield ratio, and toughness, the steel plates are required to have excellent toughness of the heat-affected zone. Various techniques have been proposed to meet such a requirement.

[0009] For example, JPH06-248337A (PTL 1) proposes a technique to produce high-tension steel by quenching a steel sheet after hot rolling, heating and quenching the steel sheet again to the two-phase region of ferrite and austenite, and then subjecting steel sheet to tempering treatment.

[0010] JP2001-226740A (PTL 2) proposes a high-tension steel sheet with low yield ratio, having a specific chemical composition and an amount of retained austenite of 1.0 % or more.

[0011] JP2018-090872A (PTL 3) proposes a high-strength steel plate with low yield ratio, having a specific chemical composition, a microstructure containing bainite and martensite austenite constituent, and a controlled equivalent circular diameter and average aspect ratio of prior austenite grains.

CITATION LIST

Patent Literature

[0012]

PTL 1: JPH06-248337A
PTL 2: JP2001-226740A
PTL 3: JP2018-090872A

SUMMARY

(Technical Problem)

[0013] However, the technique proposed in PTL 1 aims to prevent cracks in small-heat input welding from occurring, and no attention was paid to the toughness of the heat-affected zone in large-heat input welding.
[0014] On the other hand, in the technique proposed in PTL 2, the toughness of the welded portion was considered. However, evaluations were conducted only at relatively low heat input of 5 kJ/mm or 15 kJ/mm, and the toughness of the heat-affected zone in large-heat input welding with an amount of welding heat input exceeding 40 kJ/mm was not considered. In the production process disclosed in PTL 2, the volume fraction of ferrite and martensite tends to change depending on the production conditions and the position in the steel sheet. Therefore, the production conditions need to be strictly adjusted to obtain the desired product, and the high operational load makes the technique proposed in PTL 2 unsuitable for industrial production.
[0015] The technique proposed in PTL 3 achieves high toughness of bond portion in large-heat input welding with an amount of welding heat input exceeding 40 kJ/mm, in addition to low yield ratio and high strength. However, in PTL 3, the area fraction of martensite austenite constituent must be 5 % or more to achieve the above properties. Moreover, in the production process in PTL 3, in order to achieve an area fraction of martensite austenite constituent of 5 % or more, after reheating the hot-rolled steel sheet, it is necessary to control the formation of martensite austenite constituent by performing a first water cooling step, an air cooling step, and a second water cooling step under controlled temperature conditions. During cooling, temperature variations are likely to occur in the longitudinal direction and width direction of the steel sheet. Thus, extremely strict adjustment of production conditions is required to control the microstructure during such a cooling process, which has a high operational burden.
[0016] The present disclosure was made in view of the above-mentioned circumstances. It could be helpful to provide a steel plate that has high strength, low yield ratio, and high toughness with excellent toughness of the bond portion at a welded joint even in large-heat input welding with an amount of welding heat input exceeding 40 kJ/mm, and is suitable for industrial production.

(Solution to Problem)

[0017] The inventors engaged in intensive studies on the above problems and made the following discoveries.

(1) By forming a specific Mn concentration distribution in a steel plate that contains bainite and martensite austenite constituent and has an area fraction of bainite of 80.0 % or more, high strength, low yield ratio, and high toughness can be achieved despite the relatively low area fraction of martensite austenite constituent of less than 5.0 %.
(2) The above Mn concentration distribution can be achieved by controlling the chemical composition, in particular, C and Mn contents, within specific ranges and by appropriately controlling the heating conditions in the reheating step after hot rolling.

[0018] This disclosure has been made based on the above discoveries. We provide the following.

1. A steel plate comprising a chemical composition containing (consisting of), in mass%,

C: 0.010 % to 0.14 %,
Si: 0.01 % to 0.50 %,
Mn: 0.9 % to 3.0 %,
P: 0.015 % or less,
S: 0.0050 % or less,
Al: 0.002 % to 0.080 %,
Ti: 0.003 % to 0.030 %, and
N: 0.0015 % to 0.0080 %,

with the balance being Fe and inevitable impurities, and the chemical composition having:
4.83C + Mn expressed by the C content (mass%) and the Mn content (mass%) of 1.4 mass% to 3.3 mass%;
a ratio Ti/N of the Ti content (mass%) to the N content (mass%) of 2.0 to 4.3; and
P_{CM} expressed by formula (1) of 0.30 mass% or less,
the steel plate comprising a microstructure containing bainite and martensite austenite constituent, with an area fraction of Bainite of 80.0 % or more and an area fraction of martensite austenite constituent of less than 5.0 %,
the steel plate comprising a Mn concentration distribution, wherein:

the area fraction of an average concentration region of Mn, defined as a region with a Mn concentration of 0.9 times to 1.1 times an average Mn content (mass%), is less than 90 %,
the area fraction of a Mn-enriched region, defined as a region with a Mn concentration of 1.15 times or more the average Mn content (mass%), is 1.0 % or more, and
the average equivalent circular diameter of the Mn-enriched region is 7.0 μm or less,

with a Charpy absorbed energy at 0 °C: vE_0 of 70 J or more:

$$P_{cm} = [C] + [Si]/30 + [Mn]/20 + [Cu]/20 + [Ni]/60 + [Cr]/20 + [Mo]/15 + [V]/10 + 5[B] \quad (1),$$

where the brackets in the formula indicate a content (mass%) of an element enclosed in the brackets and have a value of 0 if such an element is not contained.

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

Cu: 3.0 % or less,
Ni: 3.0 % or less,
Cr: 3.0 % or less,
Mo: 1.5 % or less,
W: 3.0 % or less,
Nb: 0.10 % or less,
V: 0.10 % or less,
B: 0.0050 % or less,
Ca: 0.005 % or less,
REM: 0.020 % or less,
Mg: 0.005 % or less, and
Zr: 0.020 % or less.

3. The steel plate according to 1 or 2 above, wherein, in the microstructure,

the area fraction of the martensite austenite constituent is 1.0 % or more and less than 5.0 %, and
the average equivalent circular diameter of the martensite austenite constituent is 5.0 μm or less.

4. A method of producing a steel plate, comprising:

a hot rolling step of hot rolling a steel material having the chemical composition according to 1 or 2 above to form a steel plate;
a first cooling step of cooling the steel plate after the hot rolling step;
a reheating step of heating the steel plate after the first cooling step to a reheating temperature of Ac3 point or more and Ac3 point + 60 °C or less, under a set of conditions including: an average heating rate in a temperature range from Ac1 point to Ac3 point: 2.0 °C/s or less; and a stay time in a temperature range from Ac3 point - 100 °C to Ac3 point: 60 seconds or more, at a 1/4 thickness position, and then holding the steel plate for a holding time of 10 minutes or more at the reheating temperature; and
a second cooling step of subjecting the steel plate after the reheating step to accelerated cooling to an accelerated cooling stop temperature of 100 °C to 600 °C at an average cooling rate at the 1/4 thickness position of 1.0 °C/s to 200.0 °C/s and then air cooling the steel plate to a temperature of 100 °C or less.

5. The method of producing a steel plate according to 4 above, the method further comprising a heat treatment step

after the first cooling step and before the reheating step,
wherein, in the heat treatment step, the steel plate after the first cooling step is:

heated to a heat treatment temperature of Ac3 point or more and 1050 °C or less;
held at the heat treatment temperature for a holding time of 5 minutes or more; and
then cooled to a cooling stop temperature of 500 °C or less.

(Advantageous Effect)

[0019] According to this disclosure, it is possible to obtain a steel plate that has high strength, low yield ratio, and high toughness with excellent toughness of the bond portion at a welded joint even in large-heat input welding with an amount of welding heat input exceeding 40 kJ/mm. The steel plate of this disclosure can be used extremely well as a construction steel material and contributes to the increase in size and improvement in seismic resistance of steel structures. In addition, the steel plate of this disclosure can be produced in a process with low operational load and is suitable for industrial production.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] In the accompanying drawings:

FIG. 1 is a schematic diagram illustrating a groove geometry in electroslag welding performed to evaluate the toughness of bond portion; and
FIG. 2 is a schematic diagram illustrating a collection location of a Charpy impact test piece from the electroslag welded portion.

DETAILED DESCRIPTION

[0021] The following describes embodiments of the present disclosure. The following merely provides one of the preferred disclosed embodiments, and this disclosure is by no means limited to the following description. In this specification, the toughness of an unwelded steel plate itself is sometimes referred to as "toughness of base metal" to distinguish it from the toughness of bond portion after welding.

[Chemical composition]

[0022] A steel plate of this disclosure and a steel material used for producing the steel plate need to have the chemical composition described above. The following describes each of the components contained in the above chemical composition. Note that "%" indicating the content of each component is "mass%", unless otherwise stated.

C: 0.010 % to 0.14 %

[0023] C is an element that has an effect of increasing the strength of the steel plate. When the C content is less than 0.010 %, the desired tensile strength cannot be achieved. The C content is therefore 0.010 % or more, preferably 0.020 % or more, and more preferably 0.030 % or more. On the other hand, when the C content exceeds 0.14 %, the formation of coarse martensite austenite constituent and cementite is promoted, resulting in a decrease in toughness of base metal and a significant degradation in toughness of the bond portion. The C content is therefore 0.14 % or less, preferably 0.10 % or less, and more preferably 0.08 % or less.

Si: 0.01 % to 0.50 %

[0024] Si is an element that functions as a deoxidizer and has an effect of increasing the strength of the steel plate. To achieve the effect, the Si content is 0.01 % or more. On the other hand, when the Si content exceeds 0.50 %, the formation of coarse martensite austenite constituent is promoted, and a decrease in toughness of base metal and toughness of the bond portion becomes apparent. The Si content is therefore 0.50 % or less, and preferably 0.35 % or less.

Mn: 0.9 % to 3.0 %

[0025] Mn is an element that has an effect of increasing the strength of the steel plate. In addition, high strength, low yield ratio, and high toughness can be achieved by controlling a Mn concentration distribution as described below. When the Mn content is less than 0.9 %, the effect cannot be achieved. The Mn content is therefore 0.9 % or more, and preferably 1.2 % or more. On the other hand, when the Mn content exceeds 3.0 %, the area fraction of a Mn-enriched portion increases to form coarse MA, resulting in a decrease in toughness of base metal. In addition, the heat-affected zone hardens to significantly decrease the toughness of bond portion. The Mn content is therefore 3.0 % or less, and preferably 2.6 % or less.

[0026] The chemical composition described here is an average composition of the steel plate. Therefore, the above Mn content is used as the "average Mn content" in the specification of the Mn concentration distribution described below.

P: 0.015 % or less

[0027] P is an element that degrades the toughness of base metal and the toughness of bond portion. Thus, the P content is desirably reduced as much as possible. When the P content exceeds 0.015 %, the toughness of base metal and the toughness of bond portion significantly decrease. This is thought to be due to the segregation of P in the Mn-enriched portion at high P content, resulting in hardening of the microstructure. The P content is therefore 0.015 % or less. On the other hand, no particular lower limit is placed on the P content, and the P content may be 0 %. Excessive reduction, however, leads to higher costs. Therefore, from the viewpoint of production cost, the P content is preferably 0.001 % or more.

S: 0.0050 % or less

[0028] S is an element that degrades the toughness of base metal. Thus, the S content is desirably reduced as much as possible. When the S content is higher than 0.0050 %, the desired toughness of base metal and toughness of bond portion cannot be achieved. The S content is therefore 0.0050 % or less. On the other hand, no particular lower limit is placed on the S content, and the S content may be 0 %. Excessive reduction, however, leads to higher costs. Therefore, from the viewpoint of production cost, the S content is preferably 0.0003 % or more.

Al: 0.002 % to 0.080 %

[0029] Al is an element that acts as a deoxidizer. Al also fixes N in steel as AlN to contribute to the improvement in toughness of base metal. To achieve the effect, the Al content is 0.002 % or more, and preferably 0.010 % or more. On the other hand, when the Al content exceeds 0.080 %, the toughness of base metal decreases. The Al content is therefore 0.080 % or less, and preferably 0.060 % or less.

Ti: 0.003 % to 0.030 %

[0030] Ti is an element that functions as a deoxidizer and contributes to the improvement in strength of the steel plate. Ti also combines with N to precipitate as TiN, a nitride that is stable even at high temperatures. Therefore, the pinning effect of TiN prevents austenite grain coarsening when heated, resulting in an improvement in toughness of base metal and toughness of bond portion. To achieve the effect, the Ti content is 0.003 % or more, and preferably 0.005 % or more. On the other hand, when the Ti content exceeds 0.030 %, the toughness of base metal and the toughness of bond portion deteriorate. The Ti content is therefore 0.030 % or less, preferably 0.025 % or less, and more preferably 0.020 % or less.

N: 0.0015 % to 0.0080 %

[0031] N combines with Al or Ti to precipitate a nitride. The nitride inhibits the coarsening of austenite grains to improve the toughness of base metal and bond portion. To achieve the effect, the N content is 0.0015 % or more, and preferably 0.0025 % or more. On the other hand, when the N content exceeds 0.0080 %, the toughness of base metal and bond portion are rather reduced due to the increase in solute N content. The N content is therefore 0.0080 % or less, preferably 0.0065 % or less, and more preferably 0.0060 % or less.

[0032] The chemical composition according to one of the embodiments can contain the above elements, with the balance being Fe and inevitable impurities. However, there is no intention in this expression of precluding the inclusion of other trace elements, without impairing the action or effect of this disclosure. Examples of the inevitable impurities include oxygen (O). The content of oxygen contained as inevitable impurities is preferably 0.0030 % or less.

4.83C + Mn: 1.4 mass% to 3.3 mass%

[0033] In the steel plate of this disclosure, excellent mechanical properties are achieved by forming a specific Mn concentration distribution, as described below. To achieve the Mn concentration distribution, the value of "4.83C + Mn" determined from the C content and the Mn content in the above chemical composition needs to be 1.4 mass% or more. The reason for this is described below.

[0034] To form the Mn concentration distribution in a steel plate to be finally obtained, it is necessary to create microscopic variations in Mn concentration inside the steel plate during the process of producing the steel plate. To create the variations, it is necessary to set 4.83C + Mn to 1.4 mass% or more and control heating conditions in a reheating step as described below. Reheating a steel sheet with 4.83C + Mn of 1.4 mass% or more under specific conditions can promote the distribution of Mn into the reverse transformation austenite to form microscopic variations in Mn concentration. When the value of 4.83C + Mn is less than 1.4 mass%, the desired Mn concentration distribution cannot be achieved due to insufficient distribution of Mn into the reverse transformation austenite. As a result, the strength of the steel plate decreases to increase the yield ratio. Therefore, 4.83C + Mn is 1.4 mass% or more, and preferably 1.7 mass% or more. On the other hand, when 4.83C + Mn exceeds 3.3 mass%, the effect is saturated. Therefore, 4.83C + Mn is 3.3 mass% or less.

Ti/N: 2.0 to 4.3

[0035] TiN has a pinning effect that suppresses austenite grain growth in the heat-affected zone and improves the toughness of bond portion. When Ti/N is less than 2.0, the amount of TiN necessary to achieve the effect cannot be secured to deteriorate the toughness of bond portion. Therefore, Ti/N is 2.0 or more, and preferably 2.4 or more. On the other hand, when Ti/N exceeds 4.3, the toughness of base metal and the toughness of bond portion deteriorate due to the formation of TiC particles and the coarsening of TiN. Therefore, Ti/N is 4.3 or less, and preferably 4.0 or less.

P_{CM}: 0.30 mass% or less

[0036] When P_{CM} defined by the following formula (1) is higher than 0.30 mass%, good toughness of bond portion cannot be achieved. Therefore, P_{CM} is 0.30 mass% or less, preferably 0.28 mass% or less, and more preferably 0.26 mass% or less:

$$P_{cm} = [C] + [Si]/30 + [Mn]/20 + [Cu]/20 + [Ni]/60 + [Cr]/20 + [Mo]/15 + [V]/10 + 5[B] \quad (1),$$

where the brackets in the above formula indicate a content (mass%) of an element enclosed in the brackets and have a value of 0 if such an element is not contained.

[0037] On the other hand, no particular lower limit is placed on P_{CM}. However, an excessively low P_{CM} reduces the strength of the steel plate. Therefore, P_{CM} is preferably 0.15 mass% or more, more preferably 0.17 mass% or more, and further preferably 0.19 mass% or more.

[0038] In other disclosed embodiments, the above chemical composition can optionally further contain at least one selected from the group consisting of Cu, Ni, Cr, Mo, W, Nb, V, B, Ca, REM, Mg, and Zr.

Cu: 3.0 % or less

[0039] Cu is an element that further improves the strength while maintaining the high toughness of the steel plate and can be optionally contained depending on the strength required. However, when the Cu content exceeds 3.0 %, hot brittleness occurs to deteriorate the surface characteristics of the steel plate. Therefore, when Cu is contained, the Cu content is 3.0 % or less. The Cu content is preferably 2.0 % or less. On the other hand, no particular lower limit is placed on the Cu content. However, to sufficiently achieve the effect, the Cu content is preferably 0.01 % or more, and more preferably 0.05 % or more.

Ni: 3.0 % or less

[0040] Like Cu, Ni is an element that further improves the strength while maintaining the high toughness of the steel plate and can be optionally contained depending on the strength required. However, when the Ni content exceeds 3.0 %, the effect of addition is saturated, which is economically disadvantageous. Therefore, when Ni is contained, the Ni content is 3.0 % or less. The N content is preferably 2.0 % or less. On the other hand, no particular lower limit is placed on the Ni content. However, to sufficiently achieve the effect, the Ni content is preferably 0.01 % or more, and more preferably 0.10 % or more.

Cr: 3.0 % or less

[0041] Cr is an element that further improves the strength of the steel plate and can be optionally contained depending on the strength required. However, when the Cr content exceeds 3.0 %, the toughness of the base metal and the bond portion deteriorates. Therefore, when Cr is contained, the Cr content is 3.0 % or less. The Cr content is preferably 2.0 % or less. On the other hand, no particular lower limit is placed on the Cr content. However, in terms of sufficiently achieving the strength improving effect by Cr, the Cr content is preferably 0.01 % or more, and more preferably 0.10 % or more.

Mo: 1.5 % or less

[0042] Like Cr, Mo is an element that further improves the strength of the steel plate and can be optionally contained depending on the strength required. However, when the Mo content exceeds 1.5 %, the toughness of the base metal and the bond portion deteriorates. In addition, quench cracks are more likely to occur during the process of producing the steel plate, resulting in reduced manufacturability. Therefore, when Mo is contained, the Mo content is 1.5 % or less, and preferably 1.0 % or less. On the other hand, no particular lower limit is placed on the Mo content. However, in terms of sufficiently achieving the strength improving effect by Mo, the Mo content is preferably 0.01 % or more, and more preferably 0.10 % or more.

W: 3.0 % or less

[0043] Like Cr and Mo, W is an element that further improves the strength of the steel plate and can be optionally contained depending on the strength required. However, when the W content exceeds 3.0 %, the toughness of the base metal and the bond portion deteriorates. Therefore, when W is contained, the W content is 3.0 % or less, and preferably 2.0 % or less. On the other hand, no particular lower limit is placed on the W content. However, in terms of sufficiently achieving the strength improving effect by W, the W content is preferably 0.01 % or more, and more preferably 0.10 % or more.

Nb: 0.10 % or less

[0044] Like Cr, Mo, and W, Nb is an element that further improves the strength of the steel plate and can be optionally contained depending on the strength required. However, when the Nb content exceeds 0.10 %, the toughness of the base metal and the bond portion decreases. Therefore, when Nb is contained, the Nb content is 0.10 % or less, and preferably 0.05 % or less. On the other hand, no particular lower limit is placed on the Nb content. However, in terms of sufficiently achieving the strength improving effect by Nb, the Nb content is preferably 0.005 % or more.

V: 0.10 % or less

[0045] Like Cr, Mo, W, and Nb, V is an element that further improves the strength of the steel plate and can be optionally contained depending on the strength required. However, when the V content exceeds 0.10 %, the toughness of the base metal and the bond portion decreases. Therefore, when V is contained, the V content is 0.10 % or less, and preferably 0.05 % or less. On the other hand, no particular lower limit is placed on the V content. However, in terms of sufficiently achieving the strength improving effect by V, the V content is preferably 0.005 % or more.

B: 0.0050 % or less

[0046] B is an element that has an action of further increasing the strength of the steel plate by improving the quench hardenability. B also has an effect of further improving the toughness of bond portion by sticking solute nitrogen as a nitride in the heat-affected zone during large-heat input welding. However, when the B content exceeds 0.0050 %, the quench hardenability is excessively high, and the toughness of the base metal and the bond portion is rather reduced. Therefore, when B is contained, the B content is 0.0050 % or less, and preferably 0.0020 % or less. On the other hand, no particular lower limit is placed on the B content. However, in terms of sufficiently achieving the effect of addition of B, the B content is preferably 0.0003 % or more.

Ca: 0.005 % or less

[0047] Ca is an element that has an effect of further improving the toughness of base metal by refinement of crystal grains and can be optionally contained depending on the toughness of base metal required. However, when the Ca content exceeds 0.005 %, the effect of addition is saturated. Therefore, when Ca is contained, the Ca content is 0.005 % or less. On the other hand, no particular lower limit is placed on the Ca content. However, in terms of sufficiently achieving the toughness improving effect by Ca, the Ca content is preferably 0.001 % or more.

REM: 0.020 % or less

[0048] Like Ca, REM (rare earth metal) is an element that has an effect of further improving the toughness of base metal by refinement of crystal grains and can be optionally contained depending on the toughness of base metal required. However, when the REM content exceeds 0.020 %, the effect of addition is saturated. Therefore, when REM is contained, the REM content is 0.020 % or less. On the other hand, no particular lower limit is placed on the REM content. However, in terms of sufficiently achieving the toughness improving effect by REM, the REM content is preferably 0.002 % or more.

Mg: 0.005 % or less

[0049] Like Ca and REM, Mg is an element that has an effect of further improving the toughness of base metal by refinement of crystal grains and can be optionally contained depending on the toughness of base metal required. However, when the Mg content exceeds 0.005 %, the effect of addition is saturated. Therefore, when Mg is contained, the Mg content is 0.005 % or less. On the other hand, no particular lower limit is placed on the Mg content. However, in terms of sufficiently achieving the toughness improving effect by Mg, the Mg content is preferably 0.001 % or more.

Zr: 0.020 % or less

[0050] Like Ca, REM, and Mg, Zr is an element that has an effect of further improving the toughness of base metal by refinement of crystal grains and can be optionally contained depending on the toughness of base metal required. However, when the Zr content exceeds 0.020 %, the effect of addition is saturated. Therefore, when Zr is contained, the Zr content is 0.020 % or less. On the other hand, no particular lower limit is placed on the Zr content. However, in terms of sufficiently achieving the toughness improving effect by Zr, the Zr content is preferably 0.002 % or more.

[Microstructure]

[0051] The steel plate of this disclosure has a microstructure that contains bainite and martensite austenite constituent, with an area fraction of bainite of 80.0 % or more. The reason for limiting the microstructure to the above range is described below. The term "area fraction" in the following description refers to an area fraction relative to the whole microstructure, unless otherwise specified. The above microstructure refers to a microstructure at a 1/4 thickness position of the steel plate.

Microstructure containing bainite and martensite austenite constituent

[0052] Bainite is a microstructure necessary to improve the strength and toughness of the steel plate, as described below. On the other hand, martensite austenite constituent (MA) is an even harder microstructure than bainite because of its C enrichment. Therefore, forming MA can improve the tensile strength. In addition, a large amount of mobile dislocation is introduced around MA, which suppresses the increase in yield stress. Therefore, to achieve both high strength and low yield ratio, the microstructure needs to contain bainite and martensite austenite constituent.

Area fraction of bainite: 80.0 % or more

[0053] When the area fraction of bainite is less than 80.0 %, sufficient strength and toughness of base metal cannot be achieved. Therefore, the area fraction of bainite is 80.0 % or more, preferably 85.0 % or more, and more preferably 90.0 % or more. On the other hand, no particular upper limit is placed on the area fraction of bainite. However, when the area fraction of bainite is excessively high, the area fraction of martensite austenite constituent is relatively low, making it difficult to sufficiently reduce the yield ratio. Therefore, the area fraction of bainite is preferably 99.0 % or less. The area fraction of bainite can be measured by the method described in Examples.

Area fraction of martensite austenite constituent

[0054] As a result of the inventors' investigation, it was found that even with MA in the base metal, the toughness of bond portion decreases when the area fraction is 5.0 % or more. This is thought to be because of the following reasons. That is, since the bond portion is heated to a high temperature close to the melting point during welding, MA contained in the steel plate is once decomposed by the heating. However, during the cooling process after welding, MA is regenerated in the bond portion. The amount of MA regenerated in this process increases with the amount of MA contained in the steel plate prior to welding. When the amount of MA regenerated in the bond portion is high, the toughness of bond portion decreases. Therefore, in this disclosure, the area fraction of martensite austenite constituent in the microstructure of the steel plate is less than 5.0 %, preferably 4.9 % or less, more preferably 4.7 % or less, and further preferably 4.5 % or less, in order to improve the toughness of bond portion.

[0055] On the other hand, no particular lower limit is placed on the area fraction of MA. However, as described above, MA has an effect of improving the tensile strength and an effect of suppressing the increase in yield stress. From the viewpoint of sufficiently providing these effects, the area fraction of MA in the above microstructure is preferably 1.0 % or more, and more preferably 2.0 % or more.

[0056] In PTL 3, since the desired mechanical properties are achieved by increasing the area fraction of MA, the area fraction of MA must be 5 % or more. In contrast, this disclosure achieves the desired mechanical properties by controlling the Mn concentration distribution, as described below. Therefore, excellent mechanical properties can be achieved even though the area fraction of MA is less than 5.0 %. The area fraction of MA in the base metal is low, less than 5.0 %, and the toughness of bond portion is thus superior to that of PTL 3. The difference between the steel plate of this disclosure and the steel plate disclosed in PTL 3 is clear also from this fact. Furthermore, there is no need to control MA generation through complex cooling control consisting of the first water-cooling step, air-cooling step, and second water-cooling step, as in PTL 3.

Average equivalent circular diameter of martensite austenite constituent

[0057] No particular size is placed on MA. MA may have any size. However, when MA is excessively coarse, the toughness of the steel plate decreases. Therefore, from the viewpoint of further improving the toughness, the average equivalent circular diameter of MA is preferably 5.0 μm or less, and preferably 4.0 μm or less. On the other hand, no particular lower limit is placed on the average equivalent circular diameter of MA. However, the average equivalent circular diameter of MA usually may be 0.8 μm or more, or 1.0 μm or more.

[0058] The area fraction and average equivalent circular diameter of MA can be determined by applying LePera corrosion (Journal of Metals, March, 1980, p. 38-39) to a steel sheet as a sample, observing the steel sheet using a scanning electron microscope (SEM) at a magnification of 1000×, and then analyzing captured images using image interpretation equipment.

Other microstructures

[0059] The microstructure according to one of the embodiments may consist of bainite and martensite austenite constituent. The microstructures according to other disclosed embodiments may also contain another structure, in addition to bainite and martensite austenite constituent. The other structure may be any structure without limitation. For example, the other structure may be at least one selected from the group consisting of ferrite, pearlite, martensite, or retained austenite. When the other structure is contained in the microstructure, the total area fraction of the other structure is preferably 19 % or less, more preferably 15 % or less, and further preferably 10 % or less.

[0060] The steel plate according to one of the embodiments consists of, with area fraction:

80 % to 99.0 % of bainite;
1.0 % to 15.0 % of martensite austenite constituent; and a residual microstructure, and
the residual microstructure may be at least one selected from the group consisting of ferrite, pearlite, martensite, or retained austenite.

[Mn concentration distribution]

[0061] The inventors found that it is possible to intentionally form microscopic variations in Mn concentration inside the steel plate by controlling the C and Mn contents and the heating conditions in the reheating step after hot rolling. Then, it was found that by appropriately controlling the microscopic variations in Mn concentration, i.e., the Mn concentration distribution, a steel plate with high strength, low yield ratio, and high toughness can be obtained. This may be because the distribution and size of MA are affected by the Mn concentration distribution. For example, MA tends to be formed in a Mn-enriched region. As described above, MA has an effect of increasing the strength because it is a harder microstructure than bainite. In addition, MA has an action for decreasing the yield ratio through the introduction of mobile dislocation. Therefore, by controlling the Mn concentration distribution, the distribution of MA can be controlled, resulting in both high strength and low yield ratio.

[0062] This disclosure is based on the above technical concept. Specifically, the steel plate of this disclosure has a Mn concentration distribution that satisfies the following conditions (1) to (3). The Mn concentration distribution in this disclosure refers to a Mn concentration distribution at a 1/4 thickness position of the steel plate:

(1) Area fraction of average concentration region of Mn of less than 90 %;

(2) Area fraction of Mn-enriched region of 1.0 % or more; and
(3) Average equivalent circular diameter of Mn-enriched region of 7.0 μm or less.

(1) Area fraction of average concentration region of Mn: less than 90 %

[0063] When the area fraction of the average concentration region of Mn is 90 % or more, the hard microstructure containing MA is insufficient to achieve the desired strength. In addition, the enrichment of Mn for the Mn-enriched region is insufficient, making the effect of yield stress reduction due to MA formation insufficient. As a result, the yield ratio is also likely to be high. Therefore, the area fraction of the average concentration region of Mn is less than 90 %, preferably 85 % or less, and more preferably 80 % or less. On the other hand, no particular lower limit is placed on the area fraction of the average concentration region of Mn. However, when the area fraction of the average concentration region of Mn is too low, the size of the Mn-enriched region increases, resulting in the coarsening of MA formed in the enriched region. Therefore, the area fraction of the average concentration region of Mn is preferably 50 % or more, and more preferably 60 % or more. The "average concentration region of Mn" is defined here as a region with a Mn concentration of 0.9 times to 1.1 times the average Mn content (mass%).

(2) Area fraction of Mn-enriched region: 1.0 % or more

[0064] When the area fraction of the Mn-enriched region is less than 1.0 %, the formation of MA is insufficient, and both high strength and low yield ratio cannot be achieved. Therefore, the area fraction of the Mn-enriched region is 1.0 % or more, preferably 1.5 % or more, more preferably 2.0 % or more, and further preferably 6.2 % or more. On the other hand, no particular upper limit is placed on the area fraction of the Mn-enriched region. However, when the area fraction of the Mn-enriched region is too high, the size of the enriched region increases, and the MA formed in the enriched region is likely to become coarse. Therefore, the area fraction of the Mn-enriched region is preferably less than 50 %, more preferably less than 40 %, and further preferably 20 % or less. The Mn-enriched region is eliminated by heating during welding. Thus, the existence of the enriched region does not adversely affect the toughness of bond portion after welding. Therefore, this disclosure can achieve both excellent mechanical properties of the steel plate and high toughness of bond portion.

Average equivalent circular diameter of Mn-enriched region: 7.0 μm or less

[0065] When the average equivalent circular diameter of the Mn-enriched region is larger than 7.0 μm, MA formed within the Mn-enriched region also becomes coarse, resulting in reduced toughness of the steel plate. Therefore, the average equivalent circular diameter of the Mn-enriched region is 7.0 μm or less, and preferably 4.0 μm or less. On the other hand, no particular lower limit is placed on the average equivalent circular diameter of the Mn-enriched region. However, the average equivalent circular diameter of the Mn-enriched region generally may be 1.0 μm or more, or 1.5 μm or more.
[0066] The Mn concentration distribution can be measured using an electron probe microanalyzer (EPMA). Specifically, a test piece is taken from the steel plate so that the observation position is at a 1/4 thickness position. The Mn concentration distribution in the test piece is measured by the EPMA to calculate the area fraction of the average concentration region of Mn, the area fraction of the Mn-enriched region, and the average equivalent circular diameter of the Mn-enriched region. The measurement of the Mn concentration distribution by the EPMA is performed in two or more randomly selected fields of view, with the size of one field of view being 50 μm × 50 μm and 250 × 250 measurement points per field of view.

[Mechanical properties]

- Toughness

[0067] The steel plate of this disclosure has a Charpy absorbed energy at 0 °C: vE_0 of 70 J or more. The Charpy absorbed energy is one of the indices of toughness. The steel plate of this disclosure with vE_0 of 70 J or more produces excellent seismic safety even when used in high-rise buildings. vE_0 is preferably 80 J or more, and more preferably 100 J or more. On the other hand, a higher vE_0 is better from the viewpoint of seismic resistance. Thus, no particular upper limit is placed on vE_0. However, vE_0 generally may be 250 J or less, 220 J or less, or 210 J or less.
[0068] The Charpy absorbed energy at 0 °C of the above steel sheet can be measured in accordance with the provisions of JIS Z 2242 using a V-notch test piece taken from a 1/4 thickness position of the steel plate in accordance with the provisions of JIS Z 2202.

- Yield stress

[0069] No particular limitation is placed on the yield stress (YS) of the steel plate of this disclosure. However, from the viewpoint of increasing the strength associated with increased height in building structures, the yield stress is preferably 600 MPa or more, and preferably 620 MPa or more. No particular upper limit is also placed on the yield stress. However, the yield stress may be, for example, 900 MPa or less, 880 MPa or less, or 850 MPa or less.

- Tensile strength

[0070] No particular limitation is placed on the tensile strength (TS) of the steel plate of this disclosure. However, from the viewpoint of increasing the strength associated with increased height in building structures, the tensile strength is preferably 780 MPa or more, and more preferably 800 MPa or more. No particular upper limit is also placed on the tensile strength. However, the tensile strength may be, for example, 1100 MPa or less, or 1000 MPa or less.

- Yield ratio

[0071] No particular limitation is placed on the yield ratio (YR) of the steel plate of this disclosure. However, from the viewpoint of improving the deformation performance of building structures considering the allowable margin against fracture during earthquakes, the yield ratio is preferably 85 % or less. On the other hand, no lower limit is also placed on the yield ratio. However, the yield ratio may be, for example, 70 % or more, or 75 % or more. The yield ratio is here a value expressed as a percentage of the ratio of yield stress (YS) to tensile strength (TS), i.e., YS/TS $\times$ 100 (%).

[0072] The above yield stress and tensile strength can be measured by a tensile test in accordance with JIS Z 2241, using a JIS No. 4 tensile test piece taken from a 1/4 thickness position of the steel plate. The yield ratio can be calculated from the yield stress and tensile strength measured by the above method.

- Toughness of bond portion

[0073] No particular limitation is placed on the toughness of bond portion of the steel plate of this disclosure. However, the Charpy absorbed energy at 0 °C (vE_0) of the bond portion is preferably 47 J or more. No particular upper limit is also placed on vE_0 in the bond portion. However, vE_0 generally may be 150 J or less.

[0074] vE_0 in the bond portion is a value measured by producing a welded joint by electroslag welding with an amount of welding heat input of 40 kJ/mm or more and then using a JIS No. 4 Charpy impact test piece taken from the welded joint so that the notch position is at the bond portion. More specifically, vE_0 in the bond portion can be measured by the method described in Examples.

- Plate thickness

[0075] No particular limitation is placed on the plate thickness of the above steel plate. The plate thickness can be any thickness. The plate thickness of the steel plate is preferably 6 mm or more, more preferably 9 mm or more, and further preferably 12 mm or more. From the viewpoint of the response to increased height in building structures, the plate thickness is preferably 40 mm or more, and more preferably 60 mm or more. On the other hand, no particular upper limit is also placed on the plate thickness of the steel plate. However, the plate thickness is preferably 100 mm or less.

[Production method]

[0076] The following describes a method of producing a steel plate according to one of the embodiments. The steel plate can be produced by applying the steps (a) to (d) sequentially to a steel material having the above-described chemical composition:

(a) Hot rolling step;
(b) First cooling step;
(c) Reheating step; and
(d) Second cooling step.

[0077] Conditions in the respective steps are described in detail below. In the following description, unless otherwise specified, the temperature means a temperature at the center of the plate thickness (position of plate thickness $\times$ 1/2). The temperature at the center of the plate thickness can be determined by heat transfer calculation from the surface temperature of the steel plate measured by a radiation thermometer. The temperatures under the heating conditions and cooling conditions after the hot rolling step are temperatures at a 1/4 thickness position. The heating rate and the cooling rate also mean an average heating rate and an average cooling rate calculated based on the temperatures at the 1/4 thickness position, respectively.

(Steel material)

[0078] Any form of material can be used as the above steel material. The steel material may be, for example, steel slab. No particular limitation is placed on the method of producing the steel material. However, the steel material can be produced, for example, by melting and casting steel having the above-described chemical composition. The melting can be performed by any method using a converter, an electric furnace, an induction furnace, or the like. The casting is preferably performed by continuous casting in terms of productivity, but also can be performed by ingot casting and blooming.

(Hot rolling step)

[0079] In the hot rolling step, the above steel material is hot rolled to form a steel plate. No particular limitation is placed on the conditions of the hot rolling. The hot rolling can be performed under any conditions. Typically, the steel material is heated to a specific heating temperature and then rolled. The heating may be performed after the steel material obtained by a method such as casting is once cooled. Alternatively, the obtained steel material may be directly subjected to the heating without cooling it.

[0080] In this disclosure, the microstructure and properties of the steel plate are controlled in the reheating step and the second cooling step after the hot rolling. Therefore, no particular limitation is placed on the heating temperature in the hot rolling step. The heating temperature can be any temperature. However, when the heating temperature is less than 1000 °C, the load on the rolling mill during hot rolling may increase due to the high deformation resistance of the steel material, making it difficult to perform hot rolling. Therefore, the heating temperature is preferably 1000 °C or more. On the other hand, when the heating temperature is higher than 1250 °C, oxidation of the steel is more pronounced, resulting in increased loss due to oxidation and lower yield rate. Therefore, the heating temperature is preferably 1250 °C or less.

[0081] No particular limitation is placed on a rolling finish temperature. However, the rolling finish temperature is preferably 1000 °C or less. The rolling finish temperature is preferably 750 °C or more.

(First cooling step)

[0082] Next, the steel plate obtained in the above hot rolling step is cooled (first cooling step). In this disclosure, cooling in this first cooling step can be performed under any conditions without any particular limitations in order to control the microstructure and properties of the steel plate in the subsequent reheating step and second cooling step. However, because it is necessary to control the average heating rate in the temperature range from Ac1 point to Ac3 point in the subsequent reheating step, a cooling stop temperature in the first cooling step may be Ac1 point or less. The cooling stop temperature is preferably 500 °C or less. When the cooling stop temperature is 500 °C or less, coarsening of precipitates can be suppressed, and the Mn-enriched region can be generated more uniformly. As a result, the strength and toughness of the steel plate can be further improved, and the yield ratio can be further reduced. The cooling stop temperature is more preferably 250 °C or less. On the other hand, no lower limit is also placed on the cooling stop temperature. The steel plate can be cooled to any temperature. However, since excessive cooling reduces the productivity, the cooling stop temperature is preferably 0 °C or more, more preferably 10 °C or more, and further preferably 20 °C or more. Typically, the cooling stop temperature is preferably the room temperature or more.

[0083] The cooling in the first cooling step can be performed by any method with no particular limitation. For example, the cooling can be performed by one or both of air cooling and water cooling. From the viewpoint of further improving the strength and toughness of the steel plate, the cooling is preferably performed by water cooling. The water cooling is more preferably performed by at least one selected from the group consisting of spray cooling, mist cooling, or laminar cooling.

(Reheating step)

[0084] Next, the steel plate after the first cooling step is heated to a reheating temperature in a specific heating pattern and held at the reheating temperature.

[0085] Average heating rate in temperature range from Ac 1 point to Ac3 point: 2.0 °C/s or less

[0086] During the heating process, Mn is distributed into austenite formed by reverse transformation from bainite and martensite through the temperature range from Ac1 point or more to Ac3 point or less (two-phase region), resulting in microscopic variations in Mn concentration. However, when the average heating rate in the temperature range from Ac1 point to Ac3 point is higher than 2.0 °C/s, Mn distribution does not sufficiently progress. As a result, the desired Mn concentration distribution cannot be achieved. Therefore, in the reheating step, the steel plate after the first cooling step is heated at the average heating rate in the temperature range from Ac1 point to Ac3 point at the 1/4 thickness position: 2.0 °C/s or less. On the other hand, no particular lower limit is placed on the average heating rate. However, when the heating rate is excessively slow, the effect of controlling the heating rate is saturated, and the time required for heating increases, resulting in reduced productivity. Therefore, the average heating rate is preferably 0.01 °C/s or more.

[0087] Stay time in temperature range from Ac3 point - 100 °C to Ac3 point: 60 seconds or more

[0088] Similarly, when a stay time in the temperature range from Ac3 point - 100 °C to Ac3 point is less than 60 seconds, Mn distribution does not sufficiently progress. As a result, the desired Mn concentration distribution cannot be achieved. Therefore, during the heating process in the reheating step, the stay time in the temperature range from Ac3 point - 100 °C to Ac3 point is 60 seconds or more. On the other hand, an excessively long stay time reduces productivity. Therefore, the stay time is preferably 60 minutes or less.

[0089] The heating pattern in the above heating process just has to satisfy the above conditions, and no particular limitation is placed on the other conditions. For example, the temperature may be continuously raised to the reheating temperature or intentionally kept in the two-phase region.

[0090] Ac1 point and Ac3 point are determined by formulas (2) and (3) below:

$$\text{Ac1 } (^\circ\text{C}) = 751 - 26.6\text{C} + 17.6\text{Si} - 11.6\text{Mn} - 169\text{Al} - 23\text{Cu} - 23\text{Ni} + 24.1\text{Cr} + 22.5\text{Mo} + 233\text{Nb} - 39.7\text{V} - 5.7\text{Ti} - 895\text{B} \quad (2);$$

and

$$\text{Ac3 } (^\circ\text{C}) = 937 - 476.5\text{C} + 56\text{Si} - 19.7\text{Mn} - 16.3\text{Cu} - 4.9\text{Cr} - 26.6\text{Ni} + 38.1\text{Mo} + 124.8\text{V} + 136.3\text{Ti} + 198\text{Al} + 3315\text{B} \quad (3),$$

where the element symbol in formulas (2) and (3) above indicates a content (mass%) of each element and have a value of 0 if such an element is not contained.

Reheating temperature: Ac3 point or more, Ac3 point + 60 °C or less

[0091] In the above reheating step, the steel plate is heated to a reheating temperature of Ac3 point or more and Ac3 point + 60 °C or less. As a result, the structures such as bainite and martensite contained in the steel plate at the completion of the first cooling step undergo reverse transformation to austenite, resulting in microstructure consisting of an austenite single phase.

[0092] When the reheating temperature is less than Ac3 point, a soft recovered microstructure is formed in the microstructure to decrease the strength of the base metal. In addition, coarse MA is formed in the Mn-enriched region to decrease the toughness of the base metal. Therefore, the reheating temperature is Ac3 point or more. On the other hand, when the reheating temperature is higher than Ac3 point + 60 °C, austenite crystal grains coarsen, and homogenization of the composition progresses. As a result, the desired Mn concentration distribution cannot be achieved. Therefore, the reheating temperature is Ac3 point + 60 °C or less, more preferably Ac3 point + 55 °C or less, and further preferably Ac3 point + 50 °C or less.

Holding time at reheating temperature: 10 minutes or more

[0093] In the above reheating step, the steel plate is heated up to the above reheating temperature and then held at the re-heating temperature for a specific holding time. When the holding time is less than 10 minutes, the average equivalent circular diameter of the Mn-enriched region in the steel plate to be finally obtained cannot be 7.0 μm or less. This may be due to the short holding time, which increased the variation in grain size of the reverse transformation austenite, resulting in a non-uniformity in size of the Mn-enriched region. Therefore, the holding time is 10 minutes or more. On the other hand, no particular upper limit is placed on the holding time. However, the holding time is preferably 100 minutes or less, as excessive long holding time reduces productivity.

[0094] In the reheating step, any heating method can be used. An example of the heating method is furnace heating. For the furnace heating, a general heat treatment furnace can be used without any particular limitations.

(Second cooling step)

[0095] Next, the steel plate after the reheating step is cooled. Specifically, the steel plate after the reheating step is subjected to accelerated cooling to an accelerated cooling stop temperature of 100 °C to 600 °C at an average cooling rate at the 1/4 thickness position: 1.0 °C/s to 200.0 °C/s, and then air cooled to a temperature of 100 °C or less.

Average cooling rate: 1.0 °C/s to 200.0 °C/s

[0096] Accelerated cooling under the above conditions can transform reverse transformation austenite to bainite to obtain a bainite-dominated microstructure. When the average cooling rate is less than 1.0 °C/s, ferrite is formed, and the area fraction of bainite thus cannot be 80.0 % or more. Therefore, the average cooling rate is 1.0 °C/s or more, and preferably 5.0 °C/s or more. On the other hand, when the average cooling rate is higher than 200.0 °C/s, it is difficult to control the temperature at each position in the steel plate, which leads to material property variations in the plate transverse direction and rolling direction, resulting in material variations such as strength properties. Therefore, the average cooling rate is 200 °C/s or less, preferably 150.0 °C/s or less, and more preferably 100.0 °C/s or less.

[0097] No particular limitation is placed on the method of the accelerated cooling. Any method can be performed for cooling. Typically, the accelerated cooling is preferably performed by one or both of air cooling and water cooling, and water cooling is more preferred. Any water-based method (e.g., spray cooling, mist cooling, laminar cooling, etc.) can be used for the water cooling. Mist cooling is preferably used as the method of the water cooling.

Accelerated cooling stop temperature: 100 °C to 600 °C

[0098] In the above second cooling step, accelerated cooling is performed to the accelerated cooling stop temperature from 100 °C to 600 °C, followed by air cooling. When the accelerated cooling stop temperature is less than 100 °C, all austenite undergoes bainite transformation. Thus, the microstructure containing martensite austenite constituent cannot be obtained. In addition, the tempering effect cannot be achieved, resulting in reduce toughness of the steel plate. Therefore, the accelerated cooling stop temperature is 100 °C or more, and preferably 200 °C or more. On the other hand, when the accelerated cooling stop temperature is higher than 600 °C, ferrite is likely to be formed. Thus, the area fraction of bainite cannot be 80.0 % or more. Therefore, the accelerated cooling stop temperature is 600 °C or less, and preferably 500 °C or less.

Air cooling to temperature of 100 °C or less

[0099] After the accelerated cooling is stopped, the steel plate is further air cooled to a temperature of 100 °C or less. The air cooling may be allowed to naturally cool, i.e., natural cooling, rather than forced cooling. In the air cooling, the steel plate may be cooled to the temperature of 100 °C or less, but it is not necessary to stop air cooling at a specific temperature. The steel plate usually may be air cooled to the room temperature (ambient temperature).

[0100] Other conditions in the air cooling are not particularly limited, as they do not substantially affect the microstructure, etc. of the steel plate. For example, no particular limitation is placed on the cooling rate in the air cooling. Cooling may be performed at any rate. Typically, the cooling rate in the air cooling may be less than 1.0 °C/s, or 0.5 °C/s or less. No particular lower limit is also placed on the cooling rate in the air cooling. However, the cooling rate may be 0.001 °C/s or more, 0.01 °C/s or more, or 0.07 °C/s or more.

[0101] Similarly, no particular limitation is also placed on the time required for the air cooling (air cooling time). In this embodiment, there is no need to perform any special treatment after the air cooling, so there is no problem with time-consuming air cooling. Typically, the air cooling time may be more than 300 s, 310 s or more, or 320 s or more. On the other hand, no particular upper limit is also placed on the air cooling time. However, the air cooling time may be, for example, 24 hours or less, or 12 hours or less. The time taken from the start of air cooling to reach 100 °C is defined here as the air cooling time, in the second cooling step.

[0102] As described above, the steel plate of this disclosure can be produced by controlling the chemical composition, in particular, the C and Mn contents, within specific ranges and by appropriately controlling the heating conditions in the reheating step after hot rolling. Therefore, the steel plate of this disclosure is easier to produce and more suitable for industrial production, compared with the steel plate in PTL 3, which requires controlling the conditions during the cooling process after reheating to control the formation of MA.

[0103] In this disclosure, microscopic variations in Mn concentration are intentionally created by controlling the heating conditions in the reheating step as described above. As a result, the steel plate to be finally obtained has the above-described Mn concentration distribution. In contrast, PTL 3 does not control the heating conditions to create microscopic variations in Mn concentration as in this disclosure. Therefore, the production process described in PTL 3 cannot obtain a steel plate with the Mn concentration distribution that satisfies the conditions of this disclosure. MA is present in the steel plate in PTL 3. However, the Mn concentration around this MA is the same average concentration as the Mn concentration in the matrix. Thus, it is thought that there are no enriched regions that satisfy the conditions of this disclosure.

[0104] In another disclosed embodiment, further heat treatment can be performed after the first cooling step and before the reheating step, for higher strength and lower yield ratio of the steel plate. That is, in the embodiment, a steel plate can be produced by sequentially applying the steps (a) to (e) to a steel material having the above-described chemical composition:

(a) Hot rolling step;
(b) First cooling step;

(c) Heat treatment step;
(d) Reheating step; and
(e) Second cooling step.

(Heat treatment step)

[0105] In the above heat treatment step, the steel plate after the first cooling step is heated to a heat treatment temperature of Ac3 point or more and 1050 °C or less, held at the heat treatment temperature for a holding time of 5 minutes or more, and then cooled to a cooling stop temperature of 500 °C or less. The heat treatment can achieve both high strength and low yield ratio at an even higher level. The reason for this may be as follows. The reheating step after the heat treatment step homogenizes the present position of the Mn-enriched portion to increase the frequency of formation of the reverse transformation nucleation site. As a result, the formation of microscopic variations in Mn concentration is promoted to increase the final area fraction of the Mn-enriched region. Specifically, the area fraction of the enriched region can be 6.2 % or more. As described above, MA is formed in the Mn-enriched region, leading to both high strength and low yield ratio.

Heat treatment temperature: Ac3 point or more, 1050 °C or less

[0106] By setting the heat treatment temperature to Ac3 point or more and 1050 °C or less, desired bainite and martensitic microstructure can be obtained by ensuring quench hardenability. When the heat treatment temperature is less than Ac3 point, the desired toughness of base metal cannot be achieved. This is thought to be due to the formation of coarse ferrite during heat treatment, resulting in the formation of an upper bainitic microstructure with coarse carbides in the finally obtained microstructure. On the other hand, the desired toughness of base metal cannot be achieved also when the heat treatment temperature is higher than 1050 °C. This is thought to be due to the formation of coarse bainite and coarse martensite during heat treatment, resulting in the formation of a coarse bainitic microstructure in the finally obtained microstructure.

Holding time: 5 minutes or more

[0107] The holding time at the heat treatment temperature is 5 minutes or more, and preferably 10 minutes or more, to reduce the variation in austenite grain size. On the other hand, no particular upper limit is placed on the holding time. However, considering productivity, the holding time is preferably 100 minutes or less, and more preferably 60 minutes or less, as the effect will be saturated even if the holding time is excessively long.
[0108] Any heating method can be used for heating in the heat treatment step, as long as the heat treatment temperature and the holding time can be controlled as described above. An example of the heating method that can be used is furnace heating. For the furnace heating, a general heat treatment furnace can be used without any particular limitations.

Cooling stop temperature: 500 °C or less

[0109] After holding the steel plate at the above heat treatment temperature, the steel plate is cooled down to the cooling stop temperature of 500 °C or less. The austenite formed in the heat treatment step is transformed to a low temperature transformation phase of bainite and martensite by the cooling, and the subsequent reheating step can achieve further high strength and low yield ratio. When the cooling stop temperature is higher than 500 °C, the desired strength and toughness cannot be ensured. Therefore, the cooling stop temperature is 500 °C or less, preferably 400 °C or less, and more preferably 200 °C or less. On the other hand, no particular lower limit is placed on the cooling stop temperature. However, since excessive cooling reduces the productivity, the cooling stop temperature is preferably 0 °C or more, more preferably 10 °C or more, and further preferably 20 °C or more. Typically, the cooling stop temperature is preferably the room temperature or more.
[0110] No particular limitation is placed on the method of performing the cooling. The cooling can be performed by any method such as air cooling or water cooling. Any water-based method can be used for the water cooling, such as spray cooling, mist cooling, or laminar cooling.
[0111] When the above heat treatment step is performed, the steel plate after cooling may be subjected to the next reheating step. When the above heat treatment step is not performed, the steel plate after the first cooling step may be subjected to the next reheating step without heat treatment.
[0112] In another disclosed embodiment, a further tempering step can be optionally applied after the reheating step, such as for the purpose of correcting the shape of the steel plate. A lower cooling stop temperature in the cooling step after reheating can be expected to further improve the toughness of the base metal due to the effect of tempering. When tempering is performed, the heating temperature is preferably 200 °C to 500 °C. Cooling of the steel sheet after the above tempering step can be performed by any method, since the cooling rate does not change the material properties.

EXAMPLES

[0113] Steel plates were produced according to the following procedure, and their properties were evaluated.

[0114] First, molten steel having each chemical composition presented in Table 1 was melted in a converter and made into a steel slab (thickness: 260 mm) as a steel material by continuous casting. P_{CM} (mass%) determined by formula (1) above, Ac1 point (°C) determined by formula (2), and Ac3 point (°C) determined by formula (3) are listed in Table 1.

[0115] Each steel slab was heated to 1150 °C and then hot rolled to be a steel plate with the thickness presented in Tables 2 and 3 (hot rolling step). The rolling finish temperature in the hot rolling is presented in Tables 2 and 3.

[0116] The obtained steel plate was cooled to the cooling stop temperature presented in Tables 2 and 3 by the cooling method presented in Tables 2 and 3 (first cooling step).

[0117] Next, the steel plate after the first cooling step was reheated under the conditions presented in Tables 2 and 3 (reheating step). However, in some examples, the steel plate after the first cooling step was subjected to heat treatment under the conditions presented in Tables 2 and 3 (heat treatment step) and then reheated. The reheating was performed using a heat treatment furnace.

[0118] Finally, after the reheating, the steel plate was subjected to accelerated cooling under the conditions presented in Tables 2 and 3. After the accelerated cooling was stopped, the steel plate was air cooled (allowed to be naturally cooled) to the room temperature. The accelerated cooling was performed by water cooling. The air cooling time (time taken to reach 100 °C) in the air cooling was 1 hour or more.

[0119] The microstructure, Mn concentration distribution, mechanical properties, and post-weld toughness of bond portion were evaluated for each of the steel plates obtained as described above. The evaluations were conducted in the methods described below.

(Microstructure)

[0120] From each steel plate, a test piece for microstructure observation was taken so that the observation position was at a 1/4 thickness position. The test piece was embedded in resin so that the cross-section perpendicular to the rolling direction is the observation plane, and then mirror-polished. Next, the observation plane was subjected to LePera corrosion and then observed using a scanning electron microscope at a magnification of 1000× to capture images of the microstructure, thus identifying the martensite austenite constituent microstructure. The captured images of the five fields of view were analyzed by an image interpretation device to determine the area fraction and average equivalent circular diameter of the martensite austenite constituent microstructure.

[0121] In addition, from each steel plate, a test piece for microstructure observation was taken so that the observation position was at a 1/4 thickness position. The test piece was embedded in resin so that the cross-section perpendicular to the rolling direction is the observation plane, and then mirror-polished. Next, the observation plane was subjected to nital etching and then observed using a scanning electron microscope at a magnification of 200× to capture images of the microstructure, thus identifying the bainitic microstructure. The captured images of the five fields of view were analyzed by an image interpretation device to determine the area fraction of the bainitic microstructure.

(Mn concentration distribution)

[0122] From each steel plate, a test piece was taken so that the observation position was at a 1/4 thickness position. The Mn concentration distribution in the test piece was measured by EPMA to calculate the area fraction of the average concentration region of Mn, the area fraction of the Mn-enriched region, and the average equivalent circular diameter of the Mn-enriched region. The measurement of the Mn concentration distribution by EPMA was performed in two or more randomly selected fields of view, with the size of one field of view being 50 μm × 50 μm and 250 × 250 measurement points per field of view.

(Mechanical properties)

[0123] A JIS No. 4 tensile test piece was taken from a 1/4 thickness position of each steel plate. Using the tensile test piece, tensile test was performed in accordance with the provisions of JIS Z 2241 to measure the yield stress, tensile strength, and yield ratio of the steel plate. In addition, a V-notch test piece was taken from a 1/4 thickness position of each steel plate in accordance with the provisions of JIS Z 2202. Using the V-notch test piece, the Charpy absorption energy (vE_0) was determined by Charpy impact test at 0 °C in accordance with the provisions of JIS Z 2242 to evaluate the toughness of base metal.

(Toughness of bond portion)

[0124] To evaluate the toughness in the heat-affected zone of each steel plate, a welded joint was prepared by the following procedure, and the Charpy absorbed energy at the bond portion was measured.

[0125] First, from each steel plate, a pair of test plates for joint, each having the same plate thickness as the steel plate, was taken. Using one of the test plates for joint as a skin plate 1 and the other as a diaphragm 2, a groove 3 with the geometry illustrated in FIG. 1 was prepared. Electroslag welding was then performed with an amount of welding heat input of 40 kJ/mm or more to produce a welded joint 5.

[0126] Next, as illustrated in FIG. 2, a JIS No. 4 Charpy impact test piece 8 was taken from the welded joint 5 so that the position of a notch 9 was at the bond portion. The position of the notch 9 was the intersection of the weld line and a straight line passing a position 6 mm apart from the surface of the skin plate 1. The Charpy impact test piece 8 was taken so that the longitudinal direction of the test piece was perpendicular to the weld line.

[0127] The Charpy test piece was used to measure the absorbed energy (vE_0) at the bond portion at the welded joint in the Charpy impact test at 0 °C. For some steel plates whose base metal properties did not meet the target, the evaluation of the toughness of bond portion was not conducted.

[0128] The obtained results are presented in Tables 4 and 5. The followings were considered acceptable: yield stress of 600 MPa or more, tensile strength of 780 MPa or more, yield ratio of 85 % or less, absorbed energy at 0 °C (vE_0) of 70 J or more, and absorbed energy at 0 °C (vE_0) at the bond portion at the welded joint of 47 J or more.

[0129] All of the steel plates satisfying the conditions of this disclosure had high strength and low yield ratio as well as excellent toughness of base metal, each having a yield stress of 600 MPa or more, a tensile strength of 780 MPa or more, a yield ratio (YR) of 85 % or less, and an absorbed energy at 0 °C vE_0 of 70 J or more. Even when large-heat input welding with an amount of welding heat input exceeding 40 kJ/mm was applied, vE_0 at the bond portion at the welded joint was 47 J or more, having excellent toughness of bond portion at the welded joint. On the other hand, for the steel plates that did not satisfy the conditions of this disclosure, at least one of the following properties was inferior: base metal strength, yield ratio, toughness of base metal, and toughness of the bond portion at the welded joint.

[Table 1]

[0130]

Table 1

Steel sample ID	Chemical composition (mass%)*									4.83C + Mn (mass%)	Ti/N	P_{CM} (mass%)	Ac1 (°C)	Ac3 (°C)	Remarks
	C	Si	Mn	P	S	Al	Ti	N	Others						
A	0.052	0.11	2.5	0.003	0.0010	0.035	0.012	0.0035	-	2.8	3.43	0.181	717	878	Disclosed steel
B	0.022	0.21	2.6	0.004	0.0008	0.032	0.011	0.0040	Ni: 2.3, Ca: 0.001	2.7	2.75	0.197	666	834	Disclosed steel
C	0.046	0.15	2.3	0.003	0.0009	0.010	0.021	0.0065	Cu: 1.2, REM: 0.0020	2.5	3.23	0.226	696	863	Disclosed steel
D	0.047	0.02	1.5	0.014	0.0022	0.037	0.014	0.0050	Cr: 2.1, B: 0.0020	1.7	2.80	0.238	775	892	Disclosed steel
E	0.049	0.16	1.8	0.002	0.0009	0.042	0.006	0.0027	Cu: 1.2, Ni: 2.5, B: 0.0012	2.0	2.22	0.252	638	814	Disclosed steel
F	0.044	0.14	1.7	0.010	0.0020	0.030	0.014	0.0035	Ni: 0.8, Mo: 0.5, Nb: 0.01, V: 0.040, B: 0.0005	1.9	4.00	0.187	721	902	Disclosed steel
G	0.096	0.02	1.2	0.001	0.0010	0.005	0.017	0.0055	Cu: 1.2, Cr: 0.6, W: 0.5	1.7	3.09	0.247	721	850	Disclosed steel
H	0.035	0.06	2.1	0.005	0.0012	0.041	0.016	0.0039	Cu: 0.6, Ni: 1.3, Cr: 1.7, B: 0.0013, Ca: 0.0020	2.3	4.10	0.285	716	844	Disclosed steel
I	0.030	0.34	2.6	0.004	0.0040	0.043	0.015	0.0040	Ni: 1.6, Nb: 0.028, B: 0.0009, REM: 0.0030	2.7	3.75	0.203	688	861	Disclosed steel
J	0.042	0.20	1.6	0.005	0.0010	0.045	0.014	0.0034	Ni: 1.4, Cr: 0.7, Mo: 0.6, Mg: 0.002	1.8	4.12	0.227	725	890	Disclosed steel

(continued)

Steel sample ID	Chemical composition (mass%)*									4.83C + Mn (mass%)	Ti/N	P_{CM} (mass%)	Ac1 (°C)	Ac3 (°C)	Remarks
	C	Si	Mn	P	S	Al	Ti	N	Others						
K	0.061	0.10	1.3	0.002	0.0009	0.040	0.015	0.0043	Cr: 1.4, Mo: 1.3, Nb: 0.024, V: 0.022, Zr: 0.003	1.6	3.49	0.288	797	943	Disclosed steel
<u>L</u>	<u>0.148</u>	0.22	2.3	0.012	0.0032	0.038	0.014	0.0047	-	3.0	2.98	0.270	718	843	Comparative steel
M	<u>0.009</u>	0.25	2.5	0.006	0.0030	0.035	0.015	0.0050	Ni 2.0, Cr: 0.8, B: 0.0010	2.5	3.00	0.221	693	853	Comparative steel
<u>N</u>	0.020	0.18	<u>3.1</u>	0.009	0.0015	0.032	0.013	0.0045	-	3.2	2.89	0.181	712	885	Comparative steel
<u>O</u>	0.135	0.18	<u>0.8</u>	0.008	0.0021	0.040	0.013	0.0045	Cu: 0.5, Ni: 1.2, Mo: 0.8	1.5	2.89	0.279	713	867	Comparative steel
<u>P</u>	0.072	0.30	2.1	<u>0.020</u>	0.0035	0.038	0.010	0.0038	Mo: 0.4, W: 0.8	2.4	2.63	0.214	733	902	Comparative steel
<u>Q</u>	0.060	0.25	2.7	0.014	<u>0.0060</u>	0.035	0.012	0.0032	Cu: 1.0, Ni: 0.5, Nb: 0.025	3.0	3.75	0.262	688	848	Comparative steel
<u>R</u>	0.051	0.26	2.5	0.010	0.0022	0.045	<u>0.034</u>	0.0079	Cu: 0.8, Ni: 1.3	2.7	4.30	0.246	669	844	Comparative steel
<u>S</u>	0.032	0.12	1.7	0.005	0.0020	0.034	<u>0.002</u>	0.0017	Ni: 1.5, Mo: 1.4, B: 0.0011	1.9	<u>1.18</u>	0.245	723	919	Comparative steel
<u>T</u>	0.085	0.22	2.3	0.008	0.0018	0.031	0.022	<u>0.0087</u>	Cr: 0.8	2.7	2.53	0.247	740	869	Comparative steel
<u>U</u>	0.091	0.40	0.9	0.012	0.0015	0.037	0.011	0.0034	Cr: 0.5, Mo: 1.0	<u>1.3</u>	3.24	0.241	773	943	Comparative steel

(continued)

Steel sample ID	Chemical composition (mass%)*									4.83C + Mn (mass%)	Ti/N	P_{CM} (mass%)	Ac1 (°C)	Ac3 (°C)	Remarks
	C	Si	Mn	P	S	Al	Ti	N	Others						
V	0.034	0.24	2.2	0.007	0.0010	0.022	0.009	0.0061	Ni: 0.7, Cr: 1.0, Nb: 0.021, B: 0.0014	2.4	1.48	0.221	737	877	Comparative steel
W	0.046	0.25	2.4	0.008	0.0008	0.038	0.027	0.0057	Cr: 0.7, Mo: 0.8	2.6	4.74	0.263	755	920	Comparative steel
X	0.110	0.20	1.0	0.005	0.0009	0.035	0.013	0.0034	Cu: 0.2, Ni: 0.9, Cr: 0.6, Mo: 1.3, V: 0.055, B: 0.0012	1.5	3.82	0.320	749	915	Comparative steel

* The balance being Fe and inevitable impurities

[Table 2]

[0131]

Table 2

No.	Production conditions																	Remarks
	Steel slab			Hot rolling step		First cooling step		Heat treatment step				Reheating step				Second cooling step		
	Steel sample ID	Ac1 (°C)	Ac3 (°C)	Plate thickness (mm)	Rolling end temperature (°C)	Cooling method	Cooling stop temperature (°C)	Heat treatment temperature (°C)	Holding time (min)	Cooling method	Cooling stop temperature (°C)	Average heating rate *1 (°C/s)	Stay time *2 (s)	Reheating temperature (°C)	Holding time (min)	Average cooling rate (°C/s)	Accelerated cooling stop temperature (°C)	
1	A	717	882	50	950	Air cooling	< 250	-	-	-	-	0.6	210	930	20	7.5	380	Example
2	A	717	882	50	950	Water cooling	500	-	-	-	-	0.7	190	920	60	7.2	410	Example
3	A	717	882	12	870	Air cooling	< 250	-	-	-	-	1.1	150	930	20	85.5	440	Example
4	A	717	882	12	870	Air cooling	< 250	-	-	-	-	<u>3.0</u>	<u>40</u>	960	10	86.0	440	Comparative Example
5	A	717	882	12	870	Air cooling	< 250	-	-	-	-	<u>2.4</u>	60	960	10	85.0	440	Comparative Example
6	A	717	882	50	950	Air cooling	< 250	-	-	-	-	0.8	<u>30</u>	930	20	7.3	400	Comparative Example
7	A	717	882	50	950	Air cooling	< 250	-	-	-	-	0.7	180	<u>1030</u>	20	7.4	410	Comparative Example
8	A	717	882	50	950	Air cooling	< 250	-	-	-	-	0.6	190	<u>860</u>	30	7.5	410	Comparative Example
9	A	717	882	50	950	Air cooling	< 250	-	-	-	-	0.6	180	930	<u>3.5</u>	7.7	410	Comparative Example
10	A	717	882	50	950	Air cooling	< 250	-	-	-	-	0.6	180	930	30	<u>0.5</u>	420	Comparative Example
11	A	717	882	50	950	Air cooling	< 250	-	-	-	-	0.7	180	930	30	7.4	<u>630</u>	Comparative Example
12	A	717	882	40	950	Air cooling	< 250	-	-	-	-	1.2	120	920	30	9.5	<u>Normal temperature</u>	Comparative Example
13	B	666	834	50	950	Water cooling	350	-	-	-	-	0.5	260	870	60	7.5	380	Example

(continued)

No.	Production conditions																	Remarks
	Steel slab			Hot rolling step		First cooling step		Heat treatment step				Reheating step				Second cooling step		
	Steel sample ID	Ac1 (°C)	Ac3 (°C)	Plate thickness (mm)	Rolling end temperature (°C)	Cooling method	Cooling stop temperature (°C)	Heat treatment temperature (°C)	Holding time (min)	Cooling method	Cooling stop temperature (°C)	Average heating rate *1 (°C/s)	Stay time *2 (s)	Reheating temperature (°C)	Holding time (min)	Average cooling rate (°C/s)	Accelerated cooling stop temperature (°C)	
14	B	666	834	50	950	Air cooling	< 250	-	-	-	-	0.6	200	870	60	7.5	380	Example
15	B	666	834	12	870	Water cooling	450	-	-	-	-	1.0	120	890	30	85.5	350	Example
16	B	666	834	12	870	Water cooling	450	-	-	-	-	2.5	45	890	20	86.0	420	Comparative Example
17	B	666	834	12	870	Water cooling	450	-	-	-	-	2.3	65	890	20	85.0	420	Comparative Example
18	B	666	834	50	950	Water cooling	400	-	-	-	-	0.7	30	900	30	7.3	400	Comparative Example
19	B	666	834	50	950	Water cooling	400	-	-	-	-	0.7	180	1030	30	7.5	400	Comparative Example
20	B	666	834	50	950	Water cooling	400	-	-	-	-	0.7	180	800	30	7.5	400	Comparative Example
21	B	666	834	50	950	Water cooling	400	-	-	-	-	0.8	150	900	3	7.6	430	Comparative Example
22	B	666	834	50	950	Water cooling	400	-	-	-	-	0.7	160	900	30	0.5	480	Comparative Example
23	B	666	834	50	950	Water cooling	400	-	-	-	-	0.8	160	900	30	8.4	630	Comparative Example
24	B	666	834	40	950	Water cooling	400	-	-	-	-	1.1	100	920	30	9.1	Normal termerature	Comparative Example
25	C	696	863	50	950	Water cooling	400	920	20	Water cooling	Normal temperature	0.6	200	895	30	7.5	400	Example
26	C	696	863	85	900	Air cooling	< 250	920	40	Water cooling	Normal temperature	0.3	400	895	30	4	350	Example
27	C	696	863	12	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	2.5	55	895	30	85	480	Comparative Example

(continued)

No.	Production conditions																	Remarks
	Steel slab			Hot rolling step		First cooling step		Heat treatment step				Reheating step				Second cooling step		
	Steel sample ID	Ac1 (°C)	Ac3 (°C)	Plate thickness (mm)	Rolling end temperature (°C)	Cooling method	Cooling stop temperature (°C)	Heat treatment temperature (°C)	Holding time (min)	Cooling method	Cooling stop temperature (°C)	Average heating rate *1 (°C/s)	Stay time *2 (s)	Reheating temperature (°C)	Holding time (min)	Average cooling rate (°C/s)	Accelerated cooling stop temperature (°C)	
28	C	696	863	50	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	0.5	50	895	30	8	480	Comparative Example
29	C	696	863	50	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	0.5	280	1030	30	8.2	480	Comparative Example

*1 Average heating rate in temperature range from Ac1 point to Ac3 point
*2 Stay time in temperature range from Ac3 point - 100 °C to Ac3 point

[Table 3]

[0132]

Table 3

No.	Production conditions																	Remarks
	Steel slab			Hot rolling step		First cooling step		Heat treatment step				Reheating step				Second cooling step		
	Steel sample ID	Acl (°C)	Ac3 (°C)	Plate thickness (mm)	Rolling end temperature (°C)	Cooling method	Cooling stop temperature (°C)	Heat treatment temperature (°C)	Holding time (min)	Cooling method	Cooling stop temperature (°C)	Average heating rate *1 (°C/s)	Stay time *2 (s)	Reheating temperature (°C)	Holding time (min)	Average cooling rate (°C/s)	Accelerated cooling stop temperature (°C)	
30	C	696	863	50	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	0.5	150	840	30	8.1	480	Comparative Example
31	C	696	863	50	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	0.5	290	895	4	8	450	Comparative Example
32	C	696	863	50	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	0.5	300	895	30	0.5	350	Comparative Example
33	C	696	863	50	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	0.5	280	895	30	7.5	650	Comparative Example
34	C	696	863	50	950	Air cooling	< 250	920	20	Water cooling	Normal temperature	0.7	155	895	30	7.5	Normal temperature	Comparative Example
35	D	775	892	50	930	Air cooling	< 250	950	20	Water cooling	Normal temperature	0.5	220	940	30	7.2	420	Example
36	E	638	814	50	930	Air cooling	< 250	-	-	-	-	0.5	230	860	30	7.2	380	Example
37	F	721	902	50	930	Air cooling	< 250	950	20	Water cooling	Normal temperature	0.5	250	930	30	7.3	400	Example
38	G	720	850	30	890	Air cooling	< 250	-	-	-	-	0.4	260	860	20	22	410	Example
39	H	716	844	100	960	Water cooling	400	920	60	Water cooling	Normal temperature	0.1	1140	870	60	2.5	330	Example
40	I	688	861	50	940	Water cooling	400	-	-	-	-	0.6	245	880	30	7.5	450	Example
41	J	725	890	*50*	940	Air cooling	< 250	950	20	Water cooling	Normal temperature	0.3	410	910	20	7.5	450	Example
42	K	797	943	50	940	Air cooling	< 250	-	-	-	-	*0.5*	260	960	20	7.4	440	Example

(continued)

No.	Production conditions																	Remarks
	Steel slab			Hot rolling step		First cooling step		Heat treatment step				Reheating step				Second cooling step		
	Steel sample ID	Acl (°C)	Ac3 (°C)	Plate thickness (mm)	Rolling end temperature (°C)	Cooling method	Cooling stop temperature (°C)	Heat treatment temperature (°C)	Holding time (min)	Cooling method	Cooling stop temperature (°C)	Average heating rate *1 (°C/s)	Stay time *2 (s)	Reheating temperature (°C)	Holding time (min)	Average cooling rate (°C/s)	Accelerated cooling stop temperature (°C)	
43	L	718	843	50	930	Water cooling	300	-	-	-	-	0.5	200	860	30	7.7	400	Comparative Example
44	M	693	853	50	930	Air cool-ing	< 250	920	30	Water cooling	Normal tem-perature	0.6	200	870	30	7.5	400	Comparative Example
45	N	712	885	50	930	Air cool-ing	< 250	-	-	-	-	0.6	200	900	30	7.6	400	Comparative Example
46	O	713	867	50	930	Air cool-ing	< 250	-	-	-	-	0.6	200	890	30	7.5	400	Comparative Example
47	P	733	902	50	930	Air cool-ing	< 250	920	30	Water cooling	Normal tem-perature	0.6	200	920	30	7.3	400	Comparative Example
48	Q	688	848	50	930	Water cooling	350	-	-	-	-	0.6	200	870	30	7.5	400	Comparative Example
49	R	669	844	50	930	Air cool-ing	< 250	-	-	-	-	0.6	200	865	30	7.7	400	Comparative Example
50	S	723	919	50	930	Air cool-ing	< 250	920	30	Water cooling	Normal tem-perature	0.4	200	935	30	7.6	400	Comparative Example
51	T	740	869	50	930	Air cool-ing	< 250	-	-	-	-	0.6	200	890	30	7.5	400	Comparative Example
52	U	775	945	50	930	Air cool-ing	< 250	920	30	Water cooling	Normal tem-perature	0.6	200	960	30	7.4	400	Comparative Example
53	V	737	877	50	930	Air cool-ing	< 250	-	-	-	-	0.6	200	900	30	7.5	400	Comparative Example
54	W	755	920	50	930	Air cool-ing	< 250	-	-	-	-	0.6	200	935	30	7.3	400	Comparative Example
55	X	749	915	50	930	Air cool-ing	< 250	-	-	-	-	0.6	200	930	30	7.5	400	Comparative Example
56	A	717	882	50	950	Air cool-ing	< 250	-	-	-	-	0.3	-	720	20	7.5	380	Comparative Example

(continued)

No.	Production conditions																	Remarks
	Steel slab			Hot rolling step		First cooling step		Heat treatment step				Reheating step				Second cooling step		
	Steel sample ID	Acl (°C)	Ac3 (°C)	Plate thickness (mm)	Rolling end temperature (°C)	Cooling method	Cooling stop temperature (°C)	Heat treatment temperature (°C)	Holding time (min)	Cooling method	Cooling stop temperature (°C)	Average heating rate *1 (°C/s)	Stay time *2 (s)	Reheating temperature (°C)	Holding time (min)	Average cooling rate (°C/s)	Accelerated cooling stop temperature (°C)	
57	A	717	882	50	950	Air cooling	< 250	-	-	-	-	5	30	980	60	7.5	500	Comparative Example
58	C	696	863	50	950	Air cooling	< 250	880	5	Water cooling	490	0.6	250	875	1	7.5	550	Comparative Example

*1 Average heating rate in temperature range from Ac1 point to Ac3 point
*2 Stay time in temperature range from Ac3 point - 100 °C to Ac3 point

[Table 4]

[0133]

Table 4

No.	Steel sample ID	Microstructure			Mn concentration distribution			Mechanical properties					Remarks
		Bainite	Martensite austenite constituent		Average concentration region	Enriched region		Steel plate (Base metal)				Bond portion	
		Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Yield stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	vE_0 (J)	vE_0 (J)	
1	A	97.7	2.3	2.1	80	3.2	3.3	635	801	79.3	156	113	Example
2	A	97.4	2.6	3.2	85	3.4	3.9	625	786	79.5	175	95	Example
3	A	96.5	3.5	2.5	86	4.2	2.8	653	795	82.1	114	78	Example
4	A	99.2	0.8	0.3	92	1.5	0.5	595	696	85.5	145	86	Comparative Example
5	A	99.3	0.7	0.2	94	0.9	0.6	584	704	83.0	196	75	Comparative Example
6	A	99.4	0.6	0.2	91	0.9	0.5	615	713	86.3	85	108	Comparative Example
7	A	99.6	0.4	0.1	95	0.5	0.3	633	722	87.7	63	-	Comparative Example
8	A	88.0	12.0	6.7	67	20	82	588	738	79.7	22	-	Comparative Example
9	A	96.2	3.8	5.9	93	1.3	7.5	645	805	80.1	36	-	Comparative Example
10	A	78.3	8.0	4.3	65	18	6.5	467	612	76.3	33	-	Comparative Example
11	A	74.0	2.0	1.2	86	4.5	3.4	593	685	86.6	144	-	Comparative Example
12	A	100.0	0.0	1.3	88	4.3	3.5	674	782	86.2	45	-	Comparative Example

(continued)

No.	Steel sample ID	Microstructure			Mn concentration distribution			Mechanical properties					Remarks
		Bainite	Martensite austenite constituent		Average concentration region	Enriched region		Steel plate (Base metal)				Bond portion	
		Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Yield stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	vE_0 (J)	vE_0 (J)	
13	B	97.5	2.5	2.7	85	4.1	4.4	645	809	79.7	139	136	Example
14	B	97.0	3.0	2.8	82	4.2	3.7	639	805	79.4	146	105	Example
15	B	98.2	1.8	3.5	86	2.6	5.1	654	813	80.4	156	99	Example
16	B	99.3	0.7	0.3	93	1.8	0.5	589	692	85.1	145	87	Comparative Example
17	B	99.3	0.7	0.3	93	0.8	0.6	591	714	82.8	196	88	Comparative Example
18	B	99.4	0.6	0.1	92	0.4	0.1	622	720	86.4	85	-	Comparative Example
19	B	99.2	0.8	0.2	90	0.6	0.5	630	720	87.5	67	-	Comparative Example
20	B	83.5	16.5	7.2	68	21	9.3	551	789	69.8	24	-	Comparative Example
21	B	96.2	3.8	5.9	93	1.3	9.5	653	813	80.3	36	-	Comparative Example
22	B	78.3	8.0	4.3	65	18	5.8	487	622	78.3	33	-	Comparative Example
23	B	78.0	2.1	1.2	86	4.5	3.0	588	680	86.5	144	-	Comparative Example
24	B	100.0	0.0	1.3	88	4.3	2.9	679	779	87.2	45	-	Comparative Example
25	C	96.0	4.0	1.8	80	6.4	3.3	687	876	78.4	175	112	Example
26	C	95.5	4.5	2.1	79	6.5	3.0	681	865	78.7	156	98	Example

(continued)

No.	Steel sample ID	Microstructure			Mn concentration distribution			Mechanical properties					Remarks
		Bainite	Martensite austenite constituent		Average concentration region	Enriched region		Steel plate (Base metal)				Bond portion	
		Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Yield stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	vE_0 (J)	vE_0 (J)	
27	C	99.3	0.7	0.5	93	0.8	0.6	595	721	82.5	185	75	Comparative Example
28	C	99.4	0.6	0.4	94	0.5	0.1	633	715	88.5	106	-	Comparative Example
29	C	100.0	0.0	0.2	93	0.2	0.4	642	768	83.6	58	-	Comparative Example

[Table 5]

[0134]

Table 5

No.	Steel sample ID	Microstructure			Mn concentration distribution			Mechanical properties					Remarks
		Bainite	Martensite austenite constituent		Average concentration region	Erriche d region		Steel plate (Base metal)				Bond portion	
		Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Yield stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	vE_0 (J)	vE_0 (J)	
30	C	83.8	17.2	5.9	71	22	8.5	559	789	70.8	27	-	Comparative Example
31	C	95.9	4.1	6.1	94	5.9	92	672	821	81.9	45	-	Comparative Example
32	C	77.9	8.5	3.7	66	18.6	5.5	508	630	80.6	72	-	Comparative Example
33	C	733	1.8	1.5	88	4.3	3.5	602	680	88.5	144	-	Comparative Example
34	C	100.0	0.0	1.7	89	3.9	3.9	689	786	87.7	65	-	Comparative Example
35	D	95.1	3.3	1.6	81	9.5	3.2	656	827	79.3	154	95	Example
36	E	94.8	2.1	1.9	88	5.4	3.9	675	811	83.2	122	120	Example
37	F	93.2	4.5	1.3	78	11.0	2.9	652	826	789	149	77	Example
38	G	98.0	2.0	1.5	88	6.0	3.1	674	832	81.0	165	106	Example
39	H	96.4	3.4	1.1	80	10.0	1.5	675	840	80.4	125	132	Example
40	I	96.2	3.8	2.2	87	5.2	4.0	684	823	83.1	185	113	Example
41	J	96.0	4.0	2.3	61	15.8	6.3	691	869	79.5	202	121	Example
42	K	97.0	3.0	1.3	83	4.3	2.8	842	998	84.4	88	69	Example
43	L	95.5	4.5	5.2	85	6.0	8.8	702	897	78.3	72	25	Comparative Example

(continued)

No.	Steel sample ID	Microstructure			Mn concentration distribution			Mechanical properties					Remarks
		Bainite	Martensite austenite constituent		Average concentration region	Erriche d region		Steel plate (Base metal)				Bond portion	
		Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Yield stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	vE_0 (J)	vE_0 (J)	
44	M	99.5	0.5	0.2	72	5.6	0.3	658	765	86.0	188	63	Comparative Example
45	N	89.6	10.4	6.8	78	12.0	9.7	815	985	82.7	63	21	Comparative Example
46	O	99.9	0.1	3.5	93	0.2	4.5	645	753	85.7	144	46	Comparative Example
47	P	95.0	50	2.5	80	9.6	4.0	655	822	79.7	41	26	Comparative Example
48	Q	96.2	3.8	5.7	82	5.3	6.5	626	782	80.1	34	24	Comparative Example
49	R	96.3	3.7	2.1	80	6.5	3.5	653	799	81.7	21	17	Comparative Example
50	S	96.6	3.4	1.2	84	5.9	1.9	654	825	79.3	64	23	Comparative Example
51	T	97.0	3.0	1.6	83	7.5	2.1	768	980	78.4	35	26	Comparative Example
52	U	99.5	0.5	0.2	94	2.2	0.4	564	658	85.7	125	78	Comparative Example
53	V	98.0	2.0	2.1	83	5.5	2.8	654	954	68.6	88	24	Comparative Example
54	W	97.5	2.5	2.2	84	4.5	2.9	666	814	81.8	69	22	Comparative Example

(continued)

No.	Steel sample ID	Microstructure			Mn concentration distribution			Mechanical properties					Remarks
		Bainite	Martensite austenite constituent		Average concentration region	Erriche d region		Steel plate (Base metal)				Bond portion	
		Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Area fraction (%)	Area fraction (%)	Average equivalent circular diameter (μm)	Yield stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	vE_0 (J)	vE_0 (J)	
55	X	99.2	0.8	0.2	93	2.3	0.4	675	798	84.6	54	1.2	Comparative Example
56	A	98.7	5.8	4.7	81	7.5	8.2	635	737	86.2	59	-	Comparative Example
57	A	97.8	1.9	4.8	89	0.3	3.4	608	710	85.6	105	-	Comparative Example
58	C	88.5	6.8	4.9	92	3.3	7.2	623	785	79.4	30	-	Comparative Example

REFERENCE SIGNS LIST

[0135]

1 skin plate
2 diaphragm
3 groove
4 backing metal
5 welded joint
6 weld metal
7 heat-affected zone (HAZ)
8 Charpy impact test piece
9 notch

Claims

1. A steel plate comprising a chemical composition containing, in mass%,

C: 0.010 % to 0.14 %,
Si: 0.01 % to 0.50 %,
Mn: 0.9 % to 3.0 %,
P: 0.015 % or less,
S: 0.0050 % or less,
Al: 0.002 % to 0.080 %,
Ti: 0.003 % to 0.030 %, and
N: 0.0015 % to 0.0080 %,
with the balance being Fe and inevitable impurities, and the chemical composition having:

4.83C + Mn expressed by the C content (mass%) and the Mn content (mass%) of 1.4 mass% to 3.3 mass%;
a ratio Ti/N of the Ti content (mass%) to the N content (mass%) of 2.0 to 4.3; and
P_{CM} expressed by formula (1) of 0.30 mass% or less,
the steel plate comprising a microstructure containing bainite and martensite austenite constituent, with an area fraction of Bainite of 80.0 % or more and an area fraction of martensite austenite constituent of less than 5.0 %,
the steel plate comprising a Mn concentration distribution, wherein:

the area fraction of an average concentration region of Mn, defined as a region with a Mn concentration of 0.9 times to 1.1 times an average Mn content (mass%), is less than 90 %,
the area fraction of a Mn-enriched region, defined as a region with a Mn concentration of 1.15 times or more the average Mn content (mass%), is 1.0 % or more, and
the average equivalent circular diameter of the Mn-enriched region is 7.0 μm or less,

with a Charpy absorbed energy at 0 °C: vE_0 of 70 J or more:

$$P_{cm} = [C] + [Si]/30 + [Mn]/20 + [Cu]/20 + [Ni]/60 + [Cr]/20 + [Mo]/15 + [V]/10 + 5[B] \quad (1),$$

where the brackets in the formula indicate a content (mass%) of an element enclosed in the brackets and have a value of 0 if such an element is not contained.

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

Cu: 3.0 % or less,
Ni: 3.0 % or less,
Cr: 3.0 % or less,
Mo: 1.5 % or less,
W: 3.0 % or less,

Nb: 0.10 % or less,
V: 0.10 % or less,
B: 0.0050 % or less,
Ca: 0.005 % or less,
REM: 0.020 % or less,
Mg: 0.005 % or less, and
Zr: 0.020 % or less.

3. The steel plate according to claim 1 or 2, wherein, in the microstructure,

the area fraction of the martensite austenite constituent is 1.0 % or more and less than 5.0 %, and
the average equivalent circular diameter of the martensite austenite constituent is 5.0 μm or less.

4. A method of producing a steel plate, comprising:

a hot rolling step of hot rolling a steel material having the chemical composition according to claim 1 or 2 to form a steel plate;
a first cooling step of cooling the steel plate after the hot rolling step;
a reheating step of heating the steel plate after the first cooling step to a reheating temperature of Ac3 point or more and Ac3 point + 60 °C or less, under a set of conditions including: an average heating rate in a temperature range from Ac1 point to Ac3 point: 2.0 °C/s or less; and a stay time in a temperature range from Ac3 point - 100 °C to Ac3 point: 60 seconds or more, at a 1/4 thickness position, and then holding the steel plate for a holding time of 10 minutes or more at the reheating temperature; and
a second cooling step of subjecting the steel plate after the reheating step to accelerated cooling to an accelerated cooling stop temperature of 100 °C to 600 °C at an average cooling rate at the 1/4 thickness position of 1.0 °C/s to 200.0 °C/s and then air cooling the steel plate to a temperature of 100 °C or less.

5. The method of producing a steel plate according to claim 4, the method further comprising a heat treatment step after the first cooling step and before the reheating step,
wherein, in the heat treatment step, the steel plate after the first cooling step is:

heated to a heat treatment temperature of Ac3 point or more and 1050 °C or less;
held at the heat treatment temperature for a holding time of 5 minutes or more; and
then cooled to a cooling stop temperature of 500 °C or less.

FIG. 1

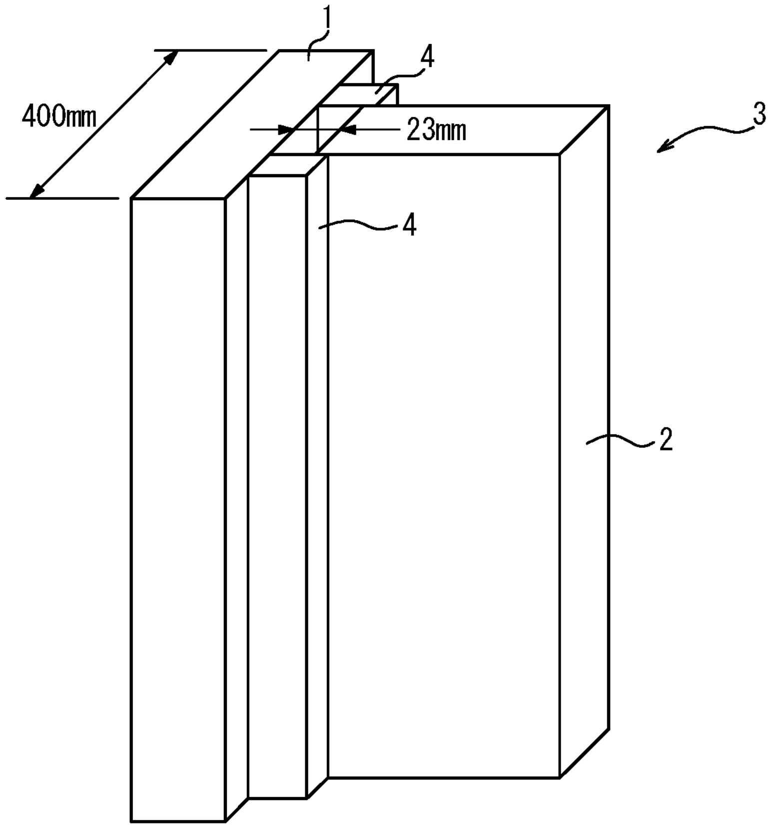
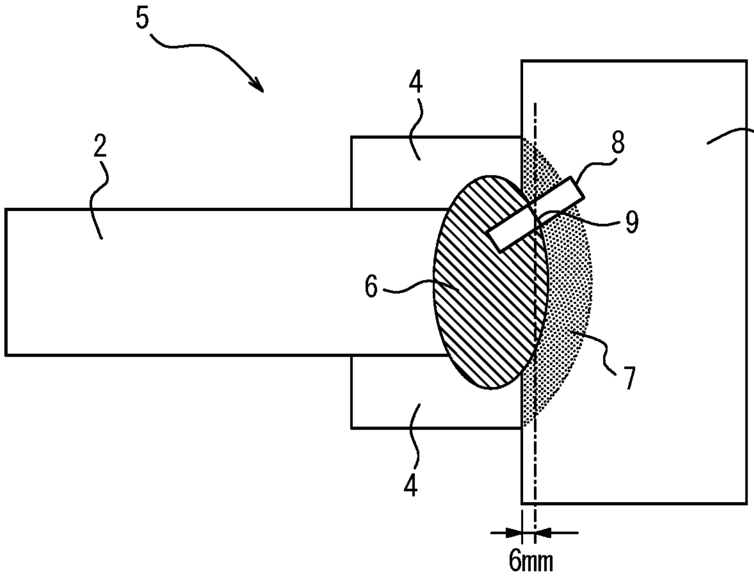


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2023/023875**

A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/02(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/14***(2006.01)i; ***C22C 38/58***(2006.01)i
FI: C22C38/00 301B; C22C38/14; C22C38/58; 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-C22C38/60

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.
X A	JP 2018-90872 A (JFE STEEL CORP.) 14 June 2018 (2018-06-14) claims, paragraphs [0088]-[0092], [0095]-[0105], tables 1-3	4 1-3, 5
P, X P, A	JP 2023-45253 A (JFE STEEL CORP.) 03 April 2023 (2023-04-03) claims, paragraphs [0001]-[0011], [0061]-[0093], tables 1-3	4 1-3, 5
A	JP 2020-117796 A (JFE STEEL CORP.) 06 August 2020 (2020-08-06) entire text	1-5
A	JP 2020-204075 A (NIPPON STEEL CORP.) 24 December 2020 (2020-12-24) claims, paragraphs [0001], [0008]	1-5
A	JP 2006-291349 A (JFE STEEL CORP.) 26 October 2006 (2006-10-26) claims, paragraph [0051], table 2	1-5
A	JP 2013-129885 A (JFE STEEL CORP.) 04 July 2013 (2013-07-04) claims, paragraph [0041], table 2	1-5

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 September 2023	**26 September 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/023875

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2020/0392608 A1 (POSCO) 17 December 2020 (2020-12-17) entire text	1-5

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/023875

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2018-90872 A	14 June 2018	(Family: none)	
JP 2023-45253 A	03 April 2023	(Family: none)	
JP 2020-117796 A	06 August 2020	(Family: none)	
JP 2020-204075 A	24 December 2020	(Family: none)	
JP 2006-291349 A	26 October 2006	(Family: none)	
JP 2013-129885 A	04 July 2013	(Family: none)	
US 2020/0392608 A1	17 December 2020	WO 2019/124926 A1 entire text EP 3730658 A1 KR 10-2019-0077180 A CA 3086838 A1 RU 2749855 C1	

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

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP H06248337 A **[0009] [0012]**
- JP 2001226740 A **[0010] [0012]**
- JP 2018090872 A **[0011] [0012]**

Non-patent literature cited in the description

- *Journal of Metals*, March 1980, 38-39 **[0058]**