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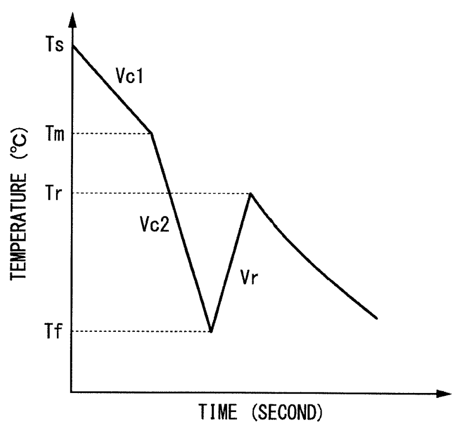
(54) STEEL PIPE AND STEEL SHEET

(57) This steel pipe has a base material portion composed of a tubular steel plate having a predetermined chemical composition and a welded part that is provided at a butt portion of the steel plate and extends in the longitudinal direction of the steel plate, an internal microstructure includes 85% or more of one or both of granular bainite and bainite in terms of the total area ratio and includes 1.0% or less of an MA in terms of the area ratio, the internal microstructure has a maximum hardness of 248 Hv or less and an average hardness of 170 to 220 Hv, the base material portion has a texture having an integration degree of {100}<110> of 1.5 or more in a plane parallel to a plate surface at a 1/4 position of a plate thickness from the surface in a plate thickness direction, a surface layer area microstructure includes 95% or more of one or both of granular bainite and tempered bainite in terms of the total area ratio, the surface layer area microstructure has a maximum hardness of 250 Hv or less, and the steel plate has a plate thickness of 15 mm or less.

FIG. 2



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Description

[Technical Field of the Invention]

[0001] The present invention relates to a steel pipe and a steel plate that is preferred as a material of the steel pipe.

[Related Art]

[0002] In recent years, due to intensifying demand for petroleum, natural gas, or the like, diversification of energy supply sources has been underway. As a result, the mining of crude oil and natural gas is actively in progress under severely corrosive environment where development has been abandoned in the related art, for example, a corrosive environment containing hydrogen sulfide, carbon dioxide, a chlorine ion, or the like. Along with the above-described fact, for steel pipes that are used for pipelines configured to transport crude oil and natural gas, there is demand for excellent hydrogen-induced cracking resistance (HIC resistance). In addition, steel pipes that are used for pipelines configured to transport oil and gas are exposed to corrosive gas produced from oil wells. Therefore, steel pipes (line pipes) that are used for pipelines are required to have not only hydrogen-induced cracking resistance (HIC resistance) but also sulfide stress cracking resistance (SSC resistance).

[0003] In addition, from the viewpoint of enhancing the easiness when line pipes are laid, there is intensifying demand for increasing the strength of steel pipes while decreasing the thickness of steel pipes. Therefore, in recent years, a steel pipe that has a thickness of 15 mm or less and a strength of X60 to X70 in terms of the API standards and is excellent in terms of SSC resistance and HIC resistance has been in demand.

[0004] Steel pipes having excellent HIC resistance have been thus far manufactured by employing a technique, for example, an increase in the purity of steel, a decrease in an inclusion, the control of the shape of a sulfide-based inclusion generated by addition of Ca, or a decrease in center segregation caused by light rolling reduction or accelerated cooling during casting as disclosed in Patent Documents 1 and 2.

[0005] In addition, Patent Document 3 discloses a method for manufacturing a thin sour-resistant steel plate having a plate thickness of 15 mm or less. The manufacturing method of Patent Document 3 defines the conditions of finish rolling from the viewpoint of improving low temperature toughness. However, in the manufacturing methods of Patent Documents 1 to 4, accelerated cooling is carried out on a steel plate, and there is a problem in that the surface layer of the steel plate is hardened. As a result of the present inventors' inspection, it was found that steel plates having a hardened surface layer have a concern that the SSC resistance may degrade.

[0006] In addition, conventionally, in a case where the plate thickness was thin, as described in Non-Patent Document 1, there was a case where accelerated cooling was not applicable and steel plates were manufactured by air cooling after rolling. However, in a case where steel plates were manufactured by air cooling, in some cases, ferrite (polygonal ferrite) was generated, and the SSC resistance degraded.

[Prior Art Document]

[Patent Document]

[0007]

[Patent Document 1] Japanese Examined Patent Application, Second Publication No. S63-001369
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. S62-112722
[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. H06-256842

[Non-Patent Document]

[0008] [Non-Patent Document 1] ISIJ International, Vol. 33 (1993), p. 1190 to 1195

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0009] As described above, in a case where an ordinary accelerated cooling process is applied, the surface layer is hardened, and it is not possible to improve SSC resistance and HIC resistance at the same time. On the other hand, in a case where a non-accelerated cooling process is applied, SSC resistance and DWTT characteristics degrade. In addition, it is necessary to add a large amount of an alloying element, which increases costs and thus also degrades productivity.

[0010] In consideration of the problems in the conventional manufacturing methods, an object of the present invention is to provide a steel pipe without using V, Cu, Ni, Mo, and/or the like, which are expensive elements that are easily segregated, as essential elements for ensuring strength and to provide a steel plate that serves as a material of the steel pipe. The steel pipe has a strength of X60 grade in terms of the API standards, has excellent DWTT characteristics at -30°C, furthermore, is excellent in terms of SSC resistance and HIC resistance, and has a plate thickness of the steel plate in the base material portion (a thickness of the steel pipe) of 15 mm or less.

[Means for Solving the Problem]

[0011] The present inventors carried out intensive studies regarding a method for solving the above-described problems. As a result, it was found that, when a hot-rolled steel plate obtained by the hot rolling of a steel piece having a predetermined chemical composition at a finish rolling temperature of 830°C to 1000°C is accelerated-cooled in two separate steps and then recuperated up to a necessary temperature, it is possible to manufacture a steel pipe that has a strength of X60 to X70 in terms of the API standards, is excellent in terms of DWTT characteristics, SSC resistance, and HIC resistance, and has a thickness of 15 mm or less.

[0012] A steel pipe according to the present embodiment can be provided with predetermined strength, DWTT characteristics, SSC resistance, and HIC resistance by maintaining a low Ceq in a steel plate having a plate thickness of 15 mm or less, which is used as a material of the base material portion, and then controlling rolling and cooling conditions in a steel plate manufacturing step. This is significantly different concept from a technique in which a steel pipe is manufactured by As roll (as rolled) or normalizing, while adding a large amount of an alloying element.

[0013] The present invention has been made based on the above-described finding, and the gist of the present invention is as described below.

(1) A steel pipe according to one aspect of the present invention has a base material portion composed of a tubular steel plate and a welded part that is provided at a butt portion of the steel plate and extends in a longitudinal direction of the steel plate, the steel plate has a chemical composition containing, by mass%, C: 0.030% to 0.070%, Si: 0.05% 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: 0.0010% to 0.0050%, 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: Fe and impurities, the steel plate has a Ceq of 0.250 to 0.350, the Ceq being defined by the following Expression (I), an internal microstructure, which is a microstructure in a range from a position deep over 1.0 mm from a surface of the base material portion to a plate thickness center in a depth direction, includes 85% or more of one or both of granular bainite and bainite in terms of a total area ratio and includes 1.0% or less of an MA in terms of an area ratio, in the internal microstructure, a maximum hardness is 248 Hv or less and an average hardness is 170 to 220 Hv, the base material portion has a texture having an integration degree of {100}<110> of 1.5 or more in a plane parallel to a plate surface at a 1/4 position of a plate thickness from the surface in a plate thickness direction, a surface layer area microstructure, which is a microstructure in a range of 1.0 mm from the surface of the base material portion in the depth direction, includes 95% or more of one or both of granular bainite and tempered bainite in terms of a total area ratio, in the surface layer area microstructure, a maximum hardness is 250 Hv or less, and a plate thickness of the steel plate is 15 mm or less.

$$Ceq = [C] + [Mn]/6 + ([Ni] + [Cu])/15 + ([Cr] + [Mo] + [V])/15 \qquad (I)$$

where [C], [Mn], [Ni], [Cu], [Cr], [Mo], and [V] in the Expression (I) are respectively the amounts of C, Mn, Ni, Cu, Cr, Mo, and V in the steel plate in terms of mass%.

(2) In the steel pipe according to (1), the chemical composition may contain, 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 internal microstructure may be ferrite.

(4) A steel plate according to another aspect of the present invention is used for the base material portion of the steel pipe according to any one of (1) to (3).

[Effects of the Invention]

[0014] According to the aspects of the present invention, it is possible to provide a steel pipe that has a strength of X60 to X70 in terms of the API standards (tensile strength of 520 MPa to 760 MPa), has excellent DWTT characteristics, is also excellent in terms of sulfide stress cracking resistance and hydrogen-induced cracking resistance, and has a thickness of 15 mm or less even without using additive elements of V, Cu, Ni, Mo, and/or the like and to provide a steel plate that is used as a base metal of the steel pipe, has excellent DWTT characteristics, and is also excellent in terms of sulfide stress cracking resistance and hydrogen-induced cracking resistance. Specifically, it is possible to provide a high-strength steel plate for a line pipe that is excellent in terms of DWTT characteristics, sulfide stress cracking resistance, and hydrogen-induced cracking resistance, which is preferred as a line pipe configured to transport petroleum, natural gas, and the like, and to provide a steel pipe for a line pipe that includes the steel plate as the base metal and is excellent in terms of DWTT characteristics, sulfide stress cracking resistance, and hydrogen-induced cracking resistance.

[Brief Description of the Drawings]

[0015]

FIG. 1 is a schematic view of an example of a steel pipe according to the present embodiment.
FIG. 2 is a schematic view of an example of a cooling curve of a steel plate that is used for a base material portion of the steel pipe after finish rolling.
FIG. 3A is a microstructural photograph observed with a scanning electron microscope that shows an internal microstructure, which is a microstructure in a range from a position deep over 1.0 mm from a surface of the base material portion to a plate thickness center of the steel pipe according to the present embodiment in a depth direction.
FIG. 3B is a microstructural photograph observed with a scanning electron microscope that shows a surface layer area microstructure, which is a microstructure in a range of 1.0 mm from the surface of the base material portion according to the present embodiment in a depth direction.

[Embodiments of the Invention]

[0016] A steel pipe according to an embodiment of the present invention (hereinafter, the steel pipe according to the present embodiment) has a base material portion composed of a tubular steel plate and a welded part that is provided at a butt portion of the steel plate and extends in a longitudinal direction of the steel plate, wherein the steel plate has a chemical composition containing, by mass%, C: 0.030% to 0.070%, Si: 0.05% 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%, and N: 0.0010% to 0.0050%, as necessary, one or more selected from the group consisting of Ni: 0.50% or less, Mo: 0.50% or less, Cr: 0.50% or less, Cu: 0.50% or less, V: 0.100% or less, Mg: 0.0100% or less, and REM: 0.0100% or less, P: limited to 0.015% or less, S: limited to 0.0015% or less, O: limited to 0.0040% or less, and a remainder: Fe and impurities, and the steel plate has a Ceq defined by the following Expression (1) is 0.250 to 0.350,
an internal microstructure, which is a microstructure in a range from a position deep over 1.0 mm from a surface of the base material portion to a plate thickness center in a depth direction, includes 85% or more of one or both of granular bainite and bainite in terms of a total area ratio, includes 1.0% or less of an MA in terms of an area ratio, and includes ferrite as a remainder in some cases,
in the internal microstructure, a maximum hardness is 248 Hv or less and an average hardness is 170 to 220 Hv,
the base material portion has a texture having an integration degree of {100}<110> of 1.5 or more in a plane parallel to a plate surface at a 1/4 position of a plate thickness from the surface in a plate thickness direction,
a surface layer area microstructure, which is a microstructure in a range of 1.0 mm from the surface of the base material portion in the depth direction, includes 95% or more of one or both of granular bainite and tempered bainite in terms of a total area ratio,
in the surface layer area microstructure, a maximum hardness is 250 Hv or less, and
a plate thickness of the steel plate is 15 mm or less.
[0017] In addition, the steel plate according to the present embodiment is used for the base material portion of the steel pipe according to the present embodiment.
[0018] Hereinafter, the steel pipe according to the present embodiment, the steel plate according to the present embodiment, and preferred manufacturing methods therefor will be described.
[0019] First, the reasons for limiting the chemical composition of the base material portion of the steel pipe according to the present embodiment (that is, the steel plate according to the present embodiment) will be described. Hereinafter, '%' regarding components indicate 'mass%'.

C: 0.030% to 0.070%

[0020] C is an element that improves the strength of steel. When a C content is less than 0.030%, the strength improvement effect cannot be sufficiently obtained. Therefore, the C content is set to 0.030% or more. The C content is preferably 0.040% or more.
[0021] On the other hand, when the C content exceeds 0.070%, the strength excessively increases, and the HIC resistance degrades. Therefore, the C content is set to 0.070% or less. From the viewpoint of preventing the degradation of weldability, toughness, or the like, the C content is preferably 0.060% or less.

Si: 0.05% to 0.50%

[0022] Si is an element that functions as a deoxidizing agent during steelmaking. When a Si content is less than 0.05%, this effect cannot be sufficiently obtained. Therefore, the Si content is set to 0.05% or more.
[0023] On the other hand, when the Si content exceeds 0.50%, the toughness of a welded heat-affected zone (HAZ) decreases. Therefore, the Si content is set to 0.50% or less. The Si content is preferably 0.35% or less.

Mn: 1.05% to 1.65%

[0024] Mn is an element that contributes to an improvement in the strength and toughness of steel. When a Mn content is less than 1.05%, the strength and toughness improvement effect cannot be sufficiently obtained. Therefore, the Mn content is set to 1.05% or more. The Mn content is preferably 1.15% or more.
[0025] On the other hand, Mn is also an element that forms MnS and degrades the HIC resistance. When the Mn content exceeds 1.65%, the HIC resistance degrades, and thus the Mn content is set to 1.65% or less. The Mn content is preferably 1.50% or less.

Al: 0.010% to 0.070%

[0026] Al is an element that functions as a deoxidizing agent. When an Al content is less than 0.010%, this effect cannot be sufficiently obtained. Therefore, the Al content is set to 0.010% or more. The Al content is preferably 0.020% or more.
[0027] On the other hand, when the Al content exceeds 0.070%, an Al oxide is piled up to form a cluster, and the HIC resistance degrades. Therefore, the Al content is set to 0.070% or less. The Al content is preferably 0.040% or less and more preferably 0.030% or less.

Ti: 0.005% to 0.020%

[0028] Ti is an element that forms a nitride and contributes to the refinement of crystal grains. When a Ti content is less than 0.005%, the above-described effect cannot be sufficiently obtained. Therefore, the Ti content is set to 0.005% or more. The Ti content is preferably 0.008% or more.
[0029] On the other hand, when the Ti content exceeds 0.020%, a coarse nitride is generated, and the HIC resistance degrades. Therefore, the Ti content is set to 0.020% or less. The Ti content is preferably 0.015% or less.

Nb: 0.005% to 0.045%

[0030] Nb is an element that contributes to an improvement in the strength of steel by expanding the non-recrystallization temperature range, refining crystal grains, and forming a carbide or a nitride. When a Nb content is less than 0.005%, the above-described effects cannot be sufficiently obtained. Therefore, the Nb content is set to 0.005% or more. The Nb content is preferably 0.010% or more.
[0031] On the other hand, when the Nb content exceeds 0.045%, a coarse carbide or nitride is generated, and the HIC resistance degrades. In addition, the elongation and the toughness also decrease. Therefore, the Nb content is set to 0.045% or less. The Nb content is preferably 0.035% or less.

Ca: 0.0010% to 0.0050%

[0032] Ca is an element that contributes to an improvement in the HIC resistance by forming CaS and preventing the formation of MnS that extends in a rolling direction. When a Ca content is less than 0.0010%, the above-described effect cannot be sufficiently obtained. Therefore, the Ca content is set to 0.0010% or more. The Ca content is preferably 0.0020% or more.

[0033] On the other hand, when the Ca content exceeds 0.0050%, a Ca oxide is piled up, and the HIC resistance degrades. Therefore, the Ca content is set to 0.0050% or less. The Ca content is preferably 0.0040% or less.

N: 0.0010% to 0.0050%

[0034] N is an element that contributes to the refinement of the microstructure by forming a nitride that prevents the coarsening of austenite grains during heating. When a N content is less than 0.0010%, the microstructure refinement effect cannot be sufficiently obtained. Therefore, the N content is set to 0.0010% or more. The N content is preferably 0.0020% or more.
[0035] On the other hand, when the N content exceeds 0.0050%, a coarse nitride is generated, and the HIC resistance degrades. Therefore, the N content is set to 0.0050% or less. The N content is preferably 0.0040% or less.
[0036] The base material portion of the steel pipe according to the present embodiment (the steel plate according to the present embodiment) may contain, in addition to the above-described elements, one or more of Ni, Mo, Cr, Cu, V, Mg, and REM as necessary in the following ranges in order to improve strength, toughness, and other characteristics. However, since all of these elements are optional elements that are not essential elements, the lower limits thereof are 0%.

Ni: 0% to 0.50%

[0037] Ni is an element that contributes to an improvement in the toughness, strength, and corrosion resistance of steel. When a Ni content is less than 0.05%, the above-described effects cannot be sufficiently obtained. Therefore, in a case where it is necessary to obtain the above-described effects, the Ni content is preferably set to 0.05% or more. The Ni content is more preferably 0.10% or more.
[0038] On the other hand, when the Ni content exceeds 0.50%, the hardness of the base material portion exceeds 248 Hv, and the HIC resistance deteriorates. Therefore, even in a case where Ni is contained, the Ni content is set to 0.50% or less. The Ni content is preferably 0.35% or less.

Mo: 0% to 0.50%

[0039] Mo is an element that contributes to an improvement in the hardenability of steel. When a Mo content is less than 0.05%, the above-described effect cannot be sufficiently obtained. Therefore, in a case where it is necessary to obtain the above-described effect, the Mo content is preferably set to 0.05% or more. The Mo content is more preferably 0.10% or more.
[0040] On the other hand, when the Mo content exceeds 0.50%, the hardness of the base material portion exceeds 248 Hv, and the HIC resistance deteriorates. Therefore, even in a case where Mo is contained, the Mo content is set to 0.50% or less. The Mo content is preferably 0.35% or less.

Cr: 0% to 0.50%

[0041] Cr is an element that contributes to an improvement in the strength of steel. When a Cr content is less than 0.05%, the above-described effect cannot be sufficiently obtained. Therefore, in a case where it is necessary to obtain the above-described effect, the Cr content is preferably set to 0.05% or more. The Cr content is more preferably 0.10% or more.
[0042] On the other hand, when the Cr content exceeds 0.50%, the strength excessively increases, and the toughness degrades. Therefore, even in a case where Cr is contained, the Cr content is set to 0.50% or less. The Cr content is preferably 0.35% or less.

Cu: 0% to 0.50%

[0043] Cu is an element that contributes to an increase in the strength of steel and an improvement in the corrosion resistance. When a Cu content is less than 0.05%, the above-described effects cannot be sufficiently obtained. Therefore, in a case where it is necessary to obtain the above-described effects, the Cu content is preferably set to 0.05% or more. The Cu content is more preferably 0.10% or more.
[0044] On the other hand, when the Cu content exceeds 0.50%, the maximum hardness of the base material portion exceeds 248 Hv, and the HIC resistance deteriorates. Therefore, even in a case where Cu is contained, the Cu content is set to 0.50% or less. The Cu content is preferably 0.35% or less.

V: 0% to 0.100%

[0045] V is an element that forms a carbide or a nitride and contributes to an improvement in the strength of steel. When a V content is less than 0.010%, the above-described effects cannot be sufficiently obtained. Therefore, in a case where it is necessary to obtain the above-described effects, the V content is preferably set to 0.010% or more. The V content is more preferably 0.030% or more.

[0046] On the other hand, when the V content exceeds 0.100%, the toughness of steel degrades. Therefore, the V content is set to 0.100% or less. The V content is preferably 0.080% or less.

Mg: 0% to 0.0100%

[0047] Mg is an element that forms a fine oxide that contributes to an improvement in toughness by preventing the coarsening of crystal grains. When a Mg content is less than 0.0001%, the above-described effect cannot be sufficiently obtained. Therefore, in a case where it is necessary to obtain the above-described effect, the Mg content is preferably set to 0.0001% or more. The Mg content is more preferably 0.0010% or more.

[0048] On the other hand, when the Mg content exceeds 0.0100%, oxides agglomerate and coarsen, and the HIC resistance or the toughness degrades. Therefore, even in a case where Mg is contained, the Mg content is set to 0.0100% or less. The Mg content is preferably 0.0050% or less.

REM: 0% to 0.0100%

[0049] REM is an element that contributes to an improvement in the toughness by controlling the form of a sulfide-based inclusion. When an REM content is less than 0.0001%, the above-described effect cannot be sufficiently obtained. Therefore, in a case where it is necessary to obtain the above-described effect, the REM content is preferably set to 0.0001% or more. The REM content is more preferably 0.0010% or more.

[0050] On the other hand, when the REM content exceeds 0.0100%, an oxide is generated, the cleanliness of steel decreases, and consequently, the toughness degrades. Therefore, even in a case where REM is contained, the REM content is set to 0.0100% or less. The REM content is preferably 0.0060% or less. In the present embodiment, REM means rare earth elements and is a collective term of 17 elements of Sc, Y, and lanthanoid, and the REM content indicates a total amount of these 17 elements.

[0051] The base material portion of the steel pipe according to the present embodiment (the steel plate according to the present embodiment) basically contains the above-described essential elements and contains the above-described optional elements as necessary, and the remainder includes Fe and impurities. In addition, the impurities mean components that are incorporated from a raw material such as an ore or a scrap or from a variety of environments of a manufacturing process during the industrial manufacturing of a steel material and are allowed to be contained as long as the impurities do not adversely affect the characteristics of steel.

[0052] Among the impurities, P, S, O, Sb, Sn, Co, As, Pb, Bi, and H are preferably controlled to the ranges described below.

P: 0.015% or less

[0053] P is an impurity element. When a P content exceeds 0.015%, the HIC resistance significantly degrades. Therefore, the P content is set to 0.015% or less. The P content is preferably 0.010% or less. The content is preferably small, and thus the lower limit includes 0%. However, when the P content is decreased to less than 0.003%, the manufacturing costs significantly increase. Therefore, the practical lower limit of the P content is 0.003%.

S: 0.0015% or less

[0054] S is an element that degrades the HIC resistance by generating MnS that extends in the rolling direction during hot rolling. When a S content exceeds 0.0015%, the HIC resistance significantly degrades. Therefore, the S content is set to 0.0015% or less. The S content is preferably 0.0010% or less. The S content is preferably small, and thus the lower limit includes 0%. However, when the S content is decreased to less than 0.0001%, the manufacturing costs significantly increase. Therefore, the practical lower limit of the S content is 0.0001%.

O: 0.0040% or less

[0055] O is an element that inevitably remains in steel after deoxidation. When an O content exceeds 0.0040%, an oxide is generated, and the HIC resistance degrades. Therefore, the O content is set to 0.0040% or less. The O content is preferably 0.0030% or less. The O content is preferably small, and thus the lower limit includes 0%. However, when the O content is decreased to less than 0.0010%, the manufacturing costs significantly increase, and thus the practical lower limit of the O content is 0.0010% in consideration of the fact that the steel plate is a practical steel plate.

[0056] As other impurities, for example, 0.10% or less of Sb, Sn, Co, or As may remain in the steel plate, 0.005% or less of Pb or Bi may remain in the steel plate, and 0.0005% or less of H may remain in the steel plate.

[0057] In the base material portion of the steel pipe according to the present embodiment, it is necessary to control the amount of each element in the above-described range and then control the Ceq in a predetermined range. The Ceq is calculated from the amounts of the components as described below.

Ceq: 0.250 to 0.350

[0058] The Ceq (carbon equivalent) is an index that indicates the hardenability of the steel plate. In order to secure a necessary strength in the steel pipe according to the present embodiment, the Ceq is set to 0.250 to 0.350. The Ceq is defined by Expression (1).

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

[0059] Here, [C], [Mn], [Ni], [Cu], [Cr], [Mo], and [V] in Expression (1) are respectively the amounts of C, Mn, Ni, Cu, Cr, Mo, and V in the steel plate in terms of mass%.

[0060] When the Ceq is less than 0.250, the hardenability is low, and it is not possible to secure a necessary strength of the steel pipe. Therefore, the Ceq is set to 0.250 or more. The Ceq is preferably 0.260 or more. On the other hand, when the Ceq exceeds 0.350, the hardenability becomes too high, the maximum hardness in the internal microstructure exceeds 248 Hv, and/or the maximum hardness of the surface layer area microstructure exceeds 250 Hv. As a result, the HIC resistance and/or the SSC resistance degrades. Therefore, the Ceq is set to 0.350 or less. The Ceq is preferably 0.340 or less and more preferably 0.330 or less.

[0061] Next, a microstructure of the base material portion of the steel pipe according to the present embodiment (the steel plate according to the present embodiment) will be described.

[0062] A microstructure (internal microstructure) in a range from a position deep over 1.0 mm apart from the surface of the steel plate in the base material portion to the plate thickness center in the depth direction (thickness direction) includes 85% or more of one or both of granular bainite and bainite in terms of the total area ratio and has an area ratio of an MA being 1.0% or less.

[0063] In order to secure excellent mechanical properties and excellent HIC resistance, the microstructure in the range from a position deep over 1.0 mm from the surface of the steel plate to the plate thickness center in the depth direction (hereinafter, simply referred to as "internal microstructure" in some cases) is set to the microstructure containing 85% or more of one or both of granular bainite and bainite in terms of the total area ratio.

[0064] In the internal microstructure, when the total of the area ratios of granular bainite and/or bainite is less than 85%, it becomes difficult to secure necessary mechanical properties and necessary HIC resistance. Therefore, the total of the area ratios of one or both of granular bainite and bainite is set to 85% or more. The total of the area ratios is preferably 90% or more. Since the area ratio depends on a kind of steel and a cooling rate, the upper limit of the area ratio may be 100%, but the practical upper limit is 95%.

[0065] In addition, in the internal microstructure, when the area ratio of a martensite-austenite constituent (MA) is more than 1.0%, the DWTT characteristics degrade. Therefore, in the internal microstructure, the area ratio of the MA is set to 1.0% or less. The MA may be 0%.

[0066] The remainder of the internal microstructure may be ferrite.

[0067] A microstructure (surface layer area microstructure) in a range of 1.0 mm from the surface of the steel plate in the depth direction includes 95% or more of one or both of granular bainite and tempered bainite in terms of the area ratio.

[0068] When the surface layer area microstructure includes a total of 95% or more of granular bainite and tempered bainite in terms of the area ratio, the SSC resistance improves, which is preferable.

[0069] The area ratios in the microstructure can be measured by observing the microstructure using a scanning electron microscope at a magnification of, for example, 1000 times. The microstructure at the 1/4 position of the plate thickness (t/4) from the surface of the steel plate shows a typical microstructure of the internal microstructure. Therefore, in the present embodiment, when the microstructure is observed at t/4 of the base material portion (steel plate) of the steel pipe, and the microstructure at t/4 is the above-described microstructure, the internal microstructure is determined to be in the above-described range.

[0070] In addition, the microstructure of the surface layer area is obtained by measuring the positions 0.1 mm, 0.2

mm, and 0.5 mm apart from the surface of the steel plate and averaging the area ratios at the respective positions.

[0071] In the present embodiment, the bainite is a microstructure in which prior austenite grain boundaries are clear, fine lath microstructures are developed in the grains, and a fine carbide and the MA are scattered in the laths and between the laths.

[0072] The tempered bainite is a microstructure having a lath shape in which a carbide is dispersed in laths and lath boundaries.

[0073] The granular bainite is generated at a transformation temperature between the transformation temperatures of acicular ferrite and bainite and has intermediate microstructural characteristics. Specifically, the granular bainite is a microstructure in which A-part and B-part are present in a mixed form. The A-part is a part in which prior austenite grain boundaries are partially visible, coarse lath microstructures are present in the grains, and a fine carbide and an austenite -martensite constituent are dispersed in the laths and between the laths. The B-part is an acicular or irregular ferrite, and in the B-part prior austenite grain boundaries are not clear.

[0074] The ferrite is a microstructure in which an internal microscopic structure is rarely present in the grains and the grains have a flat inside. The ferrite is a microstructure that appears white in the case of being observed with an optical microscope.

[0075] The MA is colored by Le Pera etching and is thus identifiable.

[0076] FIG. 3A shows an example of the microstructure captured at the t/4 position of the steel plate, which is the base material portion of the steel pipe according to the present embodiment, with a scanning electron microscope, and FIG. 3B shows an example of the microstructure captured at the position 0.5 mm from the surface of the steel plate, which is the base material portion of the steel pipe according to the present embodiment, with the scanning electron microscope.

Hardness of internal microstructure

[0077]

Maximum hardness: 248 Hv or less

Average hardness: 170 to 220Hv

[0078] In order to secure excellent strength, excellent SSC resistance, and excellent HIC resistance in the steel pipe according to the present embodiment, in the internal microstructure of the base material portion, the maximum hardness is set to 248 Hv or less, and the average hardness is set to 170 to 220 Hv.

[0079] When the maximum hardness exceeds 248 Hv, the HIC resistance degrades, and thus the maximum hardness is set to 248 Hv or less. The maximum hardness is preferably 230 Hv.

[0080] When the average hardness is less than 170 Hv, it is not possible to secure a necessary strength, and thus the average hardness is set to 170 Hv or more. The average hardness is preferably 180 Hv or more.

[0081] On the other hand, when the average hardness exceeds 220 Hv, the HIC resistance and the toughness degrade. Therefore, the average hardness is set to 220 Hv or less. The average hardness is preferably 210 Hv or less.

Maximum hardness of surface layer area microstructure: 250 Hv or less

[0082] When the maximum hardness of the surface layer area microstructure is more than 250 Hv, the SSC resistance degrades. Therefore, the maximum hardness of the surface layer area microstructure is set to 250 Hv or less. The maximum hardness is preferably 240 Hv or less.

[0083] The maximum hardness and the average hardness in the internal microstructure can be measured by the following method.

[0084] Hardness is measured with a Vickers hardness meter (load: 100 g) at points from a depth position of 1.1 mm from the surface of the steel plate as a starting point to the plate thickness center at intervals of 0.1 mm in the plate thickness direction and at 20 points for each of the corresponding depth at intervals of 1.0 mm in the width direction.

[0085] As a result of the measurement, unless two or more measurement points with a hardness value of more than 248 Hv continuously appear in the plate thickness direction, the maximum hardness of the internal microstructure is determined to be Hv 248 or less.

[0086] In the base metal of the steel pipe according to the present embodiment, there is a case where a high hardness value (abnormal value) locally appears due to an inclusion or the like. However, since an inclusion does not cause cracking, even when such an abnormal value appears, it is possible to secure the HIC resistance and the SSC resistance. On the other hand, in a case where two or more measurement points with a hardness value of more than 248 Hv are continuously present in the plate thickness direction, such hardness values are not attributed to an inclusion, and the

HIC resistance and/or the SSC resistance degrade, and thus such maximum hardness is not permissible. Therefore, in the present embodiment, even in a case where one measurement point with a hardness value of more than 248 Hv is found, unless two or more points with a hardness value of more than 248 Hv continuously appear in the plate thickness direction, such a point is regarded as an abnormal point and is not adopted, and the next highest value is regarded as the maximum hardness. On the other hand, in a case where two or more measurement points with a hardness value of more than 248 Hv are continuously present in the plate thickness direction, the highest value is adopted as the maximum hardness.

[0087] In addition, the average hardness is calculated by averaging the hardness values of all measurement points.

[0088] The maximum hardness of the surface layer area microstructure from the surface of the steel plate to a depth of 1.0 mm is measured as described below.

[0089] First, 300 mm × 300 mm steel plates are cut out by gas cutting from the 1/4 position, the 1/2 position, and the 3/4 position in the width direction of the steel plate (in the steel pipe, the three o'clock position, the six o'clock position, and the nine o'clock position respectively in a case where the welded part is regarded to be at the zero o'clock position) from an end portion of the steel plate in the width direction (in the case of the steel pipe, equivalent to the butt portion), and block test pieces having a length of 20 mm and a width of 20 mm are collected by mechanical cutting from the center of the cut-out steel plates and polished by mechanical polishing. In one block test piece, hardness is measured with a Vickers hardness meter (load: 100 g) at a total of 100 points (10 points at intervals of 0.1 mm in the plate thickness direction from the position 0.1 mm from the surface as a starting position × 10 points at intervals of 1.0 mm in the width direction at each of the corresponding depths). That is, in three block test pieces, hardness is measured at a total of 300 points.

[0090] As a result of the measurement, unless two or more measurement points with a hardness value of more than 250 Hv continuously appear in the plate thickness direction, the maximum hardness of the surface layer area is determined to be 250 Hv or less.

[0091] In the plane parallel to the plate surface at the 1/4 position of the plate thickness from the surface in the plate thickness direction, the integration degree of {100}<110> is 1.5 or more.

[0092] The steel plate according to the present embodiment is manufactured through steps such as hot rolling, cooling, and recuperating without being subjected to a quenching and tempering treatment. Therefore, the internal microstructure has a texture as described above. When the steel plate has a texture, the DWTT characteristics of the steel plate improve.

[0093] In a case where the steel plate is manufactured by quenching and tempering or a case where the steel plate is manufactured by normalizing, it is not possible to obtain such a texture.

[0094] The texture can be obtained by the following method.

[0095] When the plate thickness of the steel plate in the base material portion is indicated by t, on a plane parallel to the plate surface at a depth of t/4 from the surface, crystal orientation analysis is carried out at intervals of 0.1 mm in a 2.0 mm × 2.0 mm region using EBSP, and the integration degree of the (100)<110> texture is obtained.

[0096] Plate thickness of steel plate in base material portion (thickness of steel pipe): 15 mm or less

[0097] The steel pipe according to the present embodiment is a steel pipe for which a steel plate that is manufactured without carrying out a quenching and tempering treatment (as rolled and cooled) and has a plate thickness of 15 mm or less is used as the base material portion so as to have DWTT characteristics, SSC resistance, and HIC resistance, which are difficult to satisfy at the same time in the related art. The steel pipe according to the present embodiment has excellent SSC resistance and excellent HIC resistance even when the steel plate has a plate thickness of 12 mm or less.

[0098] The target strength of the base material portion (the steel plate according to the present embodiment) of the steel pipe according to the present embodiment is a strength corresponding to 5L-X60 to X70 in terms of the API standards (tensile strength of 520 MPa to 760 MPa) in order to reliably secure a strength necessary for steel pipes. The upper limit of the tensile strength necessary for steel pipes is preferably a tensile strength (TS) of 650 MPa or less in order to secure overmatching in the welded part during on-site welding at the time of using the steel pipe as a structural member.

[0099] Next, the welded part of the steel pipe according to the present embodiment will be described.

[0100] The steel pipe according to the present embodiment is obtained by processing the steel plate according to the present embodiment into a tubular shape and butting and welding both end portions of the tubular steel plate. Therefore, the steel pipe has a welded part that is provided at the butt portion of the steel plate and extends in the longitudinal direction of the steel plate.

[0101] Ordinarily, in the welding of steel pipes, the welded part is formed to be thicker than the base material portion. In addition, the weld metal is a higher alloy than the base metal and also has high corrosion resistance. Therefore, the welded part rarely serves as a starting point of fracture. Therefore, the welded part of the steel pipe according to the present embodiment is not particularly limited as long as the weld is obtained by SAW welding or the like under ordinary conditions.

[0102] Next, a preferred method for manufacturing the steel pipe according to the present embodiment will be described.

[0103] As long as the steel pipe according to the present embodiment has the above-described configuration, the steel pipe is capable of obtaining the effects regardless of the manufacturing method. However, when manufactured by, for example, a manufacturing method as described below, the steel pipe is capable of stably obtaining the effects, which is preferable.

[0104] The steel plate according to the present embodiment is obtained by a manufacturing method including

(i) a step of heating a steel piece having a predetermined chemical composition and a predetermined Ceq at 1050°C to 1250°C, and hot rolling the steel piece such that finish rolling is completed at 830°C to 1000°C to obtain a steel plate having a plate thickness of 15 mm or less (hot rolling step),
(ii-1) a step of cooling the rolled steel plate from higher than 750°C to 950°C to a temperature range of 660°C to 750°C at an average cooling rate of 25 to 100 °C/second (first cooling step),
(ii-2) a step of cooling the steel plate such that the surface temperature is decreased from the temperature range of 660°C to 750°C to 400°C or lower at an average cooling rate of more than 50 °C/second (second cooling step), and
(iii) a step of recuperating the steel plate at a recuperating rate of 50 °C/second or more until the surface temperature reaches higher than 550°C to 650°C (recuperating step).
In addition, the steel pipe according to the present embodiment is obtained by a manufacturing method including
(iv) a step of forming the steel plate obtained through the steps (i) to (iii) into a tubular shape (forming step) and
(v) a step of butting and welding both end portions of the tubular steel plate (welding step).

[0105] The above-described temperatures are controlled based on the surface temperature.
[0106] Hereinafter, preferred conditions for each step will be described.

<Hot rolling step>

Heating temperature of steel piece: 1050°C to 1250°C

[0107] In order to carry out hot rolling, the steel piece having the above-described chemical composition is heated. When the heating temperature of the steel piece is lower than 1050°C, a coarse non-solid-soluted carbonitride of Nb and Ti is generated, and the HIC resistance degrades. Therefore, the heating temperature of the steel piece is preferably set to 1050°C or higher. The heating temperature of the steel piece is more preferably 1100°C or higher.
[0108] On the other hand, when the heating temperature of the steel piece exceeds 1250°C, crystal grains coarsen, and low-temperature toughness degrades. Therefore, the heating temperature of the steel piece is preferably set to 1250°C or lower. The heating temperature of the steel piece is more preferably 1200°C or lower.
[0109] The casting of molten steel and the manufacturing of the steel piece prior to the hot rolling step may be carried out according to ordinary methods.

Finish rolling temperature: 830°C to 1000°C

[0110] The heated steel piece is hot-rolled to a steel plate of 15 mm or less. At that time, the finish rolling temperature is preferably set to 830°C to 1000°C. When the finish rolling temperature is lower than 830°C, there is a concern that a large amount of ferrite may be generated and it may become impossible to obtain a predetermined internal microstructure. The finish rolling temperature is preferably 850°C or higher.
[0111] On the other hand, when the finish rolling temperature exceeds 1000°C, crystal grains coarsen, and the low-temperature toughness such as the DWTT characteristics degrades. In addition, recrystallization and grain growth occur, and it is not possible to obtain a texture. Therefore, the finish rolling temperature is preferably set to 1000°C or lower. The finish rolling temperature is more preferably 980°C or lower.

<First cooling step>

[0112]

Cooling start temperature Ts: Higher than 750°C to 950°C
Average cooling rate Vc1: 25 to 100 °C/second
Cooling stop temperature Tm: 660°C to 750°C

[0113] In the first stage of accelerated cooling after the end of rolling, the steel plate having a surface temperature of a temperature Ts (cooling start temperature) which is in a temperature range of higher than 750°C to 950°C is cooled to a temperature Tm (cooling stop temperature) which is in a temperature range of 660°C to 750°C at an average cooling rate Vc1 of 25 to 50 °C/second.
[0114] When the cooling start temperature Ts is 750°C or lower in terms of the surface temperature, the area ratio of

ferrite exceeds 15%. In this case, the area ratio of one or both of granular bainite and bainite becomes less than 85%, and the HIC resistance degrades. Therefore, the cooling start temperature Ts is preferably higher than 750°C in terms of the surface temperature. The cooling start temperature Ts is more preferably 800°C or higher.

[0115] On the other hand, when the cooling start temperature Ts exceeds 950°C, crystal grains coarsen, and the low-temperature toughness degrades. In addition, there is a case where the maximum hardness of the surface layer area becomes too high. Therefore, the cooling start temperature Ts is preferably set to 950°C or lower in terms of the surface temperature. The cooling start temperature Ts is more preferably 930°C or lower.

[0116] When the average cooling rate Vc1 is less than 25 °C/second, the cooling rate is too slow, and a large amount of ferrite is generated in the surface layer and the internal microstructure. Thus, it is not possible to obtain 85% or more of one or both of granular bainite and bainite in terms of the area ratio, and the SSC resistance and the HIC resistance degrade. Therefore, the average cooling rate Vc1 is preferably set to 25 °C/second or more. The average cooling rate is more preferably 30 °C/second or more.

[0117] On the other hand, when the average cooling rate Vc1 exceeds 100 °C/second, the maximum hardness exceeds 248 Hv in the internal microstructure, and thus the HIC resistance degrades. Therefore, the average cooling rate Vc1 is preferably set to 100 °C/second or less. The average cooling rate is more preferably 50 °C/second or less and still more preferably 45°C/second or less.

[0118] When the cooling stop temperature Tm in the first cooling step is lower than 660°C in terms of the surface temperature, a large amount of ferrite is generated, it is not possible to obtain 85% or more of one or both of granular bainite and bainite in terms of the area ratio, and the SSC resistance and the HIC resistance degrade. Therefore, the cooling stop temperature Tm is preferably set to 660°C or higher. The cooling stop temperature is more preferably 680°C or higher. On the other hand, when the cooling stop temperature Tm exceeds 750°C, there is a concern that the surface layer area may be hardened and the SSC resistance may degrade. Therefore, the cooling stop temperature Tm is preferably set to 750°C or lower. The cooling stop temperature is more preferably 720°C or lower.

<Second cooling step>

[0119]

Cooling start temperature Tm: 660°C to 750°C
Average cooling rate Vc2: More than 50 °C/second
Cooling stop temperature Tf: 400°C or lower

[0120] In the second cooling step, the steel plate is cooled from the cooling stop temperature Tm of the first stage of 660°C to 750°C to a cooling stop temperature Tf of 400°C or lower at an average cooling rate of more than 50 °C/second.

[0121] In the accelerated cooling from the cooling start temperature Tm of 660°C to 750°C, when the average cooling rate Vc2 is 50 °C/second or less, the maximum hardness in the steel plate becomes high, and there is a concern that the HIC resistance may degrade. Therefore, the average cooling rate Vc2 is preferably set to more than 50 °C/second. The average cooling rate is more preferably 60 °C/second or more. The upper limit of the average cooling rate Vc2 is not particularly limited, but the cooling power of a cooling facility becomes a practical upper limit, and thus the upper limit is approximately 200 °C/second in the current status.

[0122] When the cooling stop temperature Tf exceeds 400°C in terms of the surface temperature, the average hardness after recuperating falls below 170 Hv, and it is not possible to obtain a necessary strength. Therefore, the cooling stop temperature Tf is preferably set to 400°C or lower. The cooling stop temperature is more preferably 380°C or lower. The cooling stop temperature Tf is determined depending on the kind of steel or the cooling rate, and the lower limit is not particularly set. However, from the viewpoint of obtaining a necessary microstructure or hardness by sufficiently recuperating the steel plate, the cooling stop temperature is preferably 250°C or higher.

[0123] As described above, in the method for manufacturing the steel pipe according to the present embodiment, two stages of accelerated cooling are carried out at different cooling rates. Such cooling can be carried out by, in a cooling facility in which a cooling zone is divided into a plurality of sections and disposed in the longitudinal direction (conveyance direction) of the steel plate, adjusting the amount of cooling water sprayed to the steel plate in each section of the cooling zone.

[0124] The cooling rate is obtained by dividing the temperature difference between the cooling start temperature and the cooling stop temperature by the cooling time.

<Recuperating step>

[0125]

Recuperating rate Vr: 50 °C/second or more
Steel plate surface temperature Tr after recuperating: Higher than 550°C to 650°C

[0126] After the steel plate is accelerated-cooled to the cooling stop temperature Tf of 400°C or lower as described above, the steel plate is recuperated at a recuperating rate Vr of 50 °C/second or more until the steel plate surface temperature Tr reaches higher than 550°C to 650°C.
[0127] By the cooling and the recuperating, an internal microstructure in which 85% or more of one or both of granular bainite and bainite are included in terms of the area ratio, the maximum hardness is 248 Hv or less, and the average hardness is 170 to 220 Hv, is obtained.
[0128] When the recuperating rate Vr is less than 50 °C/second, since there is a concern that the surface layer area may be hardened and the SSC resistance may degrade, the recuperating rate is set to 50 °C/second or more. Since the recuperating rate may be appropriately set in consideration of the time necessary for the surface temperature of the steel plate to reach higher than 550°C to 650°C, the upper limit is not particularly limited.
[0129] The recuperating rate is obtained by dividing the recuperating temperature width by the time necessary for recuperating.
[0130] When the steel plate surface temperature after recuperating is 550°C or lower, since the maximum hardness of the internal microstructure exceeds 248 Hv, the steel plate surface temperature after recuperating is preferably set to higher than 550°C. The steel plate surface temperature after recuperating is more preferably 580°C or higher. On the other hand, when the steel plate surface temperature after recuperating exceeds 650°C, the average hardness does not reach 170 Hv. Therefore, the steel plate surface temperature after recuperating is preferably set to 650°C or lower. The steel plate surface temperature after recuperating is more preferably 620°C or lower.
[0131] The recuperating rate and the amount of recuperating vary with the temperature difference between the surface and the inside of the steel plate when the cooling is stopped. The temperature difference between the surface and the inside of the steel plate is not simply determined by the cooling rate, but varies with the sprayed water density, the impact pressure, or the like in water cooling. Therefore, the cooling conditions need to be determined such that the recuperating rate reaches 50 °C/second or more and the surface temperature after recuperating reaches higher than 550°C to 650°C. Appropriate conditions can be set by, for example, carrying out an experiment for determining the conditions in advance.
[0132] FIG. 2 schematically shows an example of the cooling curve of the steel plate after finish rolling (a change in the steel plate surface temperature in the first cooling step, the second cooling step, and the recuperating step).
[0133] The steel plate after the recuperating step is preferably cooled to 300°C or lower at an average cooling rate of 0.01 °C/second or more. When the average cooling rate is less than 0.01 °C/second, it becomes impossible to obtain a target strength.
[0134] The steel plate that is used for the base material portion of the steel pipe according to the present embodiment can be manufactured by the above-described steps. That is, the steel plate according to the present embodiment is non-heat treated steel.

<Forming step>

<Welding step>

[0135] The steel plate according to the present embodiment obtained by the above-described steps is formed into a tubular shape, and the butt portion of the tubular steel plate (both end portions of the steel plate in the width direction) is welded to produce a steel pipe.
[0136] The forming of the steel plate according to the present embodiment into the steel pipe is not limited to specific forming. The forming may be warm working, but is preferably cold working from the viewpoint of the dimensional accuracy. The welding is also not limited to specific welding, but is preferably submerged arc welding. As the welding conditions, well-known conditions may be used depending on the thickness of the steel plate or the like.
[0137] In the steel pipe according to the present embodiment, in order to improve the toughness of the welded part, a heat treatment (seam heat treatment) may be carried out on the welded part. The heat treatment temperature may be in an ordinary temperature range, but is particularly preferably in a range of 300°C to Ac1 point.
[0138] Since the base material portion of the steel pipe according to the present embodiment is not heat-treated, the microstructure of the base material portion is the same as the microstructure of the steel plate according to the present embodiment. Therefore, the pipe according to the present embodiment is a steel pipe having sufficient mechanical properties as a steel pipe for a line pipe in both the base material portion and the welded part.

[Example 1]

[0139] Next, examples of the present invention will be described. The conditions in the examples are condition examples adopted to confirm the feasibility and effects of the present invention, and the present invention is not limited to these condition examples. The present invention is capable of adopting a variety of conditions within the scope of the gist of the present invention as long as the object of the present invention is achieved.

[0140] Steel pieces having a chemical composition (the remainder is Fe and impurities) and a Ceq shown in Table 1 were hot-rolled, cooled, and recuperated under the conditions shown in Table 2A and Table 2B to manufacture steel plates.

[Table 1]

Kind of steel	C	Si	Mn	P	S	Al	Ti	Nb	Ca	N	O	Ni	Mo	Cr	Cu	V	Mg	REM	Ceq
1	0.046	0.22	1.39	0.006	0.0002	0.019	0.012	0.018	0.0016	0.0021	0.0014	0.17		0.12	0.17				0.324
2	0.039	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			0.348
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	1.45	0.009	0.0006	0.019	0.009	0.032	0.0039	0.0029	0.0032								0.309
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		0.10	00.1					0.324
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	0.10	0.10	0.17		0.040			0.346
10	0.033	0.08	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	0.0018	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	0.048	0.0031	0.0033	0.0021	0.35		0.57	0.35			0.0120	0.404
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	0.0022	0.0023	0.60	0.25		0.60				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	0.10					0.342
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
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

(continued)

Kind of steel	C	Si	Mn	P	S	Al	Ti	Nb	Ca	N	O	Ni	Mo	Cr	Cu	V	Mg	REM	Ceq
26	0.038	0.20	1.68	0.007	0.0002	0.022	0.009	0.021	0.0025	0.0033	0.0019			0.12					0.342
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	0.052	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
32	0.052	0.22	1.42	0.007	0.0004	0.030	0.007	0.032	0.0021	0.0034	0.0029	0.10	0.10	0.24					0.363

[Table 2A]

No.	Kind of steel	Heating temperature	Finish rolling temperature	First cooling start temperature	First cooling average cooling rate	First cooling stop temperature	Second cooling start temperature	Second cooling average cooling rate	Second cooling stop temperature	Recuperating rate after second cooling	Temperature after recuperating	Average cooling rate after recuperating
		°C	°C	°C	°C/second	°C	°C	°C/second	°C	°C/second	°C	°C/second
S-1	1	1200	910	890	70	675	690	80	350	70	600	0.05
S-2	2	1200	970	770	90	675	690	120	380	100	640	0.09
S-3	3	1200	850	810	30	675	690	55	300	55	560	0.02
S-4	4	1250	940	870	40	675	690	75	300	70	600	0.04
S-5	5	1180	860	830	40	675	690	65	300	60	580	0.03
S-6	6	1050	860	830	40	675	690	65	300	60	600	0.03
S-7	7	1100	980	940	65	675	690	70	300	65	590	0.05
S-8	8	1200	880	850	65	675	690	70	350	65	590	0.05
S-9	9	1200	880	850	65	675	690	70	350	65	590	0.05
S-10	10	1200	880	850	65	675	690	70	350	65	590	0.03
S-11	1	1250	980	940	30	710	740	55	350	65	590	0.05
S-12	1	1200	880	850	50	700	700	65	370	90	560	0.02
S-13	1	1150	880	850	50	670	700	65	350	65	560	0.05
S-14	1	1200	880	850	90	700	700	65	350	65	590	0.05
S-15	1	1200	920	900	50	740	730	65	390	65	640	0.05
S-20	11	1200	880	795	35	675	705	75	325	65	600	0.05
S-21	12	1200	880	795	35	675	705	75	325	65	600	0.05
S-22	13	1200	880	795	35	675	705	75	325	65	600	0.05
S-23	14	1200	880	795	35	675	705	75	325	65	600	0.05
S-24	15	1200	880	795	35	675	705	75	325	65	600	0.05
S-25	16	1200	880	795	35	675	705	75	325	65	600	0.05

(continued)

No.	Kind of steel	Heating temperature	Finish rolling temperature	First cooling start temperature	First cooling average cooling rate	First cooling stop temperature	Second cooling start temperature	Second cooling average cooling rate	Second cooling stop temperature	Recuperating rate after second cooling	Temperature after recuperating	Average cooling rate after recuperating
		°C	°C	°C	°C/second	°C	°C	°C/second	°C	°C/second	°C	°C/second
S-26	17	1200	880	795	35	675	705	75	325	65	600	0.05
S-27	18	1200	880	795	35	675	705	75	325	65	600	0.05
S-28	19	1200	880	795	35	675	705	75	325	65	600	0.05
S-29	20	1200	880	795	35	675	705	75	325	65	600	0.05

[Table 2B]

No.	Kind of steel	Heating temperature	Finish rolling temperature	First cooling start temperature	First cooling average cooling rate	First cooling stop temperature	Second cooling start temperature	Second cooling average cooling rate	Second cooling stop temperature	Recuperating rate after second cooling	Temperature after recuperating	Average cooling rate after recuperating
		°C	°C	°C	°C/second	°C	°C	°C/second	°C	°C/second	°C	°C/second
S-30	21	1200	880	795	35	675	705	75	325	65	600	0.05
S-31	22	1200	880	795	35	675	705	75	325	65	600	0.05
S-32	23	1200	880	795	35	675	705	75	325	65	600	0.05
S-33	24	1200	880	795	35	675	705	75	325	65	600	0.05
S-34	25	1200	880	795	35	675	705	75	325	65	600	0.05
S-35	26	1200	880	795	35	675	705.	75	325	65	600	0.05
S-36	27	1200	880	795	35	675	705	75	325	65	600	0.05
S-37	28	1200	880	795	35	675	705	75	325	65	600	0.05
S-38	29	1200	880	795	35	675	705	75	325	65	600	0.05
S-39	30	1200	880	795	35	675	705	75	325	65	600	0.05
S-40	31	1200	880	795	35	675	705	75	325	65	600	0.05
S-41	32	1200	880	795	35	675	705	75	325	65	600	0.05
S-42	1	1280	900	800	35	675	705	75	325	65	600	0.05
S-43	1	1040	900	800	35	675	705	75	325	65	600	0.05
S-44	1	1250	1020	810	35	675	705	75	325	65	600	0.05
S-45	1	1200	800	770	35	675	705	75	325	65	600	0.05
S-46	1	1200	980	965	35	675	705	75	325	65	600	0.05
S-47	1	1200	890	740	35	675	705	75	325	65	600	0.05
S-48	1	1200	890	800	10	675	705	75	325	65	600	0.05
S-49	1	1200	930	800	35	620	705	75	325	65	600	0.05
S-50	1	1200	930	800	35	675	620	75	325	65	600	0.05

(continued)

No.	Kind of steel	Heating temperature	Finish rolling temperature	First cooling start temperature	First cooling average cooling rate	First cooling stop temperature	Second cooling start temperature	Second cooling average cooling rate	Second cooling stop temperature	Recuperating rate after second cooling	Temperature after recuperating	Average cooling rate after recuperating
		°C	°C	°C	°C/second	°C	°C	°C/second	°C	°C/second	°C	°C/second
S-51	1	1200	930	800	35	675	705	20	325	65	600	0.05
S-52	1	1200	930	800	35	675	705	75	440	65	600	0.05
S-53	1	1200	930	800	35	675	705	75	325	30	520	0.05
S-54	1	1200	930	795	35	675	700	75	350	65	600	0.007

[0141] A test piece was collected from a manufactured steel plate, and the internal microstructure was determined by observing the microstructure at the 1/4 position (t/4) of the plate thickness from the surface of the steel plate using a scanning electron microscope at a magnification of 1000 times.

[0142] In addition, the microstructure of the surface layer area was obtained by observing and measuring the positions 0.1 mm, 0.2 mm, and 0.5 mm apart from the surface of the steel plate and averaging the area ratios at the respective positions.

[0143] In addition, a JIS No. 5 tensile test piece was produced, a tensile test prescribed in JIS Z 2241 was carried out, and the yield strength and the tensile strength were measured.

[0144] In addition, the hardness of the internal microstructure and the hardness of the surface layer area microstructure were measured with a Vickers hardness meter.

[0145] Regarding the internal microstructure, hardness was measured with a Vickers hardness meter (load: 100 g) at points from a depth position of 1.1 mm from the surface of the steel plate as a starting point to the plate thickness center at intervals of 0.1 mm in the plate thickness direction and at 20 points for each of the corresponding depth at intervals of 1.0 mm in the width direction. As a result of the above measurement, even in a case where one measurement point with a hardness value of more than 248 Hv was found, unless two or more points with a hardness value of more than 248 Hv continuously appeared in the plate thickness direction, such a point was regarded as an abnormal point, and the next highest value was regarded as the maximum hardness. On the other hand, in a case where two or more measurement points with a hardness value of more than 248 Hv were continuously present in the plate thickness direction, the highest value was regarded as the maximum hardness. In addition, the average hardness was calculated by averaging the hardness values of all measurement points.

[0146] In the surface layer area microstructure, a 300 mm × 300 mm steel plate was cut out by gas cutting from an end portion of the steel plate in the width direction, and block test pieces having a length of 20 mm and a width of 20 mm were collected by mechanical cutting from the center of the cut-out steel plate and polished by mechanical polishing. In one block test piece, hardness was measured with a Vickers hardness meter (load: 100 g) at a total of 100 points (10 points at intervals of 0.1 mm in the plate thickness direction from the position 0.1 mm from the surface as a starting position × 10 points at intervals of 1.0 mm in the width direction at each of the corresponding depths). That is, in three block test pieces, hardness was measured at a total of 300 points. As a result of the measurement, even in a case where one measurement point with a hardness value of more than 250 Hv was found, unless two or more points with a hardness value of more than 250 Hv continuously appeared in the plate thickness direction, such a point was regarded as an abnormal point, and the next highest value was regarded as the maximum hardness. On the other hand, in a case where two or more measurement points with a hardness value of more than 250 Hv were continuously present in the plate thickness direction, the highest value was regarded as the maximum hardness.

[0147] In addition, on a plane parallel to the plate surface at a depth of t/4 from the surface, crystal orientation analysis was carried out at intervals of 0.1 mm in a 2.0 mm × 2.0 mm region using EBSP, and the integration degree of the (100)<110> texture was obtained.

[0148] A test based on TM0284 of National Association of Corrosion and Engineer (NACE) was carried out, and the presence or absence of the occurrence of hydrogen-induced cracking (HIC) was observed. In a case where the HIC fracture surface ratio was 5% or less, the HIC resistance was determined to be excellent (OK).

[0149] The NACE test is a test in which hydrogen sulfide gas is saturated in a solution (pH: 2.7) of a 5% NaCl solution and 0.5% acetic acid, the steel plate is immersed in the solution, and whether or not cracking occurs, is observed after 96 hours.

[0150] In addition, as the evaluation of the SSC resistance, four-point bending test pieces were collected, four-point bending tests were carried out based on NACE TM 0177 at a variety of hydrogen sulfide partial pressures shown in Table 4 and under 90% actual yield stress in a solution environment with a pH of 3.5, and the presence or absence of the occurrence of cracking was inspected. In a case where cracking did not occur, the SSC resistance was determined to be excellent (OK), and, in a case where cracking occurred, the SSC resistance was determined to be poor (NG).

[0151] The DWTT characteristics (ductile fracture surface ratio at -30°C) were evaluated by the following method.

[0152] A DWTT test piece was collected from the steel plate such that the width direction of the steel plate became parallel to the longitudinal direction of the test piece. The sample collection position was set to the 1/4 position of the steel plate in the width direction. The DWTT test piece was an overall thickness test piece with a press notch.

[0153] A DWTT test was carried out on this test piece at -30°C based on API 5L, and the ductile fracture surface ratio to the entire fracture surface was measured. As the numerical value of the fracture surface ratio (%) increased, the DWTT characteristics became more excellent. In the present invention, in a case where the ductile fracture surface ratio was 85% or more, the DWTT characteristics were determined to be excellent.

[0154] The results are shown in Table 3A and Table 3B.

[Table 3A]

No.	Kind of steel	Product thickness	Total fraction of granular bainite and bainite in internal micro-structure	MA fraction	Maximum hardness of internal microstructure	Average hardness of internal microstructure	Integration degree of {100}<110>	Total fraction of granular bainite and bainite in surface layer microstructure	Maximum hardness of surface layer area microstructure	Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
		mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
S-1	1	10.8	100	0.8	223	198	1.8	100	237	491	614	OK	OK	100
S-2	2	8	87	0.4	236	188	1.6	96	240	466	583	OK	OK	100
S-3	3	15	90	0.7	191	173	1.9	99	211	429	536	OK	OK	100
S-4	4	11	98	0.3	212	193	1.6	100	228	479	598	OK	OK	100
S-5	5	12.7	93	0.6	188	182	1.8	98	218	451	564	OK	OK	100
S-6	6	12.7	88	0.3	188	176	1.8	96	207	436	546	OK	OK	100
S-7	7	10.8	100	0.2	208	193	1.6	100	226	479	598	OK	OK	100
S-8	8	10.8	99	0.5	199	186	1.7	100	224	461	577	OK	OK	100
S-9	9	10.8	100	0.8	221	199	1.7	100	243	494	617	OK	OK	100
S-10	10	12.7	96	0.7	191	177	1.7	98	217	439	549	OK	OK	100
S-11	1	10.8	100	0.8	225	201	1.9	100	238	498	623	OK	OK	100
S-12	1	10.8	100	0.6	223	203	2.0	100	244	503	629	OK	OK	100
S-13	1	10.8	100	0.7	212	191	1.7	98	231	474	592	OK	OK	100
S-14	1	10.8	100	0.8	22 1	198	1.8	100	237	491	614	OK	OK	100
S-15	1	10.8	100	0.3	218	202	1.8	100	237	501	626	OK	OK	100
S-20	11	10.8	81	0.1	183	167	1.6	90	198	414	518	OK	OK	80
S-21	12	10.8	100	0.6	255	224	1.8	100	268	556	694	NG	NG	100
S-22	13	10.8	98	0.5	220	195	1.7	99	237	484	605	OK	NG	100
S-23	14	10.8	82	0.1	184	163	1.6	92	195	404	505	OK	OK	100
S-24	15	10.8	100	0.7	261	222	1.9	100	271	551	688	NG	NG	100

(continued)

No.	Kind of steel	Product thickness	Total fraction of granular bainite and bainite in internal microstructure	MA fraction	Maximum hardness of internal microstructure	Average hardness of internal microstructure	Integration degree of {100}<110>	Total fraction of granular bainite and bainite in surface layer microstructure	Maximum hardness of surface layer area microstructure	Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
		mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
S-25	16	10.8	100	0.7	222	197	1.7	100	234	489	611	OK	NG	100
S-26	17	10.8	100	0.8	225	195	1.8	100	234	484	605	OK	NG	100
S-27	18	10.8	100	0.7	222	199	1.7	100	235	494	617	OK	NG	100
S-28	19	10.8	81	0.3	181	188	1.2	88	282	466	583	NG	NG	60
S-29	20	10.8	100	0.9	262	221	1.9	100	293	548	685	NG	NG	100

[Table 3B]

No.	Kind of steel	Product thickness	Total fraction of granular bainite and bainite in internal micro-structure	MA fraction	Maximum hardness of internal micro-structure	Average hardness of internal microstructure	Integration degree of {100}<110>	Total fraction of granular bainite and bainite in surface layer microstructure	Maximum hardness of surface layer area microstructure .	Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
		mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
S-30	21	10.8	100	1.2	292	24 2	2.2	100	318	600	750	NG	NG	75
S-31	22	10.8	100	1.1	268	223	1.8	100	283	553	691	NG	NG	100
S-32	23	10.8	100	0.6	255	218	1.8	100	268	541	676	NG	NG	100
S-33	24	10.8	100	0.8	255	198	1.8	100	271	491	614	NG	NG	100
S-34	25	10.8	100	0.7	223	199	1.9	100	237	494	617	OK	NG	100
S-35	26	10.8	100	0.7	288	212	1.8	100	275	526	657	NG	NG	100
S-36	27	10.8	100	0.7	221	197	1.9	100	234	489	611	OK	NG	100
S-37	28	10.8	100	0.8	226	201	1.9	100	238	498	623	OK	NG	100
S-38	29	10.8	100	0.7	223	198	1.8	100	235	491	614	OK	NG	100
S-39	30	10.8	100	0.4	224	199	1.9	100	236	494	617	OK	NG	100
S-40	31	10.8	100	0.8	223	198	1.8	100	233	491	614	OK	NG	100
S-41	32	10.8	100	0.7	252	202	1.8	100	267	501	626	NG	NG	100
S-42	1	10.8	100	0.8	255	222	1.8	100	269	551	688	NG	NG	100
S-43	1	10.8	82	0.7	255	220	1.9	92	276	546	682	NG	NG	100
S-44	1	10.8	100	0.8	223	198	1.3	100	275	491	614	NG	NG	55
S-45	1	10.8	78	0.8	2 62	198	1.8	100	282	491	614	NG	NG	100
S-46	1	10.8	100	0.8	223	198	1.8	100	272	491	614	NG	OK	100
S-47	1	10.8	78	0.8	262	198	1.8	93	276	491	614	NG	NG	100
S-48	1	10.8	82	0.8	258	193	1.7	91	282	479	598	NG	NG	100
S-49	1	10.8	98	0.7	225	199	1.8	93	273	494	617	NG	OK	100

(continued)

No.	Kind of steel	Product thickness	Total fraction of granularbainite and bainite in internal microstructure	MA fraction	Maximum hardness of internal microstructure	Average hardness of internal microstructure	Integration degree of {100}<110>	Total fraction of granularbainite and bainite in surface layer microstructure	Maximum hardness of surface layer area microstructure .	Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
		mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
S-50	1	10.8	100	0.8	223	198	1.8	96	267	491	614	NG	OK	100
S-51	1	10.8	82	0.8	266	201	1.8	96	240	498	623	OK	NG	100
S-52	1	10.8	100	0.8	196	158	1.8	100	228	392	490	OK	OK	100
S-53	1	10.8	100	0.8	258	198	1.8	100	282	491	614	NG	NG	100
S-54	1	10.8	100	0.8	168	151	1.7	100	173	397	496	OK	OK	100

[Example 2]

[0155] The steel plates shown in Tables 1 to 3 were formed into a tubular shape by C press, U press, and O press, the end surfaces were tack-welded together, and final welding was carried out from the inner and outer surfaces. After that, the pipes were expanded to obtain steel pipes for a line pipe. As the final welding, submerged arc welding was applied.
[0156] In the table, steel pipes obtained by forming steel plates Nos. S-x (x=1 to 54) are indicated as steel pipes Nos. P-x (x=1 to 54).
[0157] Test pieces were collected from the base material portions of the manufactured steel pipes, and the fractions (area ratios) of each microstructure of the surface layer area microstructure and the internal microstructure were calculated. Specifically, the internal microstructure was determined by observing the microstructure at the 1/4 position (t/4) of the plate thickness from the surface of the steel plate using a scanning electron microscope at a magnification of 1000 times. The microstructure of the remainder not shown in the tables was ferrite. The microstructure of the surface layer area was obtained by measuring the positions 0.1 mm, 0.2 mm, and 0.5 mm apart from the surface of the steel plate and averaging the area ratios at the respective positions.
[0158] In addition, a JIS No. 5 tensile test piece was produced, a tensile test prescribed in JIS Z 2241 was carried out, and the yield strength and the tensile strength were measured.
[0159] In addition, the hardness of the internal microstructure and the hardness of the surface layer area microstructure were measured with a Vickers hardness meter.
[0160] Regarding the internal microstructure, hardness was measured with a Vickers hardness meter (load: 100 g) at points from a depth position of 1.1 mm from the surface of the steel plate as a starting point to the plate thickness center at intervals of 0.1 mm in the plate thickness direction and at 20 points for each of the corresponding depth at intervals of 1.0 mm in the width direction. As a result of the measurement, even in a case where one measurement point with a hardness value of more than 248 Hv was found, unless two or more points with a hardness value of more than 248 Hv continuously appeared in the plate thickness direction, such a point was regarded as an abnormal point, and the next highest value was regarded as the maximum hardness. On the other hand, in a case where two or more measurement points with a hardness value of more than 248 Hv were continuously present in the plate thickness direction, the highest value was regarded as the maximum hardness. In addition, the average hardness was calculated by averaging the hardness values of all measurement points.
[0161] In the surface layer area microstructure, 300 mm × 300 mm steel plates were cut out by gas cutting from the three o'clock position, the six o'clock position, and the nine o'clock position respectively in a case where the welded part from the butt portion of the steel pipe was regarded to be at the zero o'clock position, and block test pieces having a length of 20 mm and a width of 20 mm were collected by mechanical cutting from the center of the cut-out steel plates and polished by mechanical polishing. In one block test piece, hardness was measured with a Vickers hardness meter (load: 100 g) at a total of 100 points (10 points at intervals of 0.1 mm in the plate thickness direction from the position 0.1 mm from the surface as a starting position × 10 points at intervals of 1.0 mm in the width direction at each of the corresponding depths). That is, in three block test pieces, hardness was measured at a total of 300 points. As a result of the measurement, even in a case where one measurement point with a hardness value of more than 250 Hv was found, unless two or more points with a hardness value of more than 250 Hv continuously appeared in the plate thickness direction, such a point was regarded as an abnormal point, and the next highest value was regarded as the maximum hardness. On the other hand, in a case where two or more measurement points with a hardness value of more than 250 Hv were continuously present in the plate thickness direction, the highest value was regarded as the maximum hardness.
[0162] In addition, on a plane parallel to the plate surface at a depth of t/4 from the surface, crystal orientation analysis was carried out at intervals of 0.1 mm in a 2.0 mm × 2.0 mm region using EBSP, and the integration degree of the (100)<110> texture was obtained.
[0163] In addition, a test piece was collected from the base material portion of the manufactured steel pipe, and the following tests were carried out, thereby evaluating the HIC resistance and the SSC resistance.

Evaluation of HIC resistance

[0164] A test based on TM0284 of National Association of Corrosion and Engineer (NACE) was carried out, and the presence or absence of the occurrence of hydrogen-induced cracking (HIC) was observed. In a case where the HIC fracture surface ratio was 5% or less, the HIC resistance was determined to be excellent (OK), and, in a case where the HIC fracture surface ratio was more than 5%, the HIC resistance was determined to be poor (NG).
[0165] The NACE test is a test in which hydrogen sulfide gas is saturated in a solution (pH: 2.7) of a 5% NaCl solution and 0.5% acetic acid, the steel plate is immersed in the solution, and whether or not cracking occurs is observed after 96 hours.
[0166] In addition, as the evaluation of the SSC resistance, four-point bending test pieces were collected, four-point bending tests were carried out based on NACE TM 0177 at a variety of hydrogen sulfide partial pressures shown in

Table 4A and Table 4B and under 90% actual yield stress in a solution environment with a pH of 3.5, and the presence or absence of the occurrence of cracking was inspected. In a case where cracking did not occur, the SSC resistance was determined to be excellent (OK), and, in a case where cracking occurred, the SSC resistance was determined to be poor (NG).

[0167] The DWTT characteristics (ductile fracture surface ratio at -30°C) were evaluated by the following method.

[0168] A DWTT test piece was collected from the steel pipe such that the circumferential direction of the steel pipe became parallel to the longitudinal direction of the test piece. The sample collection position was set to the 90° position from the seam position of the steel pipe. Here, the DWTT test piece was an overall thickness test piece with a press notch.

[0169] A DWTT test was carried out on this test piece at -30°C based on API 5L, and the ductile fracture surface ratio to the entire fracture surface was measured. As the numerical value of the fracture surface ratio (%) increased, the DWTT characteristics became more excellent. In the present invention, in a case where the ductile fracture surface ratio was 85% or more, the DWTT characteristics were determined to be excellent.

[0170] The results are shown in Table 4A and Table 4B.

[Table 4A]

	No.	Kind of steel	Outer diameter mm	Thickness mm	Total fraction of granular bainite and bainite in internal microstructure	MA fraction	Maximum hardness of internal microstructure	Average hardness of internal microstructure .	Integration degree of {100} <110>	Total fraction of granular bainite and bainite in surface layer microstructure	Maximum hardness surface layer area microstructure	of Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
			mm	mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
Invention Example	P-1	1	7 62	10.8	100	0.8	225	199	1.8	100	248	531	624	OK	OK	100
	P-2	2	762	8	87	0.4	238	187	1.6	96	249	503	592	OK	OK	100
	P-3	3	762	15	90	0.7	193	172	1.9	99	221	465	547	OK	OK	100
	P-4	4	762	11	98	0.3	214	192	1.6	100	239	517	609	OK	OK	100
	P-5	5	762	12.7	93	0.6	190	184	1.8	98	228	488	575	OK	OK	100
	P-6	6	762	12.7	88	0.3	190	177	1.8	96	217	472	556	OK	OK	100
	P-7	7	762	10.8	100	0.2	210	195	1.6	100	237	517	609	OK	OK	100
	P-8	8	762	10.8	99	0.5	201	187	1.7	100	235	498	586	OK	OK	100
	P-9	9	762	10.8	100	0.8	223	200	1.7	100	249	533	627	OK	OK	100
	P-10	10	762	12.7	96	0.7	193	187	1.7	98	227	475	559	OK	OK	100
	P-11	1	762	10.8	100	0.8	22 7	203	1.9	100	249	539	634	OK	OK	100
	P-12	1	762	10.8	100	0.6	225	205	2.0	100	249	544	640	OK	OK	100
	P-13	1	762	10.8	100	0.7	214	189	1.7	98	242	512	602	OK	OK	100
	P-14	1	762	10.8	100	0.8	223	199	1.8	100	248	531	624	OK	OK	100
	P-15	1	762	10.8	100	0.3	220	206	1.8	100	248	541	660	OK	OK	100
Comparative Example	P-20	11	762	10.8 20	81 81	0.1	185	165	1.6	90	207	448	511	OK	OK	60
	P-21	12	762	10.8	100	0.6	258	226	1.8	100	280	600	706	NG	NG	100

(continued)

	No.	Kind of steel	Outer diameter mm	Thickness mm	Total fraction of granular bainite and bainite in internal microstructure	MA fraction	Maximum hardness of internal microstructure	Average hardness of internal microstructure .	Integration degree of {100} <110>	Total fraction of granular bainite and bainite in surface layer microstructure	Maximum hardness surface layer area microstructure	of Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
			mm	mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
	P-22	13	762	10.8	98	0.5	222	197	1.7	99	248	523	615	OK	NG	100
	P-23	14	762	10.8	82	0.1	186	165	1.6	92	204	437	514	OK	OK	100
	P-24	15	762	10.8	100	0.7	264	223	1.9	100	284	595	700	NG	NG	100
	P-25	16	762	10.8	100	0.7	224	198	1.7	100	245	528	621	OK	NG	100
	P-26	17	762	10.8	100	0.8	227	196	1.8	100	245	523	615	OK	NG	100
	P-27	18	762	10.8	100	0.7	224	200	1.7	100	246	533	627	OK	NG	100
	P-28	19	762	10.8	81	0.3	183	187	1.2	88	295	504	593	NG	NG	45
	P-29	20	762	10.8	100	0.9	265	223	1.9	100	306	592	697	NG	NG	100

[Table 4B]

	No.	Kind of steel	Outer diameter mm	Thickness mm	Total fraction of granular bainite and bainite in internal microstructure	MA fraction	Maximum hardness of internal microstructure	Average hardness of internal microstructure	Integration degree of {100} <110>	Total fraction of granular bainite and bainite in surface layer microstructure	Maximum hardness of surface layer area microstructure	Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
			mm	mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
Comparative Example	P-30	21	762	10.8	100	1.2	295	244	2.2	100	332	649	763	NG	NG	55
	P-31	22	762	10.8	100	1.1	271	224	1.8	100	296	598	703	NG	NG	100
	P-32	23	762	10.8	100	0.6	258	219	1.8	100	280	584	687	NG	NG	100
	P-33	24	762	10.8	100	0.8	258	199	1.8	100	284	531	624	NG	NG	100
	P-34	25	762	10.8	100	0.7	225	196	1.9	100	248	533	627	OK	NG	100
	P-35	26	762	10.8	100	0.7	291	214	1.8	100	288	568	668	NG	NG	100
	P-36	27	762	10.8	100	0.7	223	198	1.9	100	245	528	621	OK	NG	100
	P-37	28	762	10.8	100	0.8	228	202	1.9	100	249	539	634	OK	NG	100
	P-38	29	762	10.8	100	0.7	225	199	1.8	100	246	531	624	OK	NG	100
	P-39	30	762	10.8	100	0.4	226	200	1.9	100	247	533	627	OK	NG	100
	P-40	31	762	10.8	100	0.8	225	196	1.8	100	244	531	624	OK	NG	100
	P-41	32	762	10.8	100	0.7	255	203	1.8	100	279	541	637	NG	NG	100
	P-42	1	762	10.8	100	0.8	258	223	1.8	100	281	595	700	NG	NG	100
	P-43	1	762	10.8	82	0.7	258	221	1.9	92	289	590	694	NG	NG	100
	P-44	1	762	10.8	100	0.8	225	199	1.3	100	288	531	624	NG	NG	40
	P-45	1	762	10.8	78	0.8	265	200	1.8	100	295	531	624	NG	NG	100
	P-46	1	762	10.8	100	0.8	225	196	1.8	100	285	531	624	NG	OK	100
	P-47	1	762	10.8	78	0.8	265	197	1.8	93	289	531	624	NG	NG	100
	P-48	1	762	10.8	82	0.8	261	195	1.7	91	295	517	609	NG	NG	100

(continued)

No.	Kind of steel	Outer diameter mm	Thickness mm	Total fraction of granular bainite and bainite in internal microstructure	MA fraction	Maximum hardness of internal microstructure	Average hardness of internal microstructure	Integration degree of {100} <110>	Total fraction of granular bainite and bainite in surface layer microstructure	Maximum hardness of surface layer area microstructure	Yield strength	Tensile strength	SSC test	HIC test	DWTT ductile fracture surface ratio carried out at -30°C
		mm	mm	area%	area%	Hv	Hv		area%	Hv	MPa	MPa			%
P-49	1	762	10.8	98	0.7	227	200	1.8	93	286	533	627	NG	OK	100
P-50	1	762	10.8	100	0.8	225	197	1.8	96	279	531	624	NG	OK	100
P-51	1	762	10.8	82	0.8	269	203	1.8	96	246	539	634	OK	NG	100
P-52	1	762	10.8	100	0.8	192	165	1.8	100	237	536	497	OK	OK	100
P-53	1	762	10.8	100	0.8	259	199	1.8	100	295	531	624	NG	NG	100
P-54	1	762	10.8	100	0.8	166	156	1.7	100	182	429	506	OK	OK	100

[Industrial Applicability]

[0171] According to the present invention, it is possible to provide a steel pipe that has a strength of X60 or higher in terms of the API standards, is excellent in terms of sulfide stress cracking resistance and hydrogen-induced cracking resistance, and has a thickness of 15 mm or less even without using additive elements of V, Cu, Ni, Mo, and/or the like and to provide a steel plate that is used as a base metal of the steel pipe and is excellent in terms of sulfide stress cracking resistance and hydrogen-induced cracking resistance. Therefore, the present invention is highly applicable in the steel pipe manufacturing industry and the energy industry.

Claims

1. A steel pipe comprising:

a base material portion composed of a tubular steel plate; and
a welded part that is provided at a butt portion of the steel plate and extends in a longitudinal direction of the steel plate,
wherein the steel plate has a chemical composition containing, by mass%,
C: 0.030% to 0.070%,
Si: 0.05% 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: 0.0010% to 0.0050%,
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: Fe and impurities,
the steel plate has a Ceq of 0.250 to 0.350, the Ceq being defined by the following Expression (1),
an internal microstructure, which is a microstructure in a range from a position deep over 1.0 mm from a surface of the base material portion to a plate thickness center in a depth direction, includes 85% or more of one or both of granular bainite and bainite in terms of a total area ratio and includes 1.0% or less of an MA in terms of an area ratio,
in the internal microstructure, a maximum hardness is 248 Hv or less and an average hardness is 170 to 220 Hv,
the base material portion has a texture having an integration degree of {100}<110> of 1.5 or more in a plane parallel to a plate surface at a 1/4 position of a plate thickness from the surface in a plate thickness direction,
a surface layer area microstructure, which is a microstructure in a range of 1.0 mm from the surface of the base material portion in the depth direction, includes 95% or more of one or both of granular bainite and tempered bainite in terms of a total area ratio,
in the surface layer area microstructure, a maximum hardness is 250 Hv or less, and
a plate thickness of the steel plate is 15 mm or less,

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

where [C], [Mn], [Ni], [Cu], [Cr], [Mo], and [V] in the Expression (1) are respectively the amounts of C, Mn, Ni, Cu, Cr, Mo, and V in the steel plate in terms of mass%.

2. The steel pipe according to claim 1, wherein the chemical composition contains, 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 internal microstructure is ferrite.

4. A steel plate that is used for the base material portion of the steel pipe according to any one of claims 1 to 3.

FIG. 1

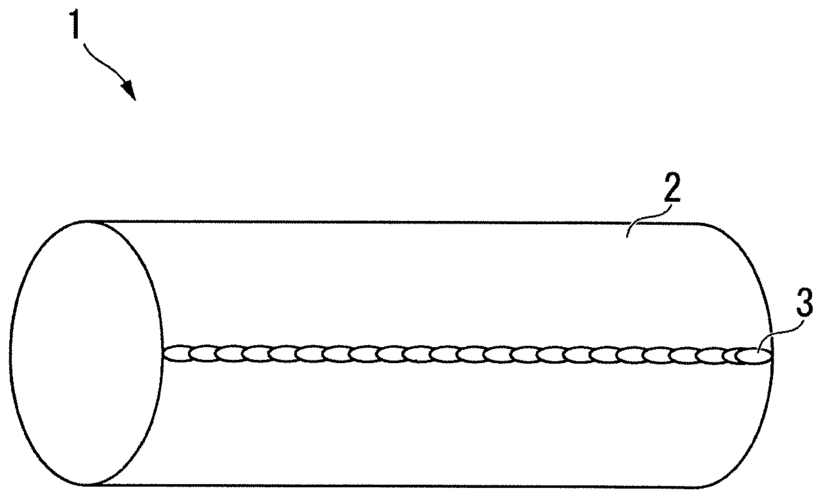


FIG. 2

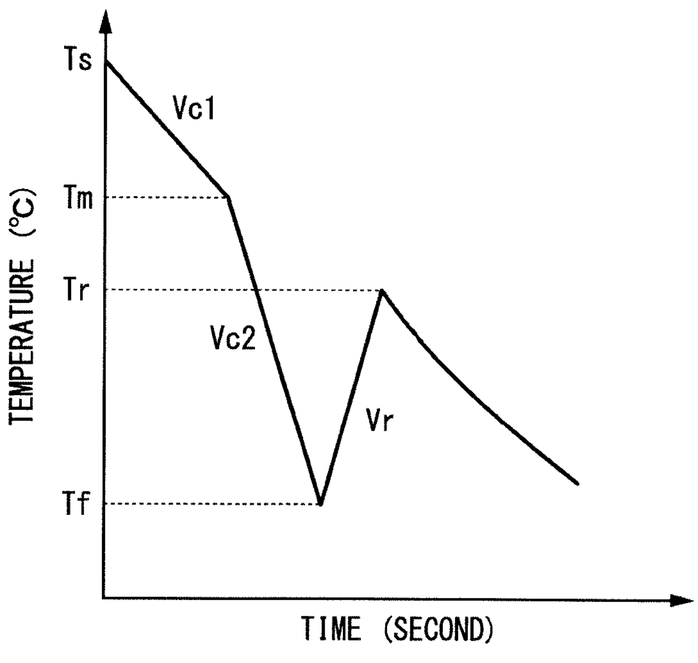
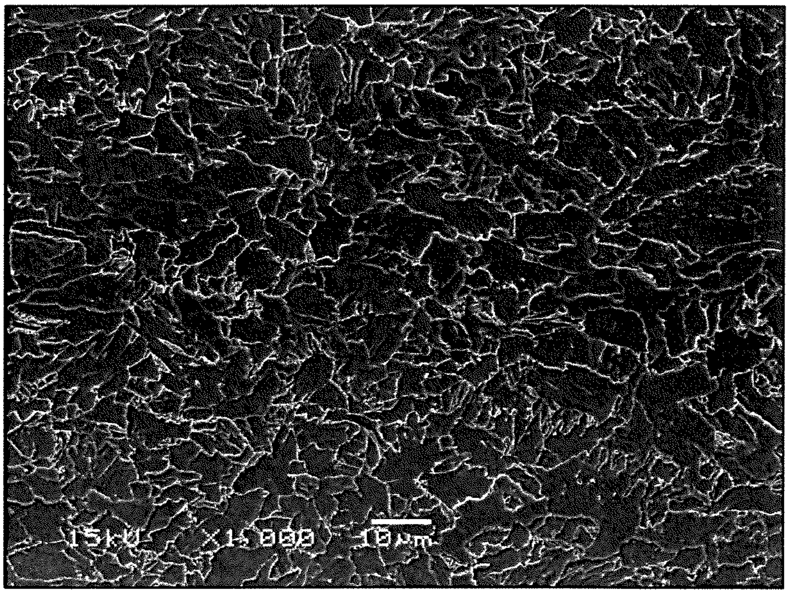
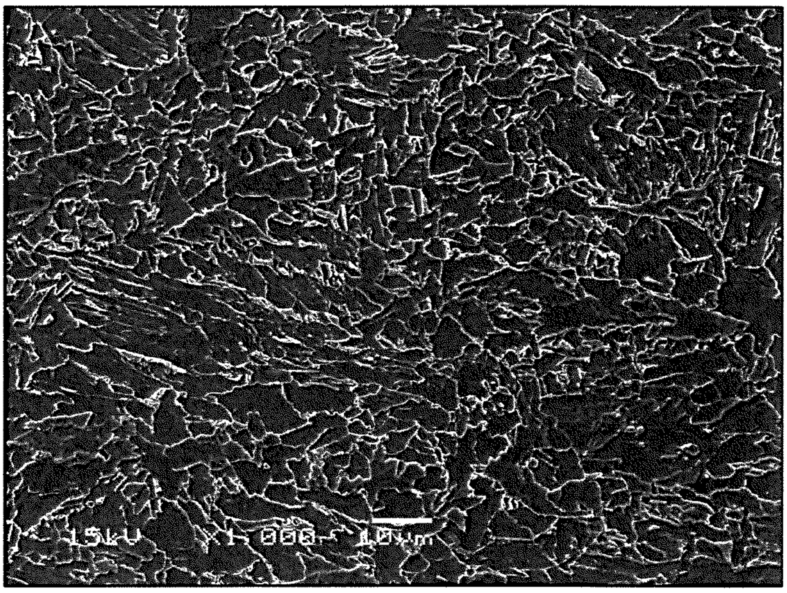


FIG. 3A



INTERNAL MICROSTRUCTURE

FIG. 3B



SURFACE LAYER AREA MICROSTRUCTURE

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/024839

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

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. C22C1/00-49/14

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 1971-2018
Registered utility model specifications of Japan 1996-2018
Published registered utility model applications of Japan 1994-2018

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 6319539 B1 (NIPPON STEEL & SUMITOMO METAL CORP.) 09 May 2018 (Family: none)	1-4
A	JP 2017-172010 A (NIPPON STEEL & SUMITOMO METAL CORP.) 28 September 2017 (Family: none)	1-4
A	JP 2016-079431 A (NIPPON STEEL & SUMITOMO METAL CORP.) 16 May 2016 (Family: none)	1-4
A	CN 105734444 A (BAOJI PETROLEUM STEEL PIPE CO., LTD.) 06 July 2016 (Family: none)	1-4
A	JP 2013-173998 A (NIPPON STEEL & SUMITOMO METAL CORP.) 05 September 2013 (Family: none)	1-4

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
04.09.2018	18.09.2018

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/024839

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-241271 A (JFE STEEL CORP.) 10 December 2012 (Family: none)	1-4
A	JP 8-309428 A (SUMITOMO METAL INDUSTRIES, LTD.) 26 November 1996 (Family: none)	1-4

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP S63001369 B **[0007]**
- JP S62112722 B **[0007]**
- JP H06256842 B **[0007]**

Non-patent literature cited in the description

- *ISIJ International,* 1993, vol. 33, 1190-1195 **[0008]**