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

(11) **EP 3 686 305 A1**

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

(43) Date of publication:
29.07.2020 Bulletin 2020/31

(21) Application number: **17926174.8**

(22) Date of filing: **19.09.2017**

(51) Int Cl.:
C22C 38/00 *(2006.01)* ***C22C 38/58*** *(2006.01)*
C21D 8/02 *(2006.01)*

(86) International application number:
PCT/JP2017/033706

(87) International publication number:
WO 2019/058420 (28.03.2019 Gazette 2019/13)

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

(71) Applicant: **Nippon Steel Corporation**
Tokyo 1008071 (JP)

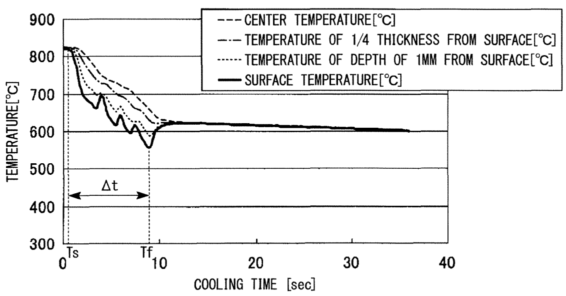
(72) Inventors:
- **SHINOHARA Yasuhiro**
  Tokyo 100-8071 (JP)
- **HARA Takuya**
  Tokyo 100-8071 (JP)
- **EBIHARA Kiyoshi**
  Tokyo 100-8071 (JP)
- **TSUTSUI Kazuteru**
  Tokyo 100-8071 (JP)
- **HATTORI Yutaka**
  Tokyo 100-8071 (JP)
- **HASHIMOTO Akira**
  Tokyo 100-8071 (JP)
- **ABE Nozomu**
  Tokyo 100-8071 (JP)

(74) Representative: **Vossius & Partner**
Patentanwälte Rechtsanwälte mbB
Siebertstrasse 3
81675 München (DE)

(54) STEEL PIPE AND STEEL PLATE

(57) A steel pipe includes: a base metal that includes a cylindrical steel plate having a predetermined chemical composition; and a weld that is provided in a seam portion of the steel plate and extends in a longitudinal direction of the steel plate, in which a surface layer microstructure that is a microstructure in a range up to 1.0 mm from a surface of the base metal in a depth direction includes polygonal ferrite and granular bainite, an area fraction of the polygonal ferrite in the surface layer microstructure is 0 to 70%, a total area fraction of the polygonal ferrite and the granular bainite in the surface layer microstructure is 50% or more, a maximum hardness in the surface layer microstructure is 270 Hv or lower, an area fraction of polygonal ferrite in an internal microstructure that is a microstructure in a range up to a thickness center from an area positioned at a distance of more than 1.0 mm from the surface of the base metal in the depth direction is 40% or less, a maximum hardness in the internal microstructure is 248 Hv or lower, and an average hardness in the internal microstructure is 150 to 220 Hv.

FIG. 2



EP 3 686 305 A1

Printed by Jouve, 75001 PARIS (FR)

Description

[Technical Field of the Invention]

[0001] The present invention relates to a steel pipe and a steel plate.

[Related Art]

[0002] Recently, demands for petroleum, natural gas, and the like have increased, and the diversification of energy supply sources has progressed. Therefore, in a harsh corrosive environment at which development was abandoned in the past, for example, in a corrosive environment including hydrogen sulfide, carbon dioxide gas, or chlorine ions, the digging of crude oil or natural gas has been actively performed. Accordingly, improvement of SSC resistance and HIC resistance is required for a steel pipe (steel pipe for a line pipe) used for a pipeline that transports crude oil, natural gas, or the like.

[0003] In addition, high-strengthening is required for the steel pipe for a line pipe in order to reduce the thickness for saving a material or to reduce the weight of a product. However, when the addition amount of an alloying element is increased to improve strength or the amount of heat input is increased for high-efficiency welding, the low-temperature toughness of a heat-affected zone (HAZ) deteriorates.

[0004] For example, as disclosed in Patent Documents 1 and 2, a steel pipe having HIC resistance has been manufactured using a technique such as an increase in the purity of steel, a reduction in the amount of an inclusion, a control of the form of a sulfide inclusion by addition of Ca, or suppression of center segregation by light rolling reduction during casting or by accelerated cooling.

[0005] However, in the steel pipe disclosed in Patent Documents 1 and 2, SSC resistance is not considered at all. Therefore, it is presumed that, in the steel pipe disclosed in Patent Documents 1 and 2, HIC resistance is satisfactory but sulfide stress cracking (SSC) resistance is not sufficient.

[Prior Art Document]

[Patent Document]

[0006]

[Patent Document 1] Japanese Examined Patent Application, Second Publication No. S63-001369
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. S62-112722

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0007] An object of the present invention is to provide: a steel pipe that is suitable for a line pipe and has a strength of API X52 to X70 grade and satisfactory SSC resistance and HIC resistance; and a steel plate that is used as a base metal of the steel pipe.

[Means for Solving the Problem]

[0008] The present invention has been made based on the above-described object, and the scope thereof is as follows.

(1) According to one aspect of the present invention, there is provided a steel pipe including:

a base metal that includes a cylindrical steel plate; and
a weld that is provided in a seam portion of the steel plate and extends in a longitudinal direction of the steel plate, in which the steel plate includes, as a chemical composition, by mass%,
C: 0.030% to 0.070%,
Si: 0.005% to 0.50%,
Mn: 1.05% to 1.65%,
Al: 0.010% to 0.070%,
Ti: 0.005% to 0.020%,
Nb: 0.005% to 0.045%,

Ca: 0.0010% to 0.0050%,
N: 0.0015% to 0.0070%,
Ni: 0% to 0.50%,
Mo: 0% to 0.50%,
Cr: 0% to 0.50%,
Cu: 0% to 0.50%,
V: 0% to 0.100%,
Mg: 0% to 0.0100%,
REM: 0% to 0.0100%,
P: limited to 0.015% or less,
S: limited to 0.0015% or less,
O: limited to 0.0040% or less, and
a remainder of Fe and impurities,
Ceq defined by the following Expression (i) in the chemical composition is 0.300 to 0.400,
a surface layer microstructure that is a microstructure in a range up to 1.0 mm from a surface of the base metal in a depth direction includes a polygonal ferrite and a granular bainite,
an area fraction of the polygonal ferrite in the surface layer microstructure is 0 to 70%,
a total area fraction of the polygonal ferrite and the granular bainite in the surface layer microstructure is 50% or more,
a maximum hardness in the surface layer microstructure is 270 Hv or lower,
an area fraction of a polygonal ferrite in an internal microstructure that is a microstructure in a range up to a thickness center from an area positioned at a distance of more than 1.0 mm from the surface of the base metal in the depth direction is 40% or less,
a maximum hardness in the internal microstructure is 248 Hv or lower, and
an average hardness in the internal microstructure is 150 to 220 Hv,

$$Ceq=[C]+[Mn]/6+([Ni]+[Cu])/15+([Cr]+[Mo]+[V])/5 \quad ... \quad (i),$$

where [C], [Mn], [Ni], [Cu], [Cr], [Mo], and [V] represent the amounts of C, Mn, Ni, Cu, Cr, Mo, and V by mass%.

(2) In the steel pipe according to (1), the chemical composition may include, by mass%, one or more selected from the group consisting of Ni: 0.05% to 0.50%, Mo: 0.05% to 0.50%, Cr: 0.05% to 0.50%, Cu: 0.05% to 0.50%, V: 0.010% to 0.100%, Mg: 0.0001% to 0.0100%, and REM: 0.0001% to 0.0100%.
(3) In the steel pipe according to (1) or (2), a remainder of the surface layer microstructure may consist of one or more selected from the group consisting of a bainite and a pseudo pearlite, and a remainder of the internal microstructure may consist of one or more selected from the group consisting of a granular bainite, a bainite, and a pseudo pearlite.
(4) According to another aspect of the present invention, there is provided a steel plate that is used as the base metal of the steel pipe according to any one of (1) to (3).

[Effects of the Invention]

[0009] According to the aspects of the present invention, it is possible to provide: a steel plate that is suitable for a line pipe and has a strength of API X52 to X70 grade and satisfactory SSC resistance and HIC resistance; and steel pipe that uses the steel plate as a base metal and has satisfactory SSC resistance and HIC resistance. Specifically, it is possible to provide a steel pipe having satisfactory sulfide stress cracking resistance (SSC resistance) and hydrogen induced cracking resistance (HIC resistance) and a steel plate that is used as a base metal of the steel pipe. The steel pipe having satisfactory sour resistance (SSC resistance and HIC resistance) is suitable as a line pipe that transports petroleum, natural gas, or the like.

[Brief Description of the Drawings]

[0010]

FIG. 1 is a schematic diagram showing a steel pipe according to an embodiment of the present invention.
FIG. 2 is a diagram showing an example of cooling curves of a steel plate.
FIG. 3A is a diagram showing the results of measuring a hardness (load: 100 g) of a surface layer microstructure

in a range of 0.1 to 1.0 mm from the surface at a position corresponding to 3 O'clock when a weld of the steel pipe is determined as a 0 O'clock position.

FIG. 3B is a diagram showing the results of measuring a hardness (load: 100 g) of the surface layer microstructure in a range of 0.1 to 1.0 mm from the surface at a position corresponding to 6 O'clock when the weld of the steel pipe is determined as the 0 O'clock position.

FIG. 3C is a diagram showing the results of measuring a hardness (load: 100 g) of the surface layer microstructure in a range of 0.1 to 1.0 mm from the surface at a position corresponding to 9 O'clock when the weld of the steel pipe is determined as the 0 O'clock position.

FIG. 4 is a diagram showing an example of a SEM image of the surface layer microstructure.

FIG. 5 is a diagram showing an example of a SEM image of an internal microstructure.

[Embodiments of the Invention]

[0011] A steel pipe according to one embodiment of the present invention (hereinafter, also referred to as the steel pipe according to the embodiment) includes:

a base metal that includes a cylindrical steel plate; and
a weld that is provided in a seam portion of the steel plate and extends in a longitudinal direction of the steel plate,
in which the steel plate includes, as a chemical composition, by mass%,
C: 0.030% to 0.070%,
Si: 0.005% to 0.50%,
Mn: 1.05% to 1.65%,
Al: 0.010% to 0.070%,
Ti: 0.005% to 0.020%,
Nb: 0.005% to 0.045%,
Ca: 0.0010% to 0.0050%,
N: 0.0015% to 0.0070%,
P: limited to 0.015% or less,
S: limited to 0.0015% or less,
O: limited to 0.0040% or less,
the steel plate optionally further includes, by mass%, one or more selected from the group consisting of Ni: 0.05% to 0.50%, Mo: 0.05% to 0.50%, Cr: 0.05% to 0.50%, Cu: 0.05% to 0.50%, V: 0.010% to 0.100%, Mg: 0.0001% to 0.0100%, and REM: 0.0001% to 0.0100%,
the steel plate includes a remainder of Fe and impurities,
Ceq represented by Ceq=[C]+[Mn]/6+([Ni]+[Cu])/15+([Cr]+[Mo]+[V])/5 is preferably 0.300 to 0.400,
a surface layer microstructure that is a microstructure in a range up to 1.0 mm from a surface of the base metal in a depth direction includes polygonal ferrite and granular bainite,
an area fraction of the polygonal ferrite in the surface layer microstructure is 0 to 70%,
a total area fraction of the polygonal ferrite and the granular bainite in the surface layer microstructure is 50% or more,
the remainder may include bainite (including tempered bainite), pseudo pearlite, or a mixture thereof,
a maximum hardness in the surface layer microstructure is 270 Hv or lower and preferably 250 Hv or lower,
an internal microstructure that is a microstructure in a range up to a thickness center from an area positioned at a distance of more than 1.0 mm from the surface of the base metal in the depth direction includes, by an area fraction, 40% or less of polygonal ferrite,
the remainder may include granular bainite, bainite, pseudo pearlite, or a mixture thereof,
a maximum hardness in the internal microstructure is 248 Hv or lower, and
an average hardness in the internal microstructure is 150 to 220 Hv.

[0012] In addition, a steel plate according to one embodiment of the present invention (hereinafter, referred to as the steel plate according to the embodiment) is used as the base metal of the steel pipe.

[0013] Hereinafter, the steel pipe according to the embodiment, the steel plate according to the embodiment, and preferable methods of manufacturing the same will be described.

[0014] First, the base metal (that is, the steel plate according to the embodiment) of the steel pipe according to the embodiment will be described.

(I) Chemical Composition

[0015] The reason for limiting the chemical composition of the base metal (the steel plate according to the embodiment) of the steel pipe according to the embodiment will be described. Hereinafter, "%" regarding the chemical composition represents "mass%".

C: 0.030% to 0.070%

[0016] C is an element that is required to improve the strength of the steel. When the C content is less than 0.030%, the effect of improving the strength cannot be sufficiently obtained. Therefore, the C content is 0.030% or more. The C content is preferably 0.040% or more.
[0017] On the other hand, when the C content is more than 0.070%, the strength of the steel excessively increases, the hardness of the surface layer microstructure and the internal microstructure, in particular, the center segregation portion is higher than 248 Hv, and SSC resistance and HIC resistance deteriorate. Therefore, the C content is 0.070% or less. From the viewpoint of suppressing deterioration in weldability, toughness, and the like, the C content is preferably 0.050% or less.

Si: 0.005% to 0.50%

[0018] Si is an element that functions as a deoxidation material during steelmaking. In addition, Si is an element that is unavoidably incorporated during steelmaking. When the Si content is less than 0.005%, the effect cannot be sufficiently obtained. Therefore, the Si content is 0.005% or more. From the viewpoint of sufficiently obtaining the deoxidation effect, the Si content is 0.050% or more.
[0019] On the other hand, when the Si content is more than 0.50%, toughness of a heat-affected zone (HAZ) deteriorates. Therefore, the Si content is 0.50% or less. The Si content is preferably 0.35% or less.

Mn: 1.05% to 1.65%

[0020] Mn is an element contributing to the strength and toughness of the steel. When the Mn content is less than 1.05%, the effect of improving the strength and toughness cannot be sufficiently obtained. Therefore, the Mn content is 1.05% or more. The Mn content is preferably 1.15% or more.
[0021] On the other hand, when the Mn content is more than 1.65%, a large amount of MnS that deteriorates HIC resistance is formed, the hardness of the internal microstructure, in particular, the center segregation portion is higher than 248 Hv, and HIC resistance deteriorates. Therefore, the Mn content is set to be 1.65% or less. The Mn content is preferably 1.50% or less.

Al: 0.010% to 0.070%

[0022] Al is an element that is added for deoxidation. When the Al content is less than 0.010%, the effect cannot be sufficiently obtained. Therefore, the Al content is 0.010% or more. The Al content is 0.020% or more.
[0023] On the other hand, when the Al content is more than 0.070%, a cluster on which an Al oxide accumulates is formed, and HIC resistance deteriorates. Therefore, the Al content is 0.070% or less. The Al content is preferably 0.045% or less.

Ti: 0.005% to 0.020%

[0024] Ti is an element that is bonded to N and forms a nitride. This nitride contributes refinement of crystal grains. When the Ti content is less than 0.005%, the effect cannot be sufficiently obtained. Therefore, the Ti content is 0.005% or more. The Ti content is preferably 0.008% or more.
[0025] On the other hand, when the Ti content is more than 0.020%, a coarse nitride is formed, and HIC resistance deteriorates. Therefore, the Ti content is 0.020% or less. The Ti content is 0.015% or less.

Nb: 0.005% to 0.045%

[0026] Nb is an element that refines crystal grains by widening non-recrystallization temperature range, form a carbide or a nitride and contributes to improvement of the strength of the steel. When the Nb content is less than 0.005%, the effect cannot be sufficiently obtained. Therefore, the Nb content is 0.005% or more. The Nb content is preferably 0.010% or more.
[0027] On the other hand, when the Nb content is more than 0.045%, a coarse carbide or nitride is formed, and HIC resistance deteriorates. Therefore, the Nb content is 0.045% or less. The Nb content is 0.035% or less.

Ca: 0.0010% to 0.0050%

[0028] Ca is an element that is bonded to S to form CaS, suppresses formation of MnS stretched in a rolling direction, and thus contributes improvement of HIC resistance. When the Ca content is less than 0.0010%, the effect cannot be sufficiently obtained. Therefore, the Ca content is 0.0010% or more. The Ca content is preferably 0.0020% or more.

[0029] On the other hand, when the Ca content is more than 0.0050%, a Ca oxide accumulates, and HIC resistance deteriorates. Therefore, the Ca content is 0.0050% or less. The Ca content is preferably 0.0040% or less.

N: 0.0015% to 0.0070%

[0030] N is an element that forms a nitride and contributes to suppressing the coarsening of austenite grains during heating. When the N content is less than 0.0015%, the effect cannot be sufficiently obtained. Therefore, the N content is 0.0015% or more. The N content is preferably 0.0020% or more.

[0031] On the other hand, when the N content is more than 0.0070%, a coarse carbonitride is formed, and HIC resistance deteriorates. Therefore, the N content is 0.0070% or less. The N content is preferably 0.0050% or less.

[0032] In order to improve strength, toughness, and other characteristics, in addition to the above-described elements, the chemical composition of the base metal (the steel plate according to the embodiment) of the steel pipe according to the embodiment may include one or more selected from the group consisting of Ni, Mo, Cr, Cu, V, Mg, and REM instead of a part of Fe within a range where the characteristics of the steel plate according to the embodiment do not deteriorate. These elements are optional elements and are not necessarily included. That is, the lower limits of the amounts of the elements are 0%.

Ni: 0% to 0.50%

[0033] Ni is an element that contributes to improvement of toughness and strength of the steel and improvement of corrosion resistance. In order to obtain these effects, the Ni content is preferably 0.05% or more. The Ni content is more preferably 0.10% or more.

[0034] On the other hand, when the Ni content is more than 0.50%, strength excessively increases, toughness deteriorates, and SSC resistance deteriorates due to grain boundary selective corrosion of the surface. Therefore, even when Ni is included, the Ni content is preferably 0.50% or less. The Ni content is preferably 0.35% or less.

Mo: 0% to 0.50%

[0035] Mo is an element that contributes to improvement of the hardenability of the steel. In order to obtain this effect, the Mo content is preferably 0.05% or more. The Mo content is more preferably 0.10% or more. On the other hand, when the Mo content is more than 0.50%, strength excessively increases, and toughness deteriorates. Therefore, even when Mo is included, the Mo content is 0.50% or less. The Mo content is preferably 0.35% or less.

Cr: 0% to 0.50%

[0036] Cr is an element that contributes to improvement of the strength of the steel. In order to obtain this effect, the Cr content is preferably 0.05% or more. The Cr content is more preferably 0.10% or more. On the other hand, when the Cr content is more than 0.50%, strength excessively increases, and toughness deteriorates. Therefore, even when Cr is included, the Cr content is 0.50% or less. The Cr content is preferably 0.35% or less.

Cu: 0% to 0.50%

[0037] Cu is an element that contributes to improvement of the strength of the steel and improvement of corrosion resistance. In order to obtain these effects, the Cu content is preferably 0.05% or more. The Cu content is more preferably 0.10% or more. On the other hand, when the Cu content is more than 0.50%, strength excessively increases, and toughness deteriorates. Therefore, even when Cu is included, the Cu content is 0.50% or less. The Cu content is preferably 0.35% or less.

V: 0% to 0.100%

[0038] V is an element that forms a carbide and/or a nitride and contributes improvement of the strength of the steel. In order to obtain this effect, the V content is preferably 0.010% or more. The V content is more preferably 0.030% or more. On the other hand, when the V content is more than 0.100%, toughness deteriorates. Therefore, even when V is included, the V content is preferably 0.100% or less. The V content is preferably 0.080% or less.

Mg: 0% to 0.0100%

[0039] Mg is an element that forms a fine oxide to suppress the coarsening of crystal grains and contributes improvement of the toughness of the steel. In order to obtain this effect, the Mg content is preferably 0.0001% or more. The Mg content is more preferably 0.0010% or more.

[0040] On the other hand, when the Mg content is more than 0.0100%, an oxide aggregates and is coarsened, and HIC resistance and toughness deteriorate. Therefore, even when Mg is included, the Mg content is 0.0100% or less. The Mg content is preferably 0.0050% or less.

REM: 0% to 0.0100%

[0041] REM is an element that contributes to improvement of SSC resistance, HIC resistance, and toughness by controlling the form of a sulfide inclusion. In order to obtain these effects, the REM content is preferably 0.0001 % or more. The REM content is more preferably 0.0010% or more.

[0042] On the other hand, when the REM content is more than 0.0100%, an oxide is formed, the cleanliness of the steel deteriorates, and HIC resistance and toughness deteriorate. Therefore, even when REM is included, the REM content is 0.0100% or less. The REM content is preferably 0.0060% or less.

[0043] In the embodiment, REM refers to rare earth elements and is a collective term for 17 elements including Sc, Y, and lanthanoids. The REM content refers to the total amount of the 17 elements.

[0044] As described above, the base metal (the steel plate according to the embodiment) of the steel pipe according to the embodiment basically has the chemical composition including the above-described essential elements and the remainder consisting of Fe and impurities. However, the base metal may have a chemical composition including the above-described essential elements, the above-described optional elements, and the remainder consisting of Fe and impurities.

[0045] Here, the impurities refer to elements which are incorporated from raw materials such as ore or scrap or incorporated in various environments of the production process when the steel is industrially produced, and the impurities are allowed to be included in the steel in a range where there are no adverse effects on the steel.

[0046] Among the impurities, it is preferable that P, S, O, Sb, Sn, Co, As, Pb, Bi, and H are controlled to be in ranges described below.

P: 0.015% or less

[0047] P is an impurity element, and the less the P content, the better. When the P content is more than 0.015%, HIC resistance significantly deteriorates. Therefore, the P content is 0.015% or less. The P content is preferably 0.010% or less.

[0048] The less the P content, the better, and the lower limit thereof may be 0%. However, when the P content is reduced to less than 0.003%, the manufacturing costs significantly increase. Therefore, the lower limit of the P content in the actual steel plate is substantially 0.003%.

S: 0.0015% or less

[0049] S is an element that forms MnS stretched in a rolling direction during hot rolling. This stretched MnS deteriorates HIC resistance. When the S content is more than 0.0015%, HIC resistance significantly deteriorates. Therefore, the S content is 0.0015% or less. The S content is preferably 0.0010% or less.

[0050] The less the S content, the better, and the lower limit thereof may be 0%. However, when the S content is reduced to less than 0.0001%, the manufacturing costs significantly increase. Therefore, the upper limit of the S content in the actual steel plate is substantially 0.0001%.

O: 0.0040% or less

[0051] O is an element that avoidably remains after deoxidation. The less the O content, the better. When the O content is more than 0.0040%, a large amount of an oxide is formed, and HIC resistance significantly deteriorates. Therefore, the O content is 0.0040% or less. The O content is preferably 0.0030% or less.

[0052] The less the O content, the better, and the lower limit thereof may be 0%. However, when the O content is reduced to less than 0.0010%, the manufacturing costs significantly increase. Therefore, the lower limit of the O content in the actual steel plate is substantially 0.0010%.

[0053] In addition, in consideration of the influence on the steel plate characteristics and the steel pipe characteristics, for example, the content each of Sb, Sn, Co, and As is 0.10% or less, the amount of each of Pb and Bi is 0.005% or less, and the H content is preferably 0.0005% or less.

Ceq: 0.300 to 0.400

[0054] In the steel pipe according to the embodiment, in order to further improve strength, SSC resistance, and HIC resistance, the chemical composition of the steel plate used for the base metal of the steel pipe satisfies not only the amount of each of the elements, but also Ceq (carbon equivalent) defined by the following Expression (1) is 0.400 or less.

$$Ceq=[C]+[Mn]/6+([Ni]+[Cu])/15+([Cr]+[Mo]+[V])/5 \quad \ldots \quad (1)$$

[0055] In the expression, [C], [Mn], [Ni], [Cu], [Cr], [Mo], and [V] represent the contents (mass%) of C, Mn, Ni, Cu, Cr, Mo, and V.

[0056] When Ceq is higher than 0.400, hardenability excessively increases, the maximum hardness of the surface layer microstructure of the base metal (steel plate) described below is higher than 270 Hv, and thus SSC resistance deteriorates. In addition, the maximum hardness of the internal microstructure is higher than 248 Hv, and HIC resistance deteriorates. Therefore, Ceq is 0.400 or lower. Ceq is preferably 0.350 or lower. In order to secure a predetermined strength, the lower limit of Ceq is 0.300 or higher.

(II) Microstructure

[0057] Next, the microstructure (the microstructure and the hardness thereof) of the base metal of the steel pipe according to the embodiment will be described.

[0058] When controlled cooling is performed on the steel plate, the surface layer of the steel plate is more rapidly cooled as compared to the inside of the steel plate. This implies that a difference in mechanical properties is generated due to a difference between the microstructure of the surface layer of the steel plate and the microstructure of the inside of the steel plate. In particular, the hardness of the surface layer of the steel plate is higher than that of the inside of the steel plate. The present inventors found that, in the steel plate and the steel pipe having the above-described microstructure, SSC resistance is poor in a range (surface layer) up to 1.0 mm from the surface in the depth direction (through-thickness direction).

[0059] On the other hand, the present inventors found that, by using recuperating during controlled cooling of the steel plate, the microstructure of the surface layer of the steel plate and the microstructure of the inside of the steel plate can be controlled, and thus an increase in the hardness of the surface layer of the steel plate can be suppressed.

[0060] In the steel pipe according to the embodiment, in order to secure satisfactory SSC resistance and HIC resistance, the microstructure of the steel plate of the base metal is divided into (i) a microstructure (surface layer microstructure) in a range up to 1.0 mm from the surface of the steel plate in the depth direction (through-thickness direction) and (ii) a microstructure (internal microstructure) in a range up to a thickness center from an area positioned at a distance of more than 1.0 mm from the surface of the base metal in the depth direction. In each of the microstructures, the kind, the fraction (area fraction), and the hardness of the microstructure are defined.

[0061] In the steel pipe according to the embodiment, the range up to 1.0 mm from the surface of the steel plate as the base metal in the depth direction will be referred to as "surface layer" (hereinafter, also simply referred to as "the surface layer of the steel plate). According to accelerated cooling, in particular, the hardness of the range up to a depth of 1.0 mm from the surface becomes high. Therefore, the surface layer microstructure is defined as the microstructure in a range up to 1.0 mm from the steel plate surface in the depth direction.

[0062] The surface layer microstructure in a range up to a depth of 1.0 mm from the surface of the steel plate as the base metal includes polygonal ferrite and granular bainite, the area fraction of polygonal ferrite is 0% to 70%, the total area fraction of polygonal ferrite and granular bainite is 50% or more, and the maximum hardness is 270 Hv or lower.

[0063] When the area fraction of polygonal ferrite in the surface layer is more than 70%, a high concentration of C accumulates on the remainder, a hardening region is formed, and thus SSC resistance deteriorates. Therefore, the area fraction of polygonal ferrite is 70% or less. The area fraction of polygonal ferrite is preferably 50% or less. In addition, in order to secure SSC resistance, the total area fraction of polygonal ferrite and granular bainite is 50% or more.

[0064] The remainder of the surface layer microstructure may include one or more selected from the group consisting of bainite and pseudo pearlite. However, the remainder is not necessarily included. That is, the total area fraction of polygonal ferrite and granular bainite may be 100%.

[0065] When the maximum hardness of the surface layer microstructure is higher than 270 Hv, SSC resistance deteriorates. Therefore, the maximum hardness of the surface layer microstructure is 270 Hv or lower. The maximum hardness of the surface layer microstructure is preferably 250 Hv. From the viewpoint of SSC resistance, although the lower limit of the maximum hardness of the surface layer microstructure is not necessarily determined, the maximum hardness of the surface layer microstructure is substantially 160 Hv or higher.

[0066] The area fraction of each of the microstructures can be obtained by observing the microstructure with a scanning electron microscope (SEM), for example, at a magnification of 1000-fold. The surface layer microstructure can be obtained by observing positions of 0.1 mm, 0.2 mm, and 0.5 mm from the surface of the steel plate and obtaining the average of the area fractions at the respective positions.

[0067] In the embodiment, polygonal ferrite is a microstructure that is observed as a massive microstructure not including a coarse precipitate such as coarse cementite or MA in grains.

[0068] Bainite is a microstructure in which a prior austenite grain boundary is clear, a fine lath structure is developed in grains, and a fine carbide and an austenite-martensite constituent mixture are scattered in and between laths. Here, bainite also includes tempered bainite.

[0069] Granular bainite is a microstructure that is formed at an intermediate transformation temperature between acicular ferrite and bainite, the acicular ferrite being a microstructure in which a prior austenite grain boundary is not clear and acicular-shaped ferrite (a carbide and an austenite-martensite constituent are not present) is formed in a random crystal orientation in grains. In the granular bainite, a prior austenite grain boundary partially appears, a coarse lath structure is present in grains, and a portion where a fine carbide and an austenite-martensite constituent are scattered in and between laths and a portion of acicular or amorphous ferrite where a prior austenite grain boundary is not clear are mixed.

[0070] Pseudo pearlite is pearlite in which parallel row of cementite is arranged.

[0071] FIG. 4 shows an example of a microstructure (observed with a scanning electron microscope at a magnification of 1000-fold) at a distance of 0.5 mm from the surface of the steel plate. In FIG. 4, a portion, which is surrounded by a smooth curve and in which internal portion is smooth, is polygonal ferrite, and a portion where white spots are present in internal portion is granular bainite.

[0072] The maximum hardness of the surface layer microstructure is measured as follows.

[0073] First, 300 mm×300 mm steel plates are cut out by gas cutting from positions of 1/4, 1/2, and 3/4 of the width of the steel plate (positions of 3 o'clock, 6 o'clock, and 9 o'clock when the weld of the steel pipe is 0 o'clock) from a width-direction end portion (corresponding to the seam portion in the case of the steel pipe) of the steel plate in the width direction of the steel plate. Block test pieces having a length of 20 mm and a width of 20 mm are collected by mechanical cutting from the centers of the cut steel plates and are polished by mechanical polishing. Regarding each of the block test pieces, the hardness is measured using a Vickers hardness meter (load: 100 g) at 100 points in total that are obtained by setting a point of 0.1 mm from the surface as a starting point, setting 10 pints from the starting point in a through-thickness direction at an interval of 0.1 mm, and setting 10 points at the same depth at an interval of 1.0 mm in a width direction. Unless two or more measurement points having a hardness of higher than 270 Hv among the test pieces continuously appear in the through-thickness direction as a result of the above-described measurement in every test piece, it is determined that the maximum hardness of the surface layer microstructure is 270 Hv or lower.

[0074] When two or more measurement points having a hardness of higher than 270 Hv are continuously present in the through-thickness direction, this hardness is not an abnormal value, a microstructure having a high hardness is formed, SSC resistance deteriorates, which is not allowable. Accordingly, in the embodiment, even when one measurement point having a hardness of higher than 270 Hv is present, if two or more measurement points do not continuously appear in the through-thickness direction, this point as an abnormal point is not adopted, and the second highest value is obtained as the maximum hardness. When two or more measurement points having a hardness of higher than 270 Hv are continuously present in the through-thickness direction, the highest value is adopted as the maximum hardness.

[0075] FIGS. 3A to 3C show the results of measuring the hardness of the surface layer microstructure at three positions corresponding to 3 O'clock, 6 O'clock, and 9 O'clock when the weld of the steel pipe is at a 0 O'clock position. Using a Vickers hardness meter, the hardness of the surface layer microstructure is measured under a load of 100 g by setting every 10 measurement points at the same depth at an interval of 0.1 mm in a region from a depth of 0.1 mm to a depth of 1.0 mm from the surface layer. It can be seen that, at all the points, the maximum hardness is 270 Hv or lower and SSC resistance is excellent.

[0076] The microstructure (internal microstructure) in a range up to a thickness center from an area positioned at a distance of more than 1.0 mm from the surface of the steel plate as the base metal in the depth direction: the area fraction of polygonal ferrite is 40% or less, the maximum hardness is 248 Hv or lower, and the average hardness is 150 to 220 Hv.

[0077] When the area fraction of polygonal ferrite in the internal microstructure is more than 40%, it is difficult to secure a required strength and HIC resistance. Therefore, the area fraction of polygonal ferrite is 40% or less. The area fraction of polygonal ferrite is preferably 30% or less and more preferably 25% or less.

[0078] The remainder of the internal microstructure consists of one or more selected from the group consisting of granular bainite, bainite, and pseudo pearlite.

[0079] When the maximum hardness in the internal microstructure is higher than 248 Hv, HIC resistance deteriorates.

Therefore, the maximum hardness is 248 Hv or lower. In addition, when the average hardness is lower than 150 Hv, required mechanical properties cannot be secured. Therefore, the average hardness is 150 Hv or higher. the average hardness is 160 Hv or higher. On the other hand, when the average hardness is higher than 220 Hv, HIC resistance and toughness deteriorate. Therefore, the average hardness is 220 Hv or lower. The average hardness is preferably 210 Hv or lower.

[0080] The microstructural fraction (area fraction) of the internal microstructure can be obtained by observing a 1/4 thickness (t/4) position from the surface of the steel plate with a scanning electron microscope (SEM), for example, at a magnification of 1000-fold. The reason why the observation position is the t/4 position is that the microstructure of the t/4 position is a representative microstructure of the internal microstructure.

[0081] FIG. 5 shows an example of the microstructure of the t/4 position (observed with a scanning electron microscope at a magnification of 1000-fold). In FIG. 5, a portion which is surrounded by a smooth curve and in which internal portion is smooth is polygonal ferrite. In addition, a portion where white spots or a white line appears is granular bainite or pseudo pearlite, and a portion that is surrounded by a jagged white line and where a thin pattern appears is bainite.

[0082] The maximum hardness and the average hardness in the internal microstructure can be measured using the following method.

[0083] 300 mm×300 mm steel plates are cut out by gas cutting from positions of 1/4, 1/2, and 3/4 (positions of 3 o'clock, 6 o'clock, and 9 o'clock when the weld of the steel pipe is 0 o'clock) from a width-direction end portion (corresponding to the seam portion in the case of the steel pipe) of the steel plate in the width direction of the steel plate. Block test pieces having a length of 20 mm and a width of 20 mm are collected by mechanical cutting from the centers of the cut steel plates and are polished by mechanical polishing. Regarding each of the block test pieces, the hardness is measured using a Vickers hardness meter (load: 1 kg) by setting a depth position of 1.2 mm from the surface as a starting point, setting 10 points from the starting point in a through-thickness direction at an interval of 0.2 mm, and setting 10 points at the same depth at an interval of 1.0 mm in a width direction. Unless two or more measurement points having a hardness of higher than 248 Hv continuously appear in the through-thickness direction as a result of the above-described measurement, it is determined that the maximum hardness of the surface layer microstructure is 248 Hv or lower.

[0084] In the base metal of the steel pipe according to the embodiment, a high hardness value (abnormal value) may appear locally. However, even when this abnormal value appears, HIC resistance can be secured. On the other hand, when two or more measurement points having a hardness of higher than 248 Hv are continuously present in the through-thickness direction, HIC resistance deteriorates, which is not allowable. Accordingly, in the embodiment, even when one measurement point having a hardness of higher than 248 Hv is present, unless two or more measurement points do not continuously appear in the through-thickness direction, this point as an abnormal point is not adopted, and the second highest value is obtained as the maximum hardness. On the other hand, when two or more measurement points having a hardness of higher than 248 Hv are continuously present in the through-thickness direction, the highest value is adopted as the maximum hardness.

[0085] In addition, the average hardness is calculated by obtaining the average value of the hardnesses at all the measurement points.

[0086] Next, the weld of the steel pipe according to the embodiment will be described.

[0087] The steel pipe according to the embodiment can be obtained by processing the steel plate according to the embodiment into a pipe shape, making opposite end portions (width-direction end portions of the steel pipe) of the cylindrical steel plate abut against each other, and welding the end portions. Therefore, as shown in FIG. 1, the steel pipe 1 according to the embodiment includes the weld 3 that is provided in the seam portion of the steel plate 2 and extends in the longitudinal direction of the steel plate. Typically, the weld 3 is continuously provided in a range from one end portion of the steel plate 2 in the longitudinal direction to another end portion thereof.

[0088] In general, during steel pipe welding, the weld is provided such that the thickness is more than that of the base metal. In addition, the weld metal has a higher alloy content than the base metal and also has high corrosion resistance. Therefore, the weld does not substantially cause fracture to occur. Accordingly, the weld of the steel pipe according to the embodiment is not particularly limited as long as it is obtained by SAW welding or the like under typical conditions.

[0089] It is preferable that the steel pipe according to the embodiment has a strength that satisfies X52 to X70 defined by API 5L in consideration of application to a line pipe.

[0090] Next, a preferable method of manufacturing the steel pipe according to the embodiment will be described.

[0091] As long as the steel pipe according to the embodiment has the above-described configuration, the effects thereof can be obtained irrespective of the manufacturing method thereof. For example, a manufacturing method including the following processes is preferable because the steel pipe according to the embodiment can be stably obtained.

[0092] That is, the steel plate according to the embodiment can be obtained using a manufacturing method including:

(i) a hot-rolling process of heating a slab having a predetermined chemical composition at 1050°C to 1250°C, subjecting the slab to hot rolling and finishing hot rolling at 830°C to 1000°C;

(ii) an accelerated cooling process of performing accelerated cooling on the steel plate after finishing hot rolling from a surface temperature range of 750°C to 950°C to a surface temperature range of 400°C to 650°C at an average cooling rate of 15 to 100 °C/sec such that recuperating where an increase in temperature is 5°C to 65°C is performed two or more times in the middle of the accelerated cooling.

In addition, the steel pipe according to the embodiment is obtained using a manufacturing method including (i) and (ii) described above and further including:

(iii) a forming process of forming the steel plate according to the embodiment obtained as described above into a cylindrical shape; and

(iv) a welding process of making opposite end portions of the cylindrical steel plate abut against each other and welding the end portions.

[0093] Hereinafter, preferable conditions in each of the processes will be described.

<Hot-Rolling Process>

Slab Heating Temperature: 1050°C to 1250°C

[0094] A slab that is manufactured by casting molten steel having the same chemical composition as that of the base metal of the steel pipe according to the embodiment is heated to 1050°C to 1250°C and subjected to hot rolling. The casting of the molten steel and the manufacturing of the slab before hot rolling may be performed using an ordinary method.

[0095] When the slab heating temperature is lower than 1050°C, carbonitrides of non-solid-solubilized Nb and Ti are formed, and HIC resistance deteriorates. Therefore, the slab heating temperature is preferably 1050°C or higher. The slab heating temperature is more preferably 1100°C or higher. On the other hand, when the slab heating temperature is higher than 1250°C, the crystal grain size increases, and low-temperature toughness deteriorates. In addition, the austenite grain size increases, and hardenability excessively increases. As a result, a hard phase is formed in the surface layer microstructure and the internal microstructure, and SSC resistance and HIC resistance deteriorate. Therefore, the slab heating temperature is preferably 1250°C or lower. The slab heating temperature is more preferably higher than 1200°C or lower.

[0096] During hot rolling, the slab heated to the above-described temperature is hot-rolled at a typical rolling reduction ratio to obtain a steel plate. The plate thickness may be set depending on the required thickness of a line pipe and thus is not particularly limited.

Rolling Finishing Temperature: 830°C to 1000°C

[0097] In order to obtain the predetermined surface layer microstructure and the predetermined internal microstructure by accelerated cooling after finish rolling, the rolling finishing temperature (finishing temperature) is 830°C to 1000°C. When the rolling finishing temperature is lower than 830°C, it is difficult to obtain the surface layer microstructure and the internal microstructure. Therefore, the finish rolling temperature is preferably 830°C or higher. The finish rolling temperature is more preferably 850°C or higher.

[0098] On the other hand, when the rolling finishing temperature is higher than 1000°C, crystal grains are coarsened, and low-temperature toughness deteriorates. Therefore, the rolling finishing temperature is preferably 1000°C or lower. The rolling finishing temperature is more preferably 900°C or lower.

<Accelerated Cooling Proess>

[0099]

Cooling Start Temperature Ts: 750°C to 950°C
Cooling Stop Temperature Tf: 400°C to 650°C
Average Cooling Rate Vc: 15 to 100 °C/sec
Number of Times of Recuperating: two or more
Increase in Temperature caused by Recuperating: 5°C to 65°C (excluding recuperating after stopping final water cooling)

[0100] In the accelerated cooling process, accelerated cooling is performed on the steel plate after finishing hot rolling from a surface temperature range of 750°C to 950°C to a surface temperature range of 400°C to 650°C at an average cooling rate of 15 to 100 °C/sec such that two or more times of recuperating where an increase in temperature from the start of cooling to the end of cooling is 5°C to 65°C is included.

[0101] The accelerated cooling including recuperating in the middle can be performed by adjusting the amount of cooling water that is sprayed to the steel plate per cooling zone in a cooling facility in which a plurality of divided cooling zones are arranged in a longitudinal direction of the steel plate (conveyance direction).

[0102] FIG. 2 shows an example of cooling curves of the steel plate. Four cooling curves include a cooling curve of the thickness middle portion (1/2 thickness portion), a cooling curve of a 1/4 thickness position (t/4 portion) from the surface, a cooling curve of a portion of a depth of 1.0 mm from the surface, and a cooling curve of the steel plate surface. Accelerated cooling is performed on the entire steel plate from the cooling start temperature (Ts) of 830°C to about 620°C for about 10 seconds such that recuperating is performed three times in the middle.

[0103] During this cooling, the cooling start temperature Ts and the cooling stop temperature Tf are points shown in the drawing, and the average cooling rate Vc can be obtained by dividing a temperature change ΔT (cooling start temperature Ts-cooling stop temperature Tf) by a cooling time Δt (the time for which water cooling is performed).

[0104] It can be seen from FIG. 2 that the temperature of the steel plate surface during cooling is temporarily increased by recuperating due to sensible heat inside the steel plate as a result of adjusting the amount of cooling water sprayed per cooling zone. On the other hand, the cooling curve of the steel plate surface and the cooling curve of the portion of a depth of 1.0 mm from the surface are affected by recuperating. However, the cooling curve of the thickness middle portion (1/2 thickness portion) and the cooling curve of the 1/4 thickness portion are not affected by recuperating, and it can be seen that the inside of the steel plate is cooled at a substantially constant cooling rate.

[0105] When the cooling start temperature Ts is lower than 750°C, in the surface layer microstructure, coarse ferrite is formed after rolling, and a microstructure having a high hardness such as martensite is formed as the remainder. As a result, SSC resistance deteriorates. In addition, when the cooling start temperature Ts is lower than 750°C, the ferrite fraction in the internal microstructure is excessively large, and the hardness of a hard phase is also high. Therefore, the cooling start temperature Ts is preferably 750°C or higher. The cooling start temperature Ts is more preferably 780°C or higher.

[0106] On the other hand, in a case where the cooling start temperature Ts is higher than 950°C, even when recuperating is performed two or more times, the maximum hardness of the surface layer microstructure is higher than 270 Hv, and SSC resistance deteriorates. Therefore, the cooling start temperature Ts is preferably 950°C or lower. The cooling start temperature Ts is more preferably 880°C or lower.

[0107] When the cooling stop temperature Tf is lower than 400°C, the average hardness of the internal microstructure is higher than 220 Hv, and HIC resistance deteriorates. Therefore, the cooling stop temperature Tf is preferably 400°C or higher. The cooling stop temperature Tf is more preferably 480°C or higher. On the other hand, when the cooling stop temperature Tf is higher than 650°C, the average hardness of the internal microstructure is lower than 150 Hv, and there may be a case where the predetermined strength cannot be satisfied. In addition, a microstructure having a high hardness is locally formed, and SSC resistance and HIC resistance may deteriorate. Therefore, the cooling stop temperature Tf is preferably 650°C or lower. The cooling stop temperature Tf is more preferably 580°C or lower.

[0108] When the average cooling rate Vc is slower than 15 °C/sec, polygonal ferrite having an area fraction of more than 70% is formed in the surface layer microstructure. In addition, in the internal microstructure polygonal ferrite having an area fraction of more than 40% is formed. In this case, the strength as a line pipe cannot be secured. Therefore, the average cooling rate Vc is preferably 15 °C/sec or faster. The average cooling rate Vc is more preferably 25 °C/sec or faster.

[0109] On the other hand, when the average cooling rate Vc is faster than 100 °C/sec, martensite transformation occurs, the hardness of the surface layer microstructure is higher than 270 Hv, and SSC resistance deteriorates. In addition, the maximum hardness of the internal microstructure is higher than 248 Hv, and HIC resistance deteriorates. Therefore, the average cooling rate Vc is preferably 100 °C/sec or slower. The average cooling rate Vc is more preferably 80 °C/sec or slower.

[0110] When the number of times of recuperating where the recuperated temperature during accelerated cooling is in a predetermined range is one or less, the hardness of the surface layer microstructure is higher than 270 Hv, and SSC resistance deteriorates. Therefore, the number of times of recuperating is two or more.

[0111] FIG. 2 shows the cooling curve when the number of times of recuperating is three. However, the number of times of recuperating may be appropriately determined between the cooling start temperature and the cooling stop temperature depending on the kind of steel or the plate threading speed.

[0112] In the steel plate according to the embodiment, cooling is performed in a film boiling state in order to form a predetermined microstructure. In order to perform cooling in the film boiling state, recuperating is not completed during water cooling, and an increase in the temperature caused by recuperating is 65°C or lower. When the temperature increase caused by recuperating is higher than 65°C, coarse ferrite is formed, and a predetermined microstructure cannot be obtained. On the other hand, when the temperature increase caused by recuperating is lower than 5°C, the effect of recuperating cannot be obtained. Therefore, the width of the temperature increase caused by recuperating is preferably 5°C to 65°C. The width of the temperature increase caused by recuperating is preferably 10°C to 65°C. However, regarding the final recuperating after stopping water cooling, the width of the temperature increase caused by recuperating is not necessarily 5°C to 65°C.

[0113] When the temperature of the steel plate is increased during cooling by induction heating or the like instead of recuperating, the temperature of the inside of the steel plate also increases. Therefore, even when heating is performed by induction heating or the like instead of recuperating, a predetermined microstructure cannot be obtained.

[0114] When recuperating where a temperature increase is 5°C to 65°C is performed two or more times, it is preferable that the first recuperating is performed such that the steel plate surface temperature after recuperating is 500°C or higher. Even when the steel plate surface temperature after the first recuperating is lower than 500°C, the surface layer microstructure having satisfactory SSC resistance and the internal microstructure having satisfactory HIC resistance can be secured. However, in order to stably secure the surface layer microstructure having satisfactory SSC resistance and the internal microstructure having satisfactory HIC resistance, it is preferable that the first recuperating is performed such that the steel plate surface temperature after recuperating is 500°C or higher.

[0115] After a short time from the stop of water cooling, a temperature difference between the surface temperature and the center temperature is eliminated. For example, in FIG. 2, at about 620°C, there is no temperature difference between the surface layer of the steel plate (surface temperature) and the inside of the steel plate (center temperature), and the steel plate temperature is stable. Subsequently, it is preferable to perform cooling up to 300°C or lower at an average cooling rate of 0.5 °C/sec to 5.0 °C/sec. As long as the average cooling rate is 0.5 °C/sec to 5.0 °C/sec, air cooling may be performed. When the average cooling rate is slower than 0.5 °C/sec, the predetermined strength cannot be obtained. On the other hand, when the average cooling rate is faster than 5.0 °C/sec, the toughness of the center portion deteriorates.

<Forming Process>

[0116] The formation of the steel plate according to the embodiment into the steel pipe is not limited to a specific forming method. Warm working can also be used, but cold working is preferable from the viewpoint of dimensional accuracy.

<Welding Process>

[0117] Next, opposite end portions of the steel plate formed into a cylindrical shape are made to abut against each other, and the end portions are welded. Welding is not limited to a specific welding method, but submerged arc welding (SAW) is preferable. Welding conditions may be well-known conditions depending on the plate thickness and the like.

[0118] In the method of manufacturing the steel pipe according to the embodiment, a heat treatment (seam heat treatment) may be performed such that a microstructure (ferrite and pearlite having an area fraction of more than 10%) that deteriorates the toughness of the weld is not formed. The heat treatment temperature may be a typical temperature range and is preferably in a range of 300°C to the Ac 1 point.

[0119] A heat treatment is not performed on the base metal of the steel pipe according to the embodiment. Therefore, the microstructure of the base metal is the same as the microstructure of the steel plate according to the embodiment. The base metal of the steel pipe according to the embodiment has the same microstructure as that of the steel plate according to the embodiment, and thus mechanical properties for use in a line pipe and satisfactory local weldability. In addition, since the weldability of the steel plate according to the embodiment is satisfactory, the weld of the steel pipe according to the embodiment has satisfactory mechanical properties. Accordingly, the steel pipe according to the embodiment is suitable as a steel pipe for a line pipe.

[Examples]

[0120] Next, examples of the present invention will be described. However, the conditions of the examples are merely exemplary examples to confirm the operability and the effects of the present invention, and the present invention is not limited to these condition examples. The present invention can adopt various conditions within a range not departing from the scope of the present invention as long as the object of the present invention can be achieved under the conditions.

(Example 1)

[0121] A slab having a chemical composition and Ceq shown in Table 1 was hot-rolled and cooled under conditions shown in Table 2. As a result, a steel plate was manufactured. In Table 2, the number of times of recuperating is the number of times of recuperating where a temperature increase was 5°C or higher. In addition, the maximum width of recuperating temperature is the width of a temperature increase during recuperating where the width of the temperature increase was the maximum.

[Table 1]

Kind of Steel	Chemical Composition (Remainder: Fe and Im purities)																	Ceq
	C	Si	Mn	P	S	Al	Ti	Nb	Ca	N	O	Ni	Mo	Cr	Cu	V	Mg	REM	
1	0.046	0.22	1.39	0.006	0.0002	0.019	0.012	0.018	0.0016	0.0021	0.0014		0.11	0.19					0.338
2	0.044	0.24	1.38	0.009	0.0003	0.040	0.011	0.018	0.0022	0.0032	0.0021	0.16		0.23	0.21	0.040			0.353
3	0.042	0.21	1.37	0.005	0.0002	0,032	0.012	0.021	0.0018	0.0028	0.0017			0.17					0.304
4	0.055	0.31	1.62	0.008	0.0002	0.026	0.011	0.044	0.0019	0.0022	0.0011								0.325
5	0.067	0.11	1.40	0.009	0.0006	0.019	0.009	0.032	0.0039	0.0029	0.0032								0.300
6	0.031	0.22	1.64	0.005	0.0002	0.013	0.011	0.007	0.0028	0.0021	0.0013								0.304
7	0.042	0.32	1.45	0.007	0.0003	0.021	0.019	0.009	0.0022	0.0029	0.0017		0.15	0.20					0.354
8	0.051	0.22	1.47	0.011	0.0005	0.027	0.011	0.026	0.0024	0.0043	0.0019	0.20				0.012			0.312
9	0.039	0.34	1.43	0.009	0.0004	0.032	0.013	0.028	0.0049	0.0031	0.0039	0.20	0.10	0.27		0.040			0.373
10	0.033	0.01	1.38	0.012	0.0009	0.019	0.017	0.021	0.0031	0.0016	0.0021		0.10			0.098		0.0032	0.303
11	0.027	0.19	1.43	0.009	0.0012	0.028	0.012	0.029	0.0033	0.0032	0.0019	0.15			0.15		0.0025		0.285
12	0.075	0.21	1.64	0.017	0.0008	0.021	0.022	0.018	0.0029	0.0033	0.0018	0.20	0.25						0.412
13	0.041	0.004	1.43	0.009	0.0008	0.021	0.011	0.021	0.0032	0.0031	0.0043	0.20		0.13					0.319
14	0.048	0.29	1.03	0.008	0.0005	0.029	0.011	0.029	0.0033	0.0032	0.0018	0.20		0.20					0.273
15	0.051	0.29	1.68	0.008	0.0004	0.019	0.003	0.018	0.0026	0.0032	0.0018								0.331
16	0.048	0.29	1.44	0.012	0.0017	0.031	0.009	0.044	0.0007	0.0038	0.0017	0.20			0.20				0.315
17	0.041	0.31	1.45	0.003	0.0005	0.008	0.014	0.042	0.0057	0.0029	0.0023	0.20			0.20				0.309
18	0.039	0.11	1.48	0.004	0.0005	0.043	0.013	0.044	0.0031	0.0029	0.0019		0.10						0.306
19	0.044	0.29	1.39	0.007	0.0006	0.033	0.012	0.003	0.0036	0.0031	0.0029		0.10			0.120			0.320
20	0.058	0.31	1.11	0.008	0.0007	0.029	0.008	0.021	0.0031	0.0033	0.0021	0.35	0.15	0.48	0.35				0.416
21	0.051	0.29	1.21	0.008	0.0004	0.027	0.013	0.031	0.0029	0.0075	0.0021		0.54	0.30			0.0120		0.421
22	0.044	0.11	1.41	0.008	0.0002	0.026	0.011	0.039	0.0024	0.0042	0.0023	0.60	0.25		0.60			0.0120	0.409
23	0.072	0.21	1.38	0.008	0.0004	0.040	0.011	0.042	0.0022	0.0032	0.0019		0.10	0.20					0.362
24	0.048	0.22	1.37	0.017	0.0005	0.032	0.012	0.038	0.0023	0.0021	0.0018		0.21	0.21					0.360

(continued)

Kind of Steel	Chemical Composition (Remainder: Fe and Im purities)																	Ceq
	C	Si	Mn	P	S	Al	Ti	Nb	Ca	N	O	Ni	Mo	Cr	Cu	V	Mg	REM	
25	0.042	0.21	1.42	0.008	0.0002	0.032	0.022	0.032	0.0021	0.0031	0.0018			0.20					0.319
26	0.038	0.20	1.68	0.007	0.0002	0.022	0.009	0.021	0.0025	0.0033	0.0019			0.22					0.362
27	0.032	0.23	1.43	0.007	0 .0017	0.022	0.010	0.015	0.0014	0.0042	0.0021			0.19					0.308
28	0.038	0.24	1.29	0.008	0.0008	0.019	0.011	0.015	0.0053	0.0032	0.0018	0.30		0.20	0.30				0.333
29	0.042	0.21	1.29	0.005	0.0005	0.038	0.012	0.022	0.0008	0.0034	0.0019		0.20	0.17					0.331
30	0.048	0.19	1.39	0.006	0.0005	0.009	0.014	0.028	0.0016	0.0038	0.0015			0.23					0.326
31	0.046	0.13	1.44	0.004	0.0004	0.023	0.017	0.003	0.0018	0.0022	0.0015			0.24					0.334
32	0.045	0.23	1.42	0.008	0.0004	0.021	0.011	0.048	0.0021	0.0021	0.0016		0.10	0.31					0.364
33	0.052	0.24	1.33	0.007	0.0002	0.026	0.008	0.036	0.0028	0.0072	0.0025		0.10	0.21					0.336
34	0.039	0.22	1.35	0.007	0.0004	0.030	0.007	0.032	0.0021	0.0034	0.0029	0.60	0.10						0.324

[Table 2]

Manufacturing No.	Kind of Steel	Product Thickness	Heating Temperature	Rolling Finishing Temperature	Cooling Start Temperature	Average Cooling Rate	Cooling Stop Temperature	Number of Times of Recuperating	Maximum Width of Recuperated Temperature
		mm	°C	°C	°C	°C/sec	°C	Times	°C
S1	1	8	1250	990	948	45	550	3	35
S2	2	8	1250	950	940	99	455	2	65
S3	3	20	1180	880	800	45	530	3	35
S4	4	11	1200	944	812	21	602	4	35
S5	5	42	1140	830	785	70	520	4	34
S6	6	13	1060	880	810	25	570	4	28
S7	7	20	1150	859	790	45	495	4	33
S8	8	13	1200	835	780	60	539	2	45
S9	9	32	1150	830	760	88	451	3	64
S10	10	10	1200	930	813	65	470	3	48
S11	1	20	1180	840	800	35	475	3	42
S12	1	20	1180	830	775	42	495	4	26
S13	1	10	1180	880	825	38	465	2	15
S14	11	10	1200	935	800	26	580	4	33
S15	12	10	1200	935	800	26	580	4	33
S16	13	10	1200	935	800	26	580	4	33
S17	14	10	1200	935	800	26	580	4	33
S18	15	10	1200	935	800	26	580	4	33
S19	16	10	1200	935	800	26	580	4	33
S20	17	10	1200	935	800	26	580	4	33
S21	18	13	1200	935	824	18	605	4	39
S22	19	13	1200	935	824	18	605	4	39
S23	20	13	1200	935	824	18	605	4	39

(continued)

Manufacturing No.	Kind of Steel	Product Thickness	Heating Temperature	Rolling Finishing Temperature	Cooling Start Temperature	Average Cooling Rate	Cooling Stop Temperature	Number of Times of Recuperating	Maximum Width of Recuperated Temperature
		mm	°C	°C	°C	°C/sec	°C	Times	°C
S24	21	13	1200	935	824	18	605	4	39
S25	22	13	1200	935	824	18	605	4	39
S26	23	20	1160	855	805	32	475	3	27
S27	24	20	1160	855	805	32	475	3	27
S28	25	20	1160	855	805	32	475	3	27
S29	26	20	1160	855	805	32	475	3	27
S30	27	20	1160	855	805	32	475	3	27
S31	28	20	1160	855	805	32	475	3	27
S32	29	20	1160	855	805	32	475	3	27
S33	30	20	1160	855	805	32	475	3	27
S34	31	20	1160	855	805	32	475	3	27
S35	32	20	1160	855	805	32	475	3	27
S36	33	20	1160	855	805	32	475	3	27
S37	34	20	1160	855	805	32	475	3	27
S38	1	11	1000	930	790	35	600	4	35
S39	1	11	<u>1280</u>	930	790	35	600	4	35
S40	1	11	1250	<u>1030</u>	790	<u>120</u>	600	4	35
S41	1	11	1200	<u>800</u>	<u>730</u>	35	600	4	35
S42	1	11	1200	930	790	35	<u>670</u>	4	35
S43	1	20	1200	930	790	85	<u>370</u>	<u>1</u>	35
S44	1	32	1200	930	790	90	400	<u>0</u>	-
S45	1	40	1200	930	790	<u>140</u>	<u>300</u>	<u>1</u>	30
S46	1	20	1180	855	805	<u>135</u>	425	2	27

(continued)

Manufacturing No.	Kind of Steel	Product Thickness	Heating Temperature	Rolling Finishing Temperature	Cooling Start Temperature	Average Cooling Rate	Cooling Stop Temperature	Number of Times of Recuperating	Maximum Width of Recuperated Temperature
		mm	°C	°C	°C	°C/sec	°C	Times	°C
S47	1	20	1180	825	765	40	435	3	32
S48	1	20	1180	860	745	37	485	3	28
S49	1	20	1180	985	960	44	465	3	38
S50	1	20	1180	865	800	38	375	3	32
S51	1	20	1180	840	800	35	475	1	42
S52	1	20	1180	930	813	65	470	2	75

[0122] A test piece was collected from the manufactured steel plate, the surface layer microstructure (positions of 0.1 mm, 0.2 mm, and 0.5 mm) and the internal microstructure (t/4 position) were observed with a SEM at a magnification of 1000-fold and the fractions (area fractions) of polygonal ferrite, granular bainite, and the remainder were calculated. The remainder of the surface layer microstructure consisted of one or more selected from the group consisting of bainite and pseudo pearlite, and the remainder of the internal microstructure consisted of one or more selected from the group consisting of granular bainite, bainite, and pseudo pearlite.

[0123] In addition, a JIS No.5 tensile test piece was prepared, and a tensile test according to JIS Z 2241 was performed to measure a yield strength and a tensile strength.

[0124] In addition, the hardness was measured using a Vickers hardness meter. The hardness of the surface layer microstructure was measured under a load of 100 g by setting every 10 points at the same depth at an interval of 0.1 mm in a region from a depth of 0.1 mm to a depth of 1.0 mm from the surface layer. On the other hand, the hardness of the internal microstructure was measured under a load of 1 kg by setting every 10 points at the same depth at an interval of 0.2 mm in a region from a depth of 1.2 mm from the surface layer to the thickness center. Based on the results, the maximum hardness of the surface layer microstructure was obtained, and the maximum hardness and the average hardness of the internal microstructure were obtained.

[0125] Further, a test piece was collected from the manufactured steel plate, and the following test was performed to evaluate HIC resistance and SSC resistance.

Evaluation of HIC Resistance

[0126] A test according to TM0284 of NACE (National Association of Corrosion and Engineer) was performed to observe whether or not hydrogen induced cracking (HIC) occurred. When the HIC area fraction was 5% or less, HIC resistance was evaluated to be satisfactory (OK). When the HIC area fraction was more than 5%, HIC resistance was evaluated to be poor (NG).

[0127] The NACE test is a test in which hydrogen sulfide gas is saturated in a solution including 5% NaCl solution+0.5 acetic acid and having a pH of 2.7 and the steel plate is dipped in the solution for 96 hours to observe whether or not cracking occur.

Evaluation of SSC Resistance

[0128] A full thickness test piece having a width of 15 mm and a length of 115 mm was collected from the steel plate in a width direction, and SSC resistance was evaluated in a 4 point bending test according to TM0284m ASTM (American Society for Testing and Materials) G39 of NACE.

[0129] In the 4 point bending test, the test piece to which a stress corresponding to 90% of 0.2% proof stress derived from the tensile test was applied was dipped for 720 hours in an aqueous solution including 5% sodium chloride +0.5 acetic acid at normal temperature (24°C) and having a pH of 2.7 in which hydrogen sulfide gas of 1 atm was saturated, and the test piece surface was observed at a magnification of 10-fold to determine whether or not SSC occurred.

[0130] A test piece where SSC did not occur was evaluated as "Pass (OK)", and a test piece where SSC occurred was evaluated as "Fail (NG)". The results are shown in Table 3.

[Table 3]

Manufacturing No.	Kind of Steel	Surface laver Microstructure			Internal Microstructure			Properties			
		Area Fraction of Polygonal Ferrite (%)	Total Area Fraction of Polygonal Ferrite and Granular Bainite (%)	Maximum Hardness (Load: 100 g) (Hv)	Area Fraction of Polygonal Ferrite (%)	Maximum Hardness (Load: 1 kg) (Hv)	Average Hardness (Load: 1 kg) (Hv)	Yield Strength (MPa)	Tensile Strength (MPa)	SSC Test	HIC Test
S1	1	15	97	248	5	225	195	476	595	OK	OK
S2	2	55	94	222	12	212	193	473	588	OK	OK
S3	3	45	94	190	35	165	154	393	482	OK	OK
S4	4	31	97	225	15	212	193	473	588	OK	OK
S5	5	12	95	232	13	205	193	520	583	OK	OK
S6	6	65	88	205	28	199	178	444	543	OK	OK
S7	7	13	91	218	6	186	178	452	535	OK	OK
S8	8	35	91	222	29	188	178	430	544	OK	OK
S9	9	55	87	268	22	196	184	472	565	OK	OK
S10	10	20	95	232	20	208	189	460	575	OK	OK
S11	1	55	92	232	5	218	202	533	627	OK	OK
S12	1	65	93	235	28	205	182	461	565	OK	OK
S13	1	0	95	248	0	227	205	547	634	OK	OK
S14	11	68	89	266	62	288	168	407	512	OK	NG
S15	12	0	43	278	0	277	223	578	680	NG	NG
S16	13	35	99	242	12	240	193	478	590	OK	NG
S17	14	82	95	288	75	293	159	390	480	NG	NG
S18	15	43	94	232	10	278	196	489	599	OK	NG
S19	16	35	94	243	15	236	190	466	580	OK	NG
S20	17	45	85	240	21	232	190	470	578	OK	NG
S21	18	25	94	249	14	229	198	485	605	OK	NG
S22	19	38	85	222	25	225	193	470	588	OK	NG

(continued)

Manufacturing No.	Kind of Steel	Surface layer Microstructure			Internal Microstructure			Properties			
		Area Fraction of Polygonal Ferrite (%)	Total Area Fraction of Polygonal Ferrite and Granular Bainite (%)	Maximum Hardness (Load: 100 g) (Hv)	Area Fraction of Polygonal Ferrite (%)	Maximum Hardness (Load: 1 kg) (Hv)	Average Hardness (Load: 1 kg) (Hv)	Yield Strength (MPa)	Tensile Strength (MPa)	SSC Test	HIC Test
S23	20	0	44	272	0	286	240	599	729	NG	NG
S24	21	0	47	288	0	301	235	605	713	NG	NG
S25	22	0	41	292	0	312	236	570	720	NG	NG
S26	23	12	49	278	13	265	212	512	645	NG	NG
S27	24	43	85	242	22	243	183	465	576	OK	NG
S28	25	50	87	236	19	229	178	439	558	OK	NG
S29	26	21	85	244	9	258	192	478	598	OK	NG
S30	27	52	88	233	15	212	182	448	553	OK	NG
S31	28	49	85	238	12	228	179	445	558	OK	NG
S32	29	43	99	233	13	222	180	449	558	OK	NG
S33	30	42	85	234	9	214	182	448	559	OK	NG
S34	31	68	85	243	33	258	158	448	498	OK	NG
S35	32	48	85	238	12	222	182	444	561	OK	NG
S36	33	44	89	248	18	228	186	448	563	OK	NG
S37	34	45	85	253	14	225	184	443	561	NG	OK
S38	1	65	93	248	55	277	174	420	530	OK	NG
S39	1	0	34	333	0	298	233	565	710	NG	NG
S40	1	0	24	323	0	289	239	589	729	NG	NG
S41	1	75	95	308	55	253	190	519	578	NG	NG
S42	1	78	95	322	60	323	172	435	525	NG	NG
S43	1	10	35	288	19	278	190	471	578	NG	NG
S44	1	5	91	299	17	196	172	428	535	NG	OK

(continued)

Manufacturing No.	Kind of Steel	Surface layer Microstructure			Internal Microstructure			Properties			
		Area Fraction of Polygonal Ferrite (%)	Total Area Fraction of Polygonal Ferrite and Granular Bainite (%)	Maximum Hardness (Load: 100 g) (Hv)	Area Fraction of Polygonal Ferrite (%)	Maximum Hardness (Load: 1 kg) (Hv)	Average Hardness (Load: 1 kg) (Hv)	Yield Strength (MPa)	Tensile Strength (MPa)	SSC Test	HIC Test
S45	1	10	45	305	20	255	191	466	582	NG	NG
S46	1	8	16	312	4	290	220	583	665	NG	NG
S47	1	73	85	277	18	232	188	461	563	NG	OK
S48	1	78	99	292	35	261	180	418	542	NG	NG
S49	1	44	85	273	18	242	203	540	633	NG	OK
S50	1	54	48	282	12	258	208	544	634	NG	NG
S51	1	38	85	272	5	214	201	533	622	NG	OK
S52	1	72	91	282	16	207	199	503	612	NG	OK

(Example 2)

[0131] The steel plate shown in Table 3 was formed into a pipe shape by C-press, U-press, and O-press, end surfaces were temporarily welded, main welding was performed from internal and external surfaces, and the steel pipe was expanded. As a result, a steel pipe for a line pipe was obtained. As the main welding, submerged arc welding was adopted. Manufacturing No. of the steel plate relates to Manufacturing No. of the steel pipe. For example, the steel pipe of Manufacturing No. T1 was manufactured using the steel plate of Manufacturing No. S1. the steel pipe of Manufacturing No. T2 was manufactured using the steel plate of Manufacturing No. S2.

[0132] A test piece was collected from the manufactured steel plate, the surface layer microstructure (positions of 0.1 mm, 0.2 mm, and 0.5 mm) and the internal microstructure (t/4 position) were observed with a scanning electron microscope at a magnification of 1000-fold to calculate the fractions (area fractions) of polygonal ferrite, granular bainite, and the remainder.

[0133] In addition, a JIS No.5 tensile test piece was prepared, and a tensile test according to JIS Z 2241 was performed to measure a yield strength and a tensile strength.

[0134] In addition, the hardness was measured using a Vickers hardness meter. The hardness of the surface layer microstructure was measured under a load of 100 g by setting every 10 points at the same depth at an interval of 0.1 mm in a region from a depth of 0.1 mm to a depth of 1.0 mm from the surface layer. On the other hand, the hardness of the internal microstructure was measured under a load of 1 kg by setting every 10 points at the same depth at an interval of 0.2 mm in a region from a depth of 1.2 mm from the surface layer to the thickness center.

[0135] Further, a test piece was collected from the manufactured steel plate, and the following test was performed to evaluate HIC resistance and SSC resistance.

Evaluation of HIC Resistance

[0136] A test according to TM0284 of NACE (National Association of Corrosion and Engineer) was performed to observe whether or not hydrogen induced cracking (HIC) occurred. When the HIC area fraction was 5% or less, HIC resistance was evaluated to be satisfactory (OK). When the HIC area fraction was more than 5%, HIC resistance was evaluated to be poor (NG).

[0137] The NACE test is a test in which hydrogen sulfide gas is saturated in a solution including 5% NaCl solution+0.5 acetic acid and having a pH of 2.7 and the steel plate is dipped in the solution for 96 hours to observe whether or not cracking occur.

Evaluation of SSC Resistance

[0138] A full thickness test piece having a width of 15 mm and a length of 115 mm was collected from the steel plate in a width direction (direction perpendicular to a rolling direction), and SSC resistance was evaluated in a 4 point bending test according to TM0284mASTM (American Society for Testing and Materials) G39 of NACE.

[0139] In the 4 point bending test, the test piece to which a stress corresponding to 90% of 0.2% proof stress derived from the tensile test was applied was dipped for 720 hours in an aqueous solution including 5% sodium chloride +0.5 acetic acid at normal temperature (24°C) and having a pH of 2.7 in which hydrogen sulfide gas of 1 atm was saturated, and the test piece surface was observed at a magnification of 10-fold to determine whether or not SSC occurred. A test piece where SSC did not occur was evaluated as "Pass (OK)", and a test piece where SSC occurred was evaluated as "Fail (NG)". The results are shown in Table 4.

[Table 4]

Manufacturing No.	Kind of Steel	Outer Diameter (mm)	Inner Diameter (mm)	Surface layer Microstructure			Internal Microstructure			Properties				Note
				Area Fraction of Polygonal Ferrite (%)	Total Area Fraction of Polygonal Ferrite and Granular Bainite (%)	Maximum Hardness (Load: 100 g) (Hv)	Area Fraction of Polygonal Ferrite (%)	Maximum Hardness (Load: 1 kg) (Hv)	Average Hardness (Load: 1 kg) (Hv)	Yield Strength (MPa)	Tensile Strength (MPa)	SSC Test	HIC Test	
T1	1	457.2	8	15	97	249	5	226	202	561	623	OK	OK	Example
T2	2	457.2	8	55	94	226	12	212	196	554	616	OK	OK	
T3	3	609.6	20	45	94	192	35	165	159	467	519	OK	OK	
T4	4	609.6	11	31	97	227	15	213	196	555	616	OK	OK	
T5	5	609.6	42	12	95	234	13	207	206	632	670	OK	OK	
T6	6	508.0	13	65	88	206	28	201	183	520	577	OK	OK	
T7	7	609.6	20	13	91	219	6	186	184	523	577	OK	OK	
T8	8	609.6	13	35	91	223	29	188	182	516	574	OK	OK	
T9	9	609.6	32	55	87	268	22	198	194	588	631	OK	OK	
T10	10	609.6	10	20	95	233	20	209	192	541	601	OK	OK	
T11	1	812.8	20	55	92	235	5	221	207	599	665	OK	OK	
T12	1	7620	20	65	93	237	28	207	187	541	601	OK	OK	
T13	1	457.2	10	0	95	248	0	227	209	602	669	OK	OK	

(continued)

Manufacturing No.	Kind of Steel	Outer Diameter (mm)	Inner Diameter (mm)	Surface layer Microstructure			Internal Microstructure			Properties				Note
				Area Fraction of Polygonal Ferrite (%)	Total Area Fraction of Polygonal Ferrite and Granular Bainite (%)	Maximum Hardness (Load: 100 g) (Hv)	Area Fraction of Polygonal Ferrite (%)	Maximum Hardness (Load: 1 kg) (Hv)	Average Hardness (Load: 1 kg) (Hv)	Yield Strength (MPa)	Tensile Strength (MPa)	SSC Test	HIC Test	
T14	11	457.2	10	68	89	268	62	288	172	486	541	OK	NG	Comparative Example
T15	12	457.2	10	0	43	280	0	279	228	646	718	NG	NG	
T16	13	457.2	10	35	99	244	12	241	197	561	623	OK	NG	
T17	14	457.2	10	82	95	292	75	296	162	456	507	NG	NG	
T18	15	457.2	10	43	94	233	10	279	200	569	632	OK	NG	
T19	16	457.2	10	35	94	244	15	236	194	551	612	OK	NG	
T20	17	457.2	10	45	85	242	21	232	194	549	610	OK	NG	
T21	18	508.0	13	25	94	250	14	231	203	579	643	OK	NG	
T22	19	508.0	13	38	85	223	25	225	198	563	625	OK	NG	
T23	20	508.0	13	0	44	276	0	286	246	698	775	NG	NG	
T24	21	508.0	13	0	47	291	0	303	241	682	758	NG	NG	
T25	22	508.0	13	0	41	299	0	312	242	689	765	NG	NG	
T26	23	609.6	20	12	49	283	13	268	219	626	695	NG	NG	
T27	24	609.6	20	43	85	243	22	243	189	559	621	OK	NG	
T28	25	609.6	20	50	87	239	19	231	184	541	601	OK	NG	
T29	26	609.6	20	21	85	244	9	258	198	580	644	OK	NG	
T30	27	609.6	20	52	88	234	15	221	188	536	596	OK	NG	
T31	28	609.6	20	49	85	241	12	228	185	541	601	OK	NG	
T32	29	609.6	20	43	99	235	13	224	186	541	601	OK	NG	
T33	30	609.6	20	42	85	234	9	218	188	542	602	OK	NG	
T34	31	609.6	20	68	85	248	33	260	163	483	537	OK	NG	
T35	32	609.6	20	48	85	239	12	224	188	544	605	OK	NG	
T36	33	609.6	20	44	89	248	18	231	192	546	607	OK	NG	

(continued)

Manufacturing No.	Kind of Steel	Outer Diameter (mm)	Inner Diameter (mm)	Surface layer Microstructure			Internal Microstructure			Properties				Note
				Area Fraction of Polygonal Ferrite (%)	Total Area Fraction of Polygonal Ferrite and Granular Bainite (%)	Maximum Hardness (Load: 100 g) (Hv)	Area Fraction of Polygonal Ferrite (%)	Maximum Hardness (Load: 1 kg) (Hv)	Average Hardness (Load: 1 kg) (Hv)	Yield Strength (MPa)	Tensile Strength (MPa)	SSC Test	HIC Test	
T37	34	609.6	20	45	85	255	14	225	190	544	605	NG	OK'	
T38	1	609.6	11	65	93	251	55	277	177	500	555	OK	NG	
T39	1	609.6	11	0	34	334	0	301	237	670	744	NG	NG	
T40	1	609.6	11	0	24	323	0	289	243	688	764	NG	NG	
T41	1	609.6	11	75	95	308	55	255	193	545	606	NG	NG	
T42	1	609.6	11	78	95	323	60	323	175	495	550	NG	NG	
T43	1	609.6	20	10	35	291	19	280	196	561	623	NG	NG	
T44	1	812.8	32	5	91	301	17	199	179	525	584	NG	OK	
T45	1	812.8	40	10	45	309	20	260	200	582	646	NG	NG	
T46	1	609.6	20	8	16	316	4	295	227	645	717	NG	NG	
T47	1	609.6	20	73	85	279	18	234	194	546	607	NG	OK	
T48	1	609.6	20	78	99	297	35	261	186	526	584	NG	NG	
T49	1	609.6	20	44	85	278	18	242	210	614	682	NG	OK	
T50	1	609.6	20	54	48	285	12	261	215	615	683	NG	NG	
T51	1	609.6	20	38	85	278	5	214	208	603	670	NG	OK	
T52	1	609.6	20	72	91	286	16	209	206	594	660	NG	OK	

[Industrial Applicability]

[0140] According to the present invention, it is possible to provide: a steel pipe for a line pipe that is suitable for a line pipe and has a strength of API X52 to X70 grade and satisfactory SSC resistance and HIC resistance; and a steel plate having satisfactory SSC resistance and HIC resistance that is used as a base metal of the steel pipe. Accordingly, the present invention is highly applicable to the steel plate manufacturing industry and the energy industry.

[Brief Description of the Reference Symbols]

[0141]

1: STEEL PIPE
2: STEEL PLATE (BASE METAL)
3: WELD

Claims

1. A steel pipe comprising:

a base metal that includes a cylindrical steel plate; and
a weld that is provided in a seam portion of the steel plate and extends in a longitudinal direction of the steel plate,
wherein the steel plate includes, as a chemical composition, by mass%,
C: 0.030% to 0.070%,
Si: 0.005% to 0.50%,
Mn: 1.05% to 1.65%,
Al: 0.010% to 0.070%,
Ti: 0.005% to 0.020%,
Nb: 0.005% to 0.045%,
Ca: 0.0010% to 0.0050%,
N: 0.0015% to 0.0070%,
Ni: 0% to 0.50%,
Mo: 0% to 0.50%,
Cr: 0% to 0.50%,
Cu: 0% to 0.50%,
V: 0% to 0.100%,
Mg: 0% to 0.0100%,
REM: 0% to 0.0100%,
P: limited to 0.015% or less,
S: limited to 0.0015% or less,
O: limited to 0.0040% or less, and
a remainder of Fe and impurities,
Ceq defined by the following Expression (1) in the chemical composition is 0.300 to 0.400,
a surface layer microstructure that is a microstructure in a range up to 1.0 mm from a surface of the base metal in a depth direction includes a polygonal ferrite and a granular bainite,
an area fraction of the polygonal ferrite in the surface layer microstructure is 0 to 70%,
a total area fraction of the polygonal ferrite and the granular bainite in the surface layer microstructure is 50% or more,
a maximum hardness in the surface layer microstructure is 270 Hv or lower,
an area fraction of a polygonal ferrite in an internal microstructure that is a microstructure in a range up to a thickness center from an area positioned at a distance of more than 1.0 mm from the surface of the base metal in the depth direction is 40% or less,
a maximum hardness in the internal microstructure is 248 Hv or lower, and
an average hardness in the internal microstructure is 150 to 220 Hv,

$$Ceq=[C]+[Mn]/6+([Ni]+[Cu])/15+([Cr]+[Mo]+[V])/5 \quad \ldots \quad (1),$$

where [C], [Mn], [Ni], [Cu], [Cr], [Mo], and [V] represent the amounts of C, Mn, Ni, Cu, Cr, Mo, and V by mass%.

2. The steel pipe according to claim 1,
wherein the chemical composition includes, by mass%, one or more selected from the group consisting of
Ni: 0.05% to 0.50%,
Mo: 0.05% to 0.50%,
Cr: 0.05% to 0.50%,
Cu: 0.05% to 0.50%,
V: 0.010% to 0.100%,
Mg: 0.0001% to 0.0100%, and
REM: 0.0001% to 0.0100%.

3. The steel pipe according to claim 1 or 2,
wherein a remainder of the surface layer microstructure consists of one or more selected from the group consisting of a bainite and a pseudo pearlite, and
a remainder of the internal microstructure consists of one or more selected from the group consisting of a granular bainite, a bainite, and a pseudo pearlite.

4. A steel plate that is used as the base metal of the steel pipe according to any one of claims 1 to 3.

FIG. 1

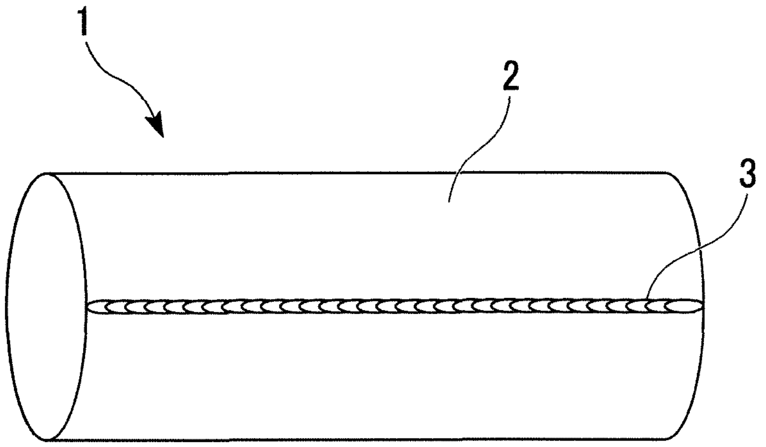

1
2
3

FIG. 2

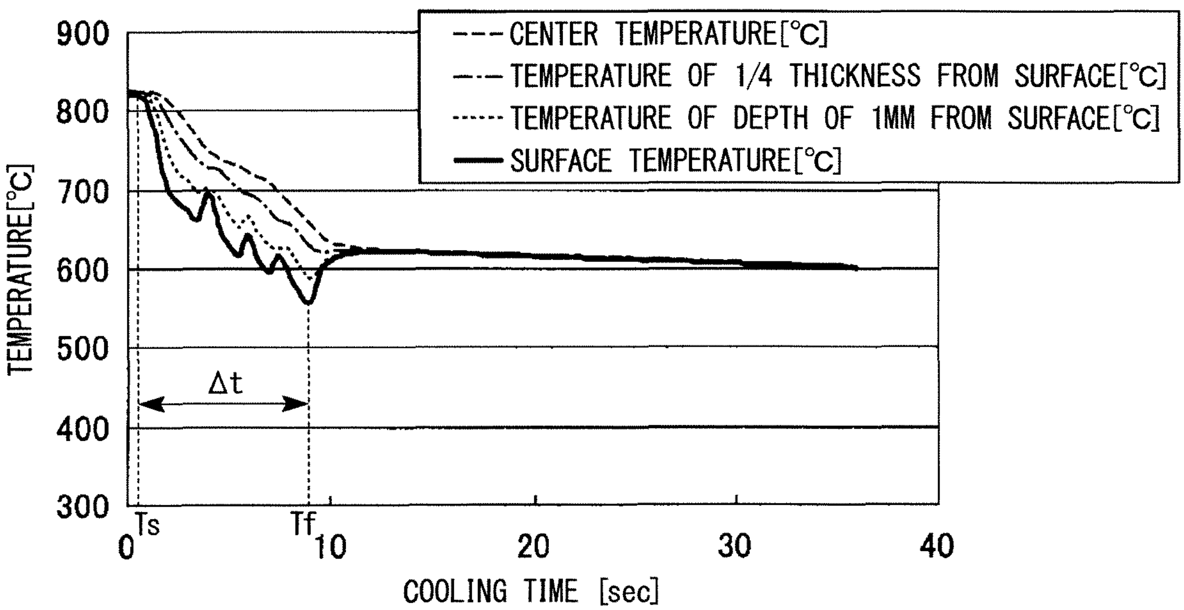

CENTER TEMPERATURE[°C]
TEMPERATURE OF 1/4 THICKNESS FROM SURFACE[°C]
TEMPERATURE OF DEPTH OF 1MM FROM SURFACE[°C]
SURFACE TEMPERATURE[°C]
TEMPERATURE[°C]
900
800
700
600
500
400
300
Δt
Ts
Tf
0
10
20
30
40
COOLING TIME [sec]

FIG. 3A

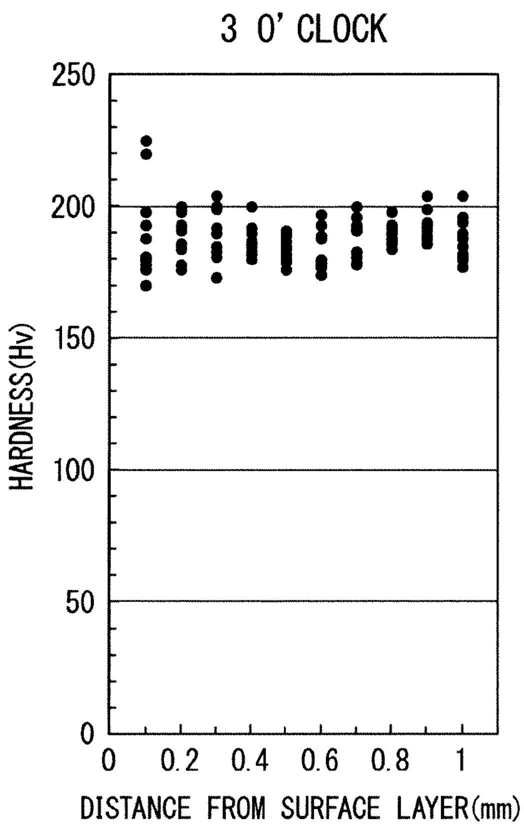

3 O' CLOCK
250
200
150
100
50
0
HARDNESS(Hv)
0
0.2
0.4
0.6
0.8
1
DISTANCE FROM SURFACE LAYER(mm)

FIG. 3B

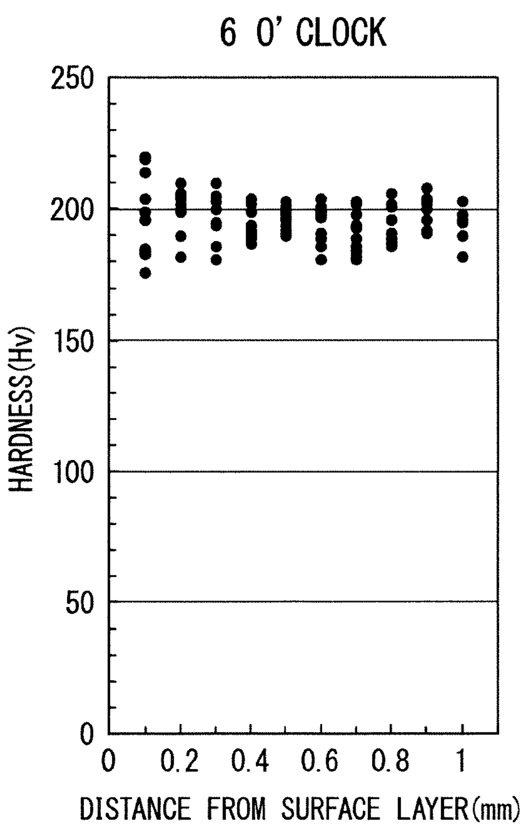
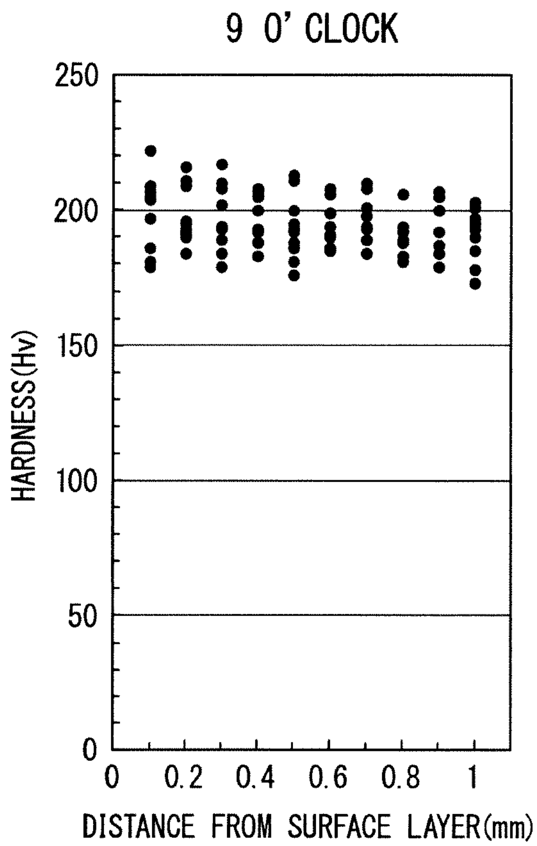

6 O' CLOCK
250
200
150
100
50
0
HARDNESS(Hv)
0
0.2
0.4
0.6
0.8
1
DISTANCE FROM SURFACE LAYER(mm)

FIG. 3C


9 O' CLOCK
250
200
150
100
50
0
HARDNESS(Hv)
0
0.2
0.4
0.6
0.8
1
DISTANCE FROM SURFACE LAYER(mm)

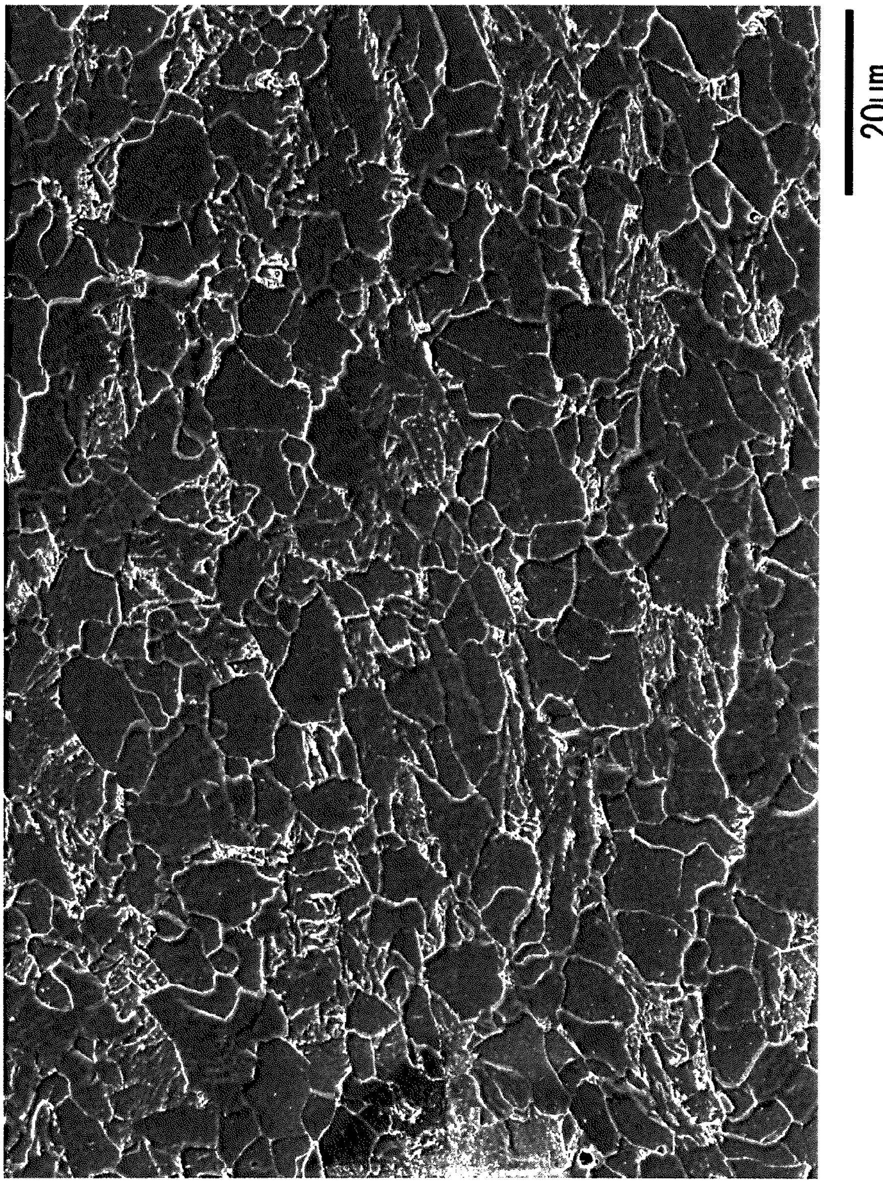


FIG. 4

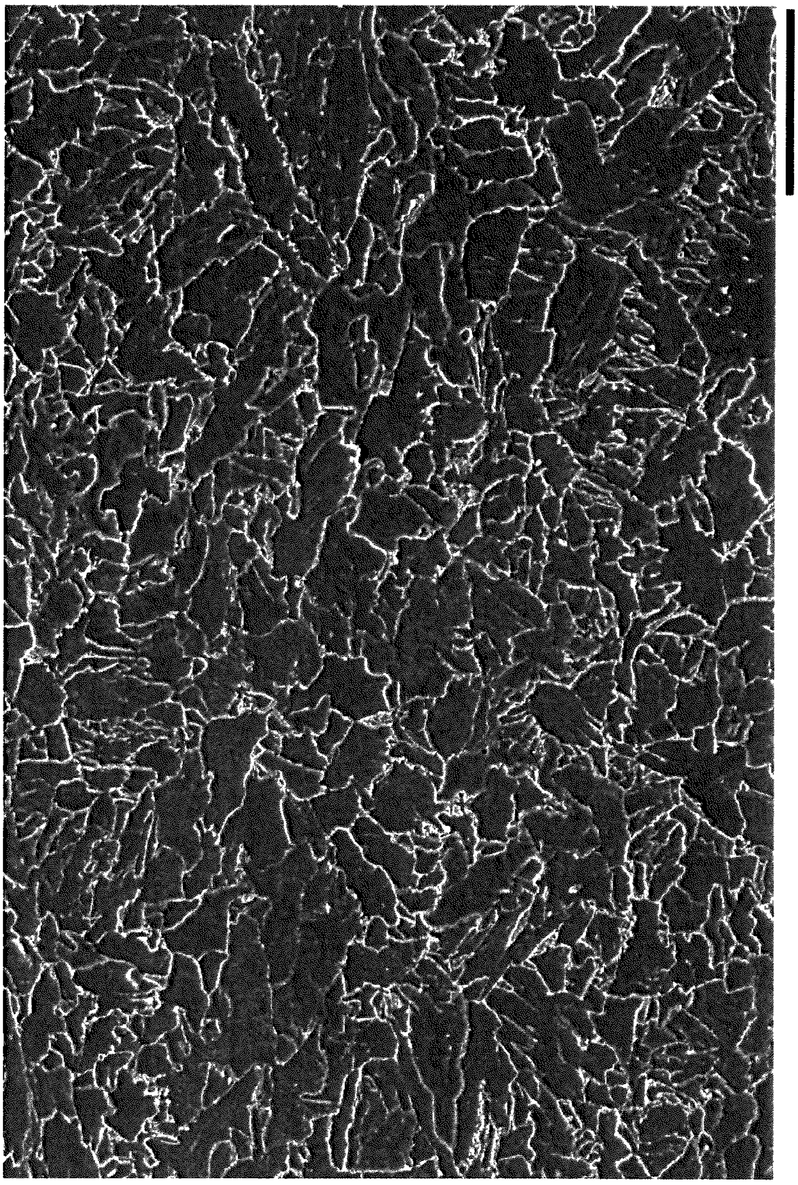


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/033706

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. C22C38/00(2006.01)i, C22C38/58(2006.01)i, C21D8/02(2006.01)n

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)
Int. Cl. C22C38/00-38/60, C21D8/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2017
Registered utility model specifications of Japan 1996-2017
Published registered utility model applications of Japan 1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2007-016302 A (JFE STEEL CORP.) 25 January 2007, (Family: none)	1-4
A	JP 2008-101242 A (JFE STEEL CORP.) 01 May 2008, (Family: none)	1-4
A	JP 2013-023714 A (JFE STEEL CORP.) 04 February 2013, (Family: none)	1-4
A	JP 2015-190026 A (JFE STEEL CORP.) 02 November 2015, (Family: none)	1-4
A	US 2007/0089813 A1 (TIVELLI, Marco, Mario et al.) 26 April 2007, & WO 2004/097059 A1 & EP 1627931 A1 & CN 1788103 A	1-4

☒ 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
06.12.2017	19.12.2017

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/033706

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 102719745 A (BAOSHAN IRON AND STEEL CO., LTD.) 10 October 2012, (Family: none)	1-4

Form PCT/ISA/210 (continuation of second sheet) (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 S63001369 B **[0006]**
- JP S62112722 B **[0006]**