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(54) ELECTROSEAMED STEEL PIPE FOR LINE PIPE

(57) An electric resistance welded steel pipe for a line pipe, in which a base metal portion includes, in terms of % by mass, 0.030 to less than 0.080% of C, 0.30 to 1.00% of Mn, 0.005 to 0.050% of Ti, 0.010 to 0.100% of Nb, 0.001 to 0.020% of N, 0.010 to 0.450% of Si, and 0.001 to 0.100% of Al, and the balance includes Fe and impurities, and wherein CNeq, expressed by Formula (1), is from 0.190 to 0.320, a Mn/Si ratio is 2.0 or more, LR, expressed by Formula (2), is 0.210 or more, in a case in which a metallographic microstructure of the base metal portion is observed using a SEM at a magnification of 1,000 times, an areal ratio of ferrite is from 40 to 80%, and the balance includes tempered bainite; CNeq = C + Mn/6 + Cr/5 + (Ni + Cu)/15 + Nb + Mo + V Formula (1); LR = (2.1 × C + Nb)/Mn Formula (2).

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Description

Technical Field

[0001] The present invention relates to an electric resistance welded steel pipe for a line pipe.

Background Art

[0002] In recent years, a line pipe which is one of types of means of primarily transporting crude oil or natural gas has increased in importance.

[0003] Electric resistance welded steel pipes used as line pipes (i.e., electric resistance welded steel pipes for line pipes) have been variously examined.

[0004] For example, Patent Document 1 proposes a hot-rolled steel sheet for a sour resistant and high strength electric resistance welded steel pipe, including 95% by volume or more of bainitic ferrite in a steel structure.

[0005] Patent Document 2 discloses a technology in which the yield ratio of an obtained electric resistance welded steel pipe in a pipe axis direction is decreased by repeatedly applying a strain to an uncoiled steel sheet which is a raw material, for example, by bending-unbending processing, before pipe-making forming, thereby inducing a Bauschinger effect.

[0006] Patent Document 3 proposes a method of producing an electric resistance welded steel pipe using a slab in which the amount of Nb is from 0.003% to less than 0.02%, as a method of producing an electric resistance welded steel pipe in which a rise in yield ratio due to heating is suppressed, and a deformation property is improved, and which has excellent strain aging resistance. In the paragraph 0019 of Patent Document 3, "In a conventional electric resistance welded steel pipe with a large amount of Nb, a work strain introduced in pipe-making causes the precipitation of Nb carbide to proceed, thereby increasing a yield strength and a tensile strength. Such precipitation strengthening was found to particularly cause a yield strength to be greatly increased, thereby resulting in an increase in yield ratio." is described.

[0007]

Patent Document 1: Japanese Patent No. 4305216
Patent Document 2: Japanese Patent No. 4466320
Patent Document 3: International Publication No. WO 2012/133558

SUMMARY OF INVENTION

Technical Problem

[0008] In recent years, a line pipe for transporting crude oil including sour gas or natural gas including sour gas has been increasingly demanded.

[0009] Under such a background, further improvement in the sour resistance (i.e., resistance to sour gas) of a steel pipe for a line pipe may be required.

[0010] A decrease in the yield ratio of a steel pipe for a line pipe is required from the viewpoint of, e.g., suppressing the buckling of a line pipe in the case of laying the line pipe.

[0011] In the technology described in Patent Document 1, however, it may be impossible to decrease a yield ratio. The reason thereof is considered to be because a steel structure mainly includes bainitic ferrite.

[0012] In the technology of Patent Document 2, a step of applying a strain to an uncoiled steel sheet is needed, and therefore, the number of steps is increased, thereby resulting in the possibility of increasing the cost of producing a steel pipe.

[0013] In the technology of Patent Document 3, a decrease in the yield ratio of an electric resistance welded steel pipe by a method other than a method of reducing the amount of Nb may be required.

[0014] An object of the present disclosure is to provide an electric resistance welded steel pipe for a line pipe, which has excellent sour resistance, which has a certain amount of tensile strength and yield strength, which has a decreased yield ratio, and which includes a base metal portion and an electric resistance welded portion thereof having excellent toughness.

Solution to Problem

[0015] Means of solving the problem described above includes the following aspects.

<1> An electric resistance welded steel pipe for a line pipe, the steel pipe comprising a base metal portion and an electric resistance welded portion,
wherein a chemical composition of the base metal portion consists of, in terms of % by mass:

0.030 to less than 0.080% of C,
0.30 to 1.00% of Mn,
0.005 to 0.050% of Ti,
0.010 to 0.100% of Nb,
0.001 to 0.020% of N,
0.010 to 0.450% of Si,
0.0010 to 0.1000% of Al,
0 to 0.030% of P,
0 to 0.0010% of S,
0 to 0.50% of Mo,
0 to 1.00% of Cu,
0 to 1.00% of Ni,
0 to 1.00% of Cr,
0 to 0.100% of V,
0 to 0.0100% of Ca,
0 to 0.0100% of Mg,
0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:
CNeq, expressed by the following Formula (1), is from 0.190 to 0.320,
a ratio of % by mass of Mn to % by mass of Si is 2.0 or more,
LR, expressed by the following Formula (2), is 0.210 or more,
in a case in which a metallographic microstructure of the base metal portion is observed using a scanning electron microscope at a magnification of 1,000 times, an areal ratio of a first phase that is ferrite is from 40 to 80%, and a second phase, which is the balance, comprises tempered bainite,
a yield strength in a pipe axis direction is from 390 to 562 MPa,
a tensile strength in the pipe axis direction is from 520 to 690 MPa,
a yield ratio in the pipe axis direction is 93% or less,
a Charpy absorbed energy in a circumferential direction of the pipe in the base metal portion is 100 J or more at 0°C, and
a Charpy absorbed energy in the circumferential direction of the pipe in the electric resistance welded portion is 80 J or more at 0°C;

$$CNeq = C + Mn/6 + Cr/5 + (Ni + Cu)/15 + Nb + Mo + V \qquad \text{Formula (1)}$$

$$LR = (2.1 \times C + Nb)/Mn \quad \text{Formula (2)}$$

wherein, in Formula (1) and Formula (2), C, Mn, Cr, Ni, Cu, Nb, Mo, and V represent % by mass of respective elements.

<2> The electric resistance welded steel pipe for a line pipe according to <1>,
wherein the chemical composition of the base metal portion comprises, in terms of % by mass, one or more of:

more than 0% but equal to or less than 0.50% of Mo,
more than 0% but equal to or less than 1.00% of Cu,
more than 0% but equal to or less than 1.00% of Ni,
more than 0% but equal to or less than 1.00% of Cr,
more than 0% but equal to or less than 0.100% of V,
more than 0% but equal to or less than 0.0100% of Ca,
more than 0% but equal to or less than 0.0100% of Mg, or
more than 0% but equal to or less than 0.0100% of REM.

<3> The electric resistance welded steel pipe for a line pipe according to <1> or <2>, wherein an areal ratio of a

precipitate having an equivalent circle diameter of 100 nm or less is from 0.100 to 1.000% in a case in which the metallographic microstructure of the base metal portion is observed using a transmission electron microscope at a magnification of 100,000 times.

<4> The electric resistance welded steel pipe for a line pipe according to any one of <1> to <3>, wherein a content of Nb in the chemical composition of the base metal portion is, in terms of % by mass, 0.020% or more.

<5> The electric resistance welded steel pipe for a line pipe according to any one of <1> to <4>, wherein the electric resistance welded steel pipe for a line pipe has a wall thickness of from 10 to 25 mm and an outer diameter of from 114.3 to 609.6 mm.

<6> The electric resistance welded steel pipe for a line pipe according to any one of <1> to <5>, wherein, in a case in which a hydrogen-induced cracking test is conducted on a specimen sampled from the base metal portion, CLR, which is a percentage of a total length of a crack with respect to a length of the specimen, is 8% or less.

Advantageous Effects of Invention

[0016] According to the present disclosure, an electric resistance welded steel pipe for a line pipe, which has excellent sour resistance, which has a certain amount of tensile strength and yield strength, which has a decreased yield ratio, and which includes a base metal portion and an electric resistance welded portion thereof having excellent toughness, can be provided.

BRIEF DESCRIPTION OF DRAWINGS

[0017] Fig. 1 is a scanning electron micrograph showing an example of the metallographic microstructure of a base metal portion in the present disclosure.

DESCRIPTION OF EMBODIMENTS

[0018] A numerical range expressed by "x to y" herein includes the values of x and y in the range as the minimum and maximum values, respectively.

[0019] The content of a component (element) expressed by "%" herein means "% by mass".

[0020] The content of C (carbon) may be herein occasionally expressed as "C content". The content of another element may be expressed similarly.

[0021] The term "step" herein encompasses not only an independent step but also a step of which the desired object is achieved even in a case in which the step is incapable of being definitely distinguished from another step.

[0022] An electric resistance welded steel pipe for a line pipe of the present disclosure (hereinafter also simply referred to as "electric resistance welded steel pipe") includes a base metal portion and an electric resistance welded portion, wherein the chemical composition of the base metal portion consists of, in terms of % by mass: 0.030 to less than 0.080% of C, 0.30 to 1.00% of Mn, 0.005 to 0.050% of Ti, 0.010 to 0.100% of Nb, 0.001 to 0.020% of N, 0.010 to 0.450% of Si, 0.0010 to 0.1000% of Al, 0 to 0.030% of P, 0 to 0.0010% of S, 0 to 0.50% of Mo, 0 to 1.00% of Cu, 0 to 1.00% of Ni, 0 to 1.00% of Cr, 0 to 0.100% of V, 0 to 0.0100% of Ca, 0 to 0.0100% of Mg, 0 to 0.0100% of REM, and the balance being Fe and impurities, wherein: CNeq, expressed by the following Formula (1), is from 0.190 to 0.320, a ratio of % by mass of Mn to % by mass of Si (hereinafter also referred to as "Mn/Si ratio") is 2.0 or more, LR, expressed by the following Formula (2), is 0.210 or more, in a case in which the metallographic microstructure of the base metal portion is observed using a scanning electron microscope at a magnification of 1,000 times, an areal ratio of a first phase that is ferrite (hereinafter also referred to as "ferrite fraction") is from 40 to 80%, and a second phase, which is the balance, includes tempered bainite, a yield strength in a pipe axis direction (hereinafter also referred to as "YS") is from 390 to 562 MPa, a tensile strength in the pipe axis direction (hereinafter also referred to as "TS") is from 520 to 690 MPa, a yield ratio in the pipe axis direction (hereinafter also referred to as "YR") is 93% or less, a Charpy absorbed energy in a circumferential direction of the pipe in the base metal portion is 100 J or more at 0°C, and a Charpy absorbed energy in the circumferential direction of the pipe in the electric resistance welded portion is 80 J or more at 0°C;

$$\mathrm{CNeq} = \mathrm{C} + \mathrm{Mn}/6 + \mathrm{Cr}/5 + (\mathrm{Ni} + \mathrm{Cu})/15 + \mathrm{Nb} + \mathrm{Mo} + \mathrm{V} \qquad \text{Formula (1)}$$

$$\mathrm{LR} = (2.1 \times \mathrm{C} + \mathrm{Nb})/\mathrm{Mn} \quad \text{Formula (2)}$$

wherein, in Formula (1) and Formula (2), C, Mn, Cr, Ni, Cu, Nb, Mo, and V represent % by mass of respective elements.

[0023] The electric resistance welded steel pipe of the present disclosure includes the base metal portion and the electric resistance welded portion.

[0024] Commonly, an electric resistance welded steel pipe is produced by forming a hot-rolled steel sheet into a pipe shape (hereinafter also referred to as "roll forming") to thereby make an open pipe, subjecting abutting portions of the obtained open pipe to electric resistance welding to form an electric resistance welded portion, and then, if necessary, subjecting the electric resistance welded portion to seam heat treatment.

[0025] In the electric resistance welded steel pipe of the present disclosure, the base metal portion refers to a portion other than the electric resistance welded portion and a heat affected zone.

[0026] The heat affected zone (hereinafter also referred to as "HAZ") refers to a portion affected by heat caused by electric resistance welding (affected by heat caused by the electric resistance welding and seam heat treatment in a case in which the seam heat treatment is performed after the electric resistance welding).

[0027] Herein, the electric resistance welded portion may be simply referred to as "welded portion".

[0028] The electric resistance welded steel pipe of the present disclosure has excellent sour resistance, has a certain amount of YS and TS (i.e., YS and TS in the ranges described above), has YR decreased to 93% or less, and has the excellent toughness of the base metal portion and the electric resistance welded portion.

[0029] In the present disclosure, the excellent toughness means that a Charpy absorbed energy (J) in the circumferential direction of the pipe at 0°C (hereinafter also referred to as "vE") is high.

[0030] Specifically, the electric resistance welded steel pipe of the present disclosure has a vE of 100 J or more in the base metal portion and a vE of 80 J or more in the electric resistance welded portion.

[0031] Herein, "excellent sour resistance" means that resistance to hydrogen-induced cracking (HIC) (hereinafter also referred to as "HIC resistance") is excellent.

[0032] The HIC resistance is evaluated based on CLR (i.e., crack to length ratio) in the case of conducting a hydrogen-induced cracking test (hereinafter also referred to as "HIC test") on a specimen sampled from the base metal portion.

[0033] CLR means the percentage of the total length of cracks with respect to the length of the specimen, i.e., a value determined by the following Formula.

$$\text{CLR (\%)} = (\text{total length of cracks/length of specimen}) \times 100\ (\%)$$

[0034] The HIC test is conducted according to NACE-TM0284.

[0035] Specifically, the specimen sampled from the base metal portion is immersed for 96 hours in a test liquid obtained by saturating 100% of H_2S gas in Solution A (i.e., aqueous solution including 5 mass% of NaCl and 0.5 mass% of glacial acetic acid).

[0036] After the immersion, the above-described CLR (%) is determined by an ultrasonic flaw detection test.

[0037] A lower CLR value means superior HIC resistance (i.e., sour resistance).

[0038] CLR is preferably 8% or less.

[0039] The electric resistance welded steel pipe of the present disclosure has low YR, and is therefore expected to exhibit the effect of being capable of suppressing the buckling of the electric resistance welded steel pipe.

[0040] Examples of a case in which the suppression of the buckling of a steel pipe is demanded include a case in which a steel pipe for a subsea pipeline is laid by reel-lay. In the reel-lay, the steel pipe is produced on land in advance, and the produced steel pipe is spooled on the spool of a barge. The spooled steel pipe is laid on a sea bottom while being unspooled at sea. In the reel-lay, plastic bending is applied to the steel pipe at the time of the spooling or unspooling of the steel pipe, and therefore, the steel pipe may be buckled. The occurrence of the buckling of the steel pipe unavoidably results in the stopping of a laying operation, and the damage caused by the stopping is enormous.

[0041] The buckling of the steel pipe can be suppressed by reducing the YR of the steel pipe.

[0042] Accordingly, the electric resistance welded steel pipe of the present disclosure is expected to exhibit the effect of being capable of suppressing buckling at the time of reel-lay, for example, in the case of being used as an electric resistance welded steel pipe for a subsea pipeline.

[0043] The electric resistance welded steel pipe of the present disclosure has the excellent toughness of the base metal portion and the electric resistance welded portion, and is therefore expected to exhibit the effect of having the excellent property of arresting crack propagation at the time of burst.

[0044] Sour resistance (i.e., CLR), YS, TS, YR, the vE of the base metal portion, and the vE of the electric resistance welded portion as described above are achieved by a combination of the chemical composition (including CNeq, a Mn/Si ratio, and LR) and the metallographic microstructure in the electric resistance welded steel pipe.

[Chemical Composition of Base Metal Portion]

[0045] With regard to the chemical composition of the base metal portion, each component in the chemical composition will be first described below, and CNeq, a Mn/Si ratio, and LR will be subsequently described.

C: 0.030 to less than 0.080%

[0046] C is an element required for improving the work hardenability of steel and achieving the lower YR of the electric resistance welded steel pipe. From the viewpoint of such an effect, a C content is 0.030% or more. The C content is preferably 0.033% or more, and more preferably 0.035% or more.
[0047] In contrast, a C content of less than 0.080% results in improvement in the sour resistance of the base metal portion. Accordingly, the C content is less than 0.080%. The C content is preferably 0.077% or less, and more preferably 0.070% or less.

Mn: 0.30 to 1.00%

[0048] Mn is an element that enhances the hardenability of steel. In addition, Mn is an essential element for detoxification of S.
[0049] A Mn content of less than 0.30% may result in embrittlement due to S and in the deterioration of the toughness of the base metal portion and the electric resistance welded portion. Accordingly, the amount of Mn is 0.30% or more. The amount of Mn is preferably 0.40% or more, and more preferably 0.50% or more.
[0050] In contrast, a Mn content of more than 1.00% may result in generation of coarse MnS in the central portion of the wall thickness and in an increase in the hardness of the central portion of the wall thickness, thereby degrading sour resistance. In addition, a Mn content of more than 1.00% may make it impossible to achieve an LR of 0.210 or more, thereby consequently making it impossible to achieve a YR of 90% or less. Accordingly, the Mn content is 1.00% or less. The Mn content is preferably 0.90% or less, and more preferably 0.85% or less.

Ti: 0.005 to 0.050%

[0051] Ti is an element forming a carbonitride and contributing to crystal grain refining.
[0052] A Ti content is 0.005% or more from the viewpoint of securing the toughness of the base metal portion and the electric resistance welded portion.
[0053] In contrast, a Ti content of more than 0.050% may result in generation of coarse TiN, thereby deteriorating the toughness of the base metal portion and the electric resistance welded portion. Accordingly, the Ti content is 0.050% or less. The Ti content is preferably 0.040% or less, still more preferably 0.030 or less, and particularly preferably 0.025%.

Nb: 0.010 to 0.100%

[0054] Nb is an element contributing to improvement in the toughness of the base metal portion.
[0055] A Nb content is 0.010% or more for improvement in toughness due to rolling in the region of nonrecrystallization temperature. The Nb content is preferably 0.015% or more, and more preferably 0.020% or more.
[0056] In contrast, a Nb content of more than 0.100% results in the deterioration of toughness due to a coarse carbide. Therefore, the Nb content is 0.100% or less. The Nb content is preferably 0.095% or less, and more preferably 0.090% or less.

N: 0.001 to 0.020%

[0057] N is an element that forms a nitride, thereby suppressing the coarsening of crystal grains and consequently improving the toughness of the base metal portion and the electric resistance welded portion. From the viewpoint of such an effect, a N content is 0.001% or more. The N content is preferably 0.003% or more.
[0058] In contrast, a N content of more than 0.020% results in an increase in the amount of generated nitride, thereby deteriorating the toughness of the base metal portion and the electric resistance welded portion. Accordingly, the N content is 0.020% or less. The N content is preferably 0.008% or less.

Si: 0.010 to 0.450%

[0059] Si is an element that functions as a deoxidizer for steel. More specifically, a Si content of 0.010% or more results in suppression of generation of a coarse oxide in the base metal and the welded portion, thereby resulting in improvement in the toughness of the base metal and the welded portion. Accordingly, the Si content is 0.010% or more. The Si content is preferably 0.015% or more, and more preferably 0.020% or more.
[0060] In contrast, a Si content of more than 0.450% may result in generation of an inclusion in the electric resistance welded portion, thereby decreasing a Charpy absorbed energy and deteriorating toughness. Accordingly, the Si content is 0.450% or less. The Si content is preferably 0.400% or less, more preferably 0.350% or less, and particularly preferably

0.300% or less.

Al: 0.001 to 0.100%

[0061] Al is an element that functions as a deoxidizer, similar to Si. More specifically, an Al content of 0.001% or more results in suppression of generation of a coarse oxide in the base metal and the welded portion, thereby resulting in improvement in the toughness of the base metal and the welded portion. Accordingly, the Al content is 0.001% or more. The Al content is preferably 0.010% or more, and more preferably 0.015% or more.
[0062] In contrast, an Al content of more than 0.100% may result in generation of an Al-based oxide during electric resistance welding, thereby deteriorating the toughness of the welded portion. Accordingly, the Al content is 0.100% or less. The Al content is preferably 0.090% or less.

P: 0 to 0.030%

[0063] P is an impurity element. A P content of more than 0.030% may result in segregation in a grain boundary, thereby degrading toughness. Accordingly, the P content is 0.030% or less. The P content is preferably 0.025% or less, more preferably 0.020% or less, and still more preferably 0.010% or less.
[0064] The P content may be 0%. From the viewpoint of reducing a dephosphorization cost, the P content may be more than 0%, and may be 0.001% or more.

S: 0 to 0.0010%

[0065] S is an impurity element. A S content of more than 0.0010% may result in degradation in sour resistance. Accordingly, the S content is 0.0010% or less. The S content is preferably 0.0008% or less.
[0066] The S content may be 0%. From the viewpoint of reducing a desulfurization cost, the S content may be more than 0%, may be 0.0001% or more, and may be 0.0003% or more.

Mo: 0 to 0.50%

[0067] Mo is an optional element. Accordingly, a Mo content may be 0%.
[0068] Mo is an element improving the hardenability of a steel and contributing to the high strength of the steel. From the viewpoint of such an effect, the Mo content may be more than 0%, may be 0.01% or more, and may be 0.03% or more.
[0069] In contrast, a Mo content of more than 0.50% may result in generation of a Mo carbonitride, thereby deteriorating toughness. Accordingly, the Mo content is 0.50% or less. The Mo content is preferably 0.40% or less, more preferably 0.30% or less, still more preferably 0.20% or less, and particularly preferably 0.10% or less.

Cu: 0 to 1.00%

[0070] Cu is an optional element. Accordingly, a Cu content may be 0%.
[0071] Cu is an element that is effective for improving the strength of a base metal. From the viewpoint of such an effect, the Cu content may be more than 0%, may be 0.01% or more, and may be 0.03% or more.
[0072] In contrast, a Cu content of more than 1.00% may result in generation of fine Cu grains, thereby considerably deteriorating toughness. Accordingly, the Cu content is 1.00% or less. The Cu content is preferably 0.80% or less, more preferably 0.70% or less, still more preferably 0.60% or less, and particularly preferably 0.50% or less.

Ni: 0 to 1.00%

[0073] Ni is an optional element. Accordingly, a Ni content may be 0%.
[0074] Ni is an element that contributes to improvement in strength and toughness. From the viewpoint of such an effect, the Ni content may be more than 0%, may be 0.01% or more, and may be 0.05% or more.
[0075] In contrast, a Ni content of more than 1.00% may result in excessively high strength. Accordingly, the Ni content is 1.00% or less. The Ni content is preferably 0.80% or less, more preferably 0.70% or less, and still more preferably 0.60% or less.

Cr: 0 to 1.00%

[0076] Cr is an optional element. Accordingly, a Cr content may be 0%.
[0077] Cr is an element that improves hardenability. From the viewpoint of such an effect, the Cr content may be more

than 0%, may be 0.01% or more, and may be 0.05% or more.

[0078] In contrast, a Cr content of more than 1.00% may result in the deterioration of the toughness of the welded portion due to Cr-based inclusions generated in the electric resistance welded portion. Accordingly, the Cr content is 1.00% or less. The Cr content is preferably 0.80% or less, more preferably 0.70% or less, still more preferably 0.50% or less, and particularly preferably 0.30% or less.

V: 0 to 0.100%

[0079] V is an optional element. Accordingly, a V content may be 0%.

[0080] V is an element that contributes to improvement in toughness. From the viewpoint of such an effect, the V content may be more than 0%, may be 0.005% or more, and may be 0.010% or more.

[0081] In contrast, a V content of more than 0.100% may result in the deterioration of toughness due to a V carbonitride. Accordingly, the V content is 0.100% or less. The V content is preferably 0.080% or less, more preferably 0.070% or less, still more preferably 0.050% or less, and particularly preferably 0.030% or less.

Ca: 0 to 0.0100%

[0082] Ca is an optional element. Accordingly, a Ca content may be 0%.

[0083] Ca is an element controlling a shape of a sulfide-based inclusion and improving low-temperature toughness. From the viewpoint of such an effect, the Ca content may be more than 0%, may be 0.0001% or more, may be 0.0010% or more, may be 0.0030% or more, and may be 0.0050% or more.

[0084] In contrast, a Ca content of more than 0.0100% may result in generation of a large-sized cluster or large-sized inclusion including CaO-CaS, thereby adversely affecting toughness. Accordingly, the Ca content is 0.0100% or less. The Ca content is preferably 0.0090% or less, more preferably 0.0080% or less, and particularly preferably 0.0060% or less.

Mg: 0 to 0.0100%

[0085] Mg is an optional element. Accordingly, a Mg content may be 0%.

[0086] Mg is an element that is effective as a deoxidizer and a desulfurization agent and that particularly forms a fine oxide, thereby contributing to improvement in the toughness of an HAZ (heat affected zone). From the viewpoint of such an effect, the Mg content may be more than 0%, may be 0.0001% or more, may be 0.0010% or more, and may be 0.0020% or more.

[0087] In contrast, a Mg content of more than 0.0100% is prone to cause an oxide to be aggregated or coarsened, thereby resulting in the deterioration of HIC resistance (hydrogen-induced cracking resistance) or the deterioration of the toughness of the base metal or the HAZ. Accordingly, the Mg content is 0.0100% or less. The Mg content is preferably 0.0080% or less.

REM: 0 to 0.0100%

[0088] REM is an optional element. Accordingly, an REM content may be 0%.

[0089] "REM" refers to a rare earth element, i.e., at least one element selected from the group consisting of Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

[0090] REM is an element effective as a deoxidizer or a desulfurization agent. From the viewpoint of such an effect, the REM content may be more than 0%, may be 0.0001% or more, and may be 0.0010% or more.

[0091] In contrast, an REM content of more than 0.0100% may result in generation of a coarse oxide, thereby resulting in the deterioration of HIC resistance or in the deterioration of the toughness of a base metal or HAZ. Accordingly, the REM content is 0.0100% or less. The REM content is preferably 0.0070% or less, and more preferably 0.0050% or less.

[0092] From the viewpoint of obtaining the effects offered by the optional elements described above, the chemical composition of the base metal portion may contain one or more of: more than 0% but equal to or less than 0.50% of Mo, more than 0% but equal to or less than 1.00% of Cu, more than 0% but equal to or less than 1.00% of Ni, more than 0% but equal to or less than 1.00% of Cr, more than 0% but equal to or less than 0.100% of V, more than 0% but equal to or less than 0.0100% of Ca, more than 0% but equal to or less than 0.0100% of Mg, and more than 0% but equal to or less than 0.0100% of REM.

[0093] The more preferred content of each optional element has been described above.

Balance: Fe and Impurities

[0094] In the chemical composition of the base metal portion, the balance excluding each element described above is Fe and impurities.
[0095] The impurities refer to components which are contained in a raw material or mixed into in a production step, and which are not intentionally incorporated into a steel.
[0096] Examples of the impurities include any elements other than the elements described above. Elements as the impurities may be only one kind, or may be two or more kinds.
[0097] Examples of the impurities include O, B, Sb, Sn, W, Co, As, Pb, Bi, and H.
[0098] Among the elements described above, O is preferably controlled to have a content of 0.006% or less.
[0099] For the other elements, typically, Sb, Sn, W, Co, or As may be included in a content of 0.1% or less, Pb or Bi may be included in a content of 0.005% or less, B may be included in a content of 0.0003% or less, H may be included in a content of 0.0004% or less, and the contents of the other elements need not particularly be controlled as long as being in a usual range.

CNeq: 0.190 to 0.320

[0100] In the chemical composition of the base metal portion, CNeq expressed by the following Formula (1) is from 0.190 to 0.320.

$$CNeq = C + Mn/6 + Cr/5 + (Ni+Cu)/15 + Nb + Mo + V \qquad \text{Formula (1)}$$

[0101] [in Formula (1), C, Mn, Cr, Ni, Cu, Nb, Mo, and V represent % by mass of the respective elements, respectively].
[0102] CNeq has a positive correlation with a yield strength.
[0103] CNeq is 0.190 or more from the viewpoint of facilitating achievement of a yield strength of 390 MPa or more. CNeq is preferably 0.200 or more, and more preferably 0.210 or more.
[0104] In contrast, CNeq is 0.320 or less from the viewpoint of facilitating achievement of a yield strength of 562 MPa or less. CNeq is preferably 0.310 or less, and more preferably 0.300 or less.

LR: 0.210 or more

[0105] In the chemical composition of the base metal portion, LR expressed by the following Formula (2) is 0.210 or more.
[0106] In the electric resistance welded steel pipe of the present disclosure, an LR of 0.210 or more may result in achievement of a YR of 93% or less.
[0107] An LR of less than 0.210 may result in a YR of more than 93%. The reason thereof can be considered to be because the amount of precipitate in a steel is decreased, and work hardenability is deteriorated (i.e., TS is decreased).

$$LR = (2.1 \times C + Nb)/Mn \quad \text{Formula (2)}$$

[0108] [in Formula (2), C, Nb, and Mn represent % by mass of the respective elements, respectively] .
[0109] The technological meaning of Formula (2) is as follows.
[0110] The reason why the amounts of C and Nb are arranged in the numerator in Formula (2) can be considered to be that C and Nb form precipitates, thereby improving the work hardenability of a steel (i.e., increasing TS) and consequently decreasing the YR of the steel.
[0111] The reason why the amount of C is multiplied by "2.1" can be considered to be because, regarding the effect of improving work hardenability due to the formation of a precipitate described above, the effect of the inclusion of C is about 2.1 times the effect of the inclusion of Nb.
[0112] The reason why the amount of Mn is arranged in the denominator in Formula (2) is because, although the inclusion of Mn enables a steel to be transformed at relatively low temperature, the inclusion of Mn causes the work hardenability in itself of the steel to be deteriorated (i.e., causes TS to be decreased), thereby increasing the YR of the steel.
[0113] As described above, LR has a positive correlation with the Nb content and the C content, and has a negative correlation with the Mn content.
[0114] In the electric resistance welded steel pipe of the present disclosure, even in a case in which the Nb content is relatively large, for example, more than the Nb content in Patent Document 3 (International Publication No. WO 2012/133558) (from 0.003% to less than 0.02%), LR may be allowed to be 0.210 or more depending on the C content

and the Mn content by allowing LR to satisfy 0.210 or more. In this case, a YR of 93% or less can be achieved.

[0115] In the electric resistance welded steel pipe of the present disclosure, a YR of 93% or less can also be achieved by allowing LR to be 0.210 or more and allowing conditions other than LR to be satisfied, in a case in which the Nb content is less than 0.02%.

[0116] From the viewpoint of further facilitating achievement of a YR of 93% or less, LR is preferably 0.220 or more, and more preferably 0.230 or more.

[0117] The upper limit of LR is not particularly restricted. From the viewpoint of the production suitability of the electric resistance welded steel pipe, LR is preferably 0.600 or less.

Mn/Si Ratio: 2.0 or more

[0118] In the chemical composition of the base metal portion, a Mn/Si ratio (i.e., a Mn/Si ratio which is a ratio of % by mass of Mn to % by mass of Si) is 2.0 or more.

[0119] In the electric resistance welded steel pipe of the present disclosure, a Mn/Si ratio of 2.0 or more results in improvement in the toughness of the welded portion, thereby allowing vE in the welded portion (i.e., a Charpy absorbed energy in the circumferential direction of the pipe at 0°C) to be 80 J or more.

[0120] In a case in which the Mn/Si ratio is less than 2.0, vE may be less than 80 J. The reason thereof can be considered to be because in a case in which the Mn/Si ratio is less than 2.0, a MnSi-based inclusion initiates brittle fracture in the welded portion, whereby toughness is deteriorated.

[0121] The Mn/Si ratio is preferably 2.1 or more from the viewpoint of further improving the toughness of the welded portion.

[0122] The upper limit of the Mn/Si ratio is not particularly restricted. From the viewpoint of further improving the toughness of the welded portion and the toughness of the base metal portion, the Mn/Si ratio is preferably 50 or less.

[Metallographic Microstructure of Base Metal Portion]

[0123] In the electric resistance welded steel pipe of the present disclosure, the metallographic microstructure of the base metal portion has a ferrite fraction (i.e., an areal ratio of a first phase that is ferrite) of from 40 to 80% and includes a second phase, which is a balance, including tempered bainite in a case in which the metallographic microstructure is observed using a scanning electron microscope at a magnification of 1,000 times.

[0124] In the electric resistance welded steel pipe of the present disclosure, a YR of 93 % or less can be achieved by allowing a ferrite fraction to be 40% or more. From the viewpoint of further reducing YR, the ferrite fraction is preferably 45% or more, and more preferably 50% or more.

[0125] In the electric resistance welded steel pipe of the present disclosure, a ferrite fraction of 80% or less results in improvement in sour resistance. From the viewpoint of the improvement in sour resistance, the ferrite fraction is preferably 75% or less.

[0126] In the electric resistance welded steel pipe of the present disclosure, the second phase which is the balance includes tempered bainite.

[0127] The inclusion of tempered bainite in the second phase means that the electric resistance welded steel pipe of the present disclosure is an electric resistance welded steel pipe tempered after pipe-making (i.e., after electric resistance welding (after seam heat treatment in the case of performing the seam heat treatment after the electric resistance welding)).

[0128] The electric resistance welded steel pipe of the present disclosure is an electric resistance welded steel pipe tempered after pipe-making, whereby a YR of 93% or less can be achieved. The reason thereof can be considered to be because YR is decreased by the tempering after the pipe-making. The reason why YR is decreased by the tempering after the pipe-making can be considered to be because YS is decreased by decreasing a dislocation density, and cementites are precipitated on a dislocation, thereby increasing work hardening (i.e., increasing TS).

[0129] Herein, tempered bainite is distinguished from bainite which is not tempered bainite, in view of including granular cementites in the structure of the tempered bainite.

[0130] The concept of "bainite" herein includes bainitic ferrite, granular bainite, upper bainite, and lower bainite.

[0131] The second phase may include tempered bainite, may be a phase consisting of tempered bainite, or may include a structure other than tempered bainite.

[0132] Examples of the structure other than tempered bainite include pearlite.

[0133] The concept of "pearlite" herein also includes pseudo-pearlite.

[0134] The measurement of the ferrite fraction and the identification of the second phase in the metallographic microstructure of the base metal portion are performed by nital-etching a metallographic microstructure at the 1/4 position of a wall thickness in an L cross-section at a base metal 90° position, and observing micrographs of the nital-etched metallographic microstructure (hereinafter also referred to as "metallographic micrographs") with a scanning electron microscope (SEM) at a magnification of 1,000 times. Metallographic micrographs corresponding to ten 1,000-times visual fields (corresponding to an actual cross-sectional area of 0.12 mm^2) are taken. The measurement of the ferrite fraction and the identification of the second phase are performed by performing image processing of the metallographic micrographs that were taken. The image processing is performed using, for example, a small-sized general-purpose image analysis apparatus LUZEX AP manufactured by NIRECO CORPORATION.

[0135] Herein, "base metal 90° position" refers to a position deviating at 90° in the circumferential direction of the pipe from a welded portion, "L cross-section" refers to a cross section parallel to a pipe axis direction and a wall thickness direction, and "1/4 position of wall thickness" refers to a position to which a distance from the outer surface of the electric resistance welded steel pipe is 1/4 of a wall thickness.

[0136] Herein, the pipe axis direction may be referred to as "L-direction".

[0137] Fig. 1 is a scanning electron micrograph (SEM micrograph; a magnification of 1,000 times) showing an example of the metallographic microstructure of a base metal portion in the present disclosure.

[0138] The SEM micrograph in Fig. 1 is one (one visual field) of SEM micrographs used in the measurement of a ferrite fraction and the identification of a second phase in Example 1 described later.

[0139] As shown in Fig. 1, a first phase that is ferrite and a second phase including tempered bainite can be confirmed. In particular, the presence of white points (cementites) reveals that the second phase includes tempered bainite.

[0140] The metallographic microstructure of the base metal portion preferably has an areal ratio (hereinafter also referred to as "specific precipitate areal ratio") of precipitates having an equivalent circle diameter of 100 nm or less (hereinafter also referred to as "specific precipitates") of from 0.100 to 1.000% in a case in which the metallographic microstructure is observed using a transmission electron microscope at a magnification of 100,000 times.

[0141] The specific precipitate areal ratio of 0.100% or more further facilitates achievement of a YR of 93% or less. The reason thereof can be considered to be because the specific precipitates (i.e., precipitates having an equivalent circle diameter of 100 nm or less) contribute to improvement in work hardening characteristic (i.e., an increase in TS), thereby resulting in a decrease in YR.

[0142] In contrast, the specific precipitate areal ratio of 1.000% or less results in suppression of brittle fracture (i.e., excellent toughness of the base metal portion). The specific precipitate areal ratio is preferably 0.900% or less, and more preferably 0.800% or less.

[0143] The specific precipitate areal ratio of from 0.100 to 1.000% can be achieved by performing tempering at a temperature of from 400°C to an Ac1 point after pipe-making.

[0144] In the present disclosure, the precipitate areal ratio (i.e., the areal ratio of precipitates having an equivalent circle diameter of 100 nm or less) is measured by observing a metallographic microstructure at a position of 1/4 of a wall thickness in an L cross-section at a base metal 90° position with a transmission electron microscope (TEM) at a magnification of 100,000 times.

[0145] More specifically, at first, on the basis of a sample taken from the position of 1/4 of the wall thickness in the L cross-section at the base metal 90° position, a replica for TEM observation is produced by SPEED method using an electrolytic solution including 10% by volume of acetylacetone, 1% by volume of tetramethylammonium chloride, and 89% by volume of methyl alcohol. Then, by observing the obtained replica for TEM observation with TEM at a magnification of 100,000 times, TEM images with a field size of 1 μm square, corresponding to ten visual fields, are obtained. The areal ratio of precipitates having an equivalent circle diameter of 100 nm or less with respect to the total area of the obtained TEM image is calculated, and the obtained result is regarded as the specific precipitate areal ratio (%).

[0146] The condition of etching in the SPEED method is set at a condition in which a charge of 10 coulombs is applied at a voltage of -200 mV with respect to a surface area of about 80 square millimeters with the use of a saturated calomel electrode as a reference electrode.

[0147] The specific precipitates (i.e., precipitates having an equivalent circle diameter of 100 nm or less) can be specifically considered to be at least one selected from the group consisting of carbides of metals other than Fe, nitrides of metals other than Fe, and carbonitrides of metals other than Fe.

[0148] Conceivable examples of the metals other than Fe include Ti and Nb. In a case in which the chemical composition contains at least one of V, Mo, or Cr, conceivable examples of the metals other than Fe include at least one of V, Mo, or Cr.

[Yield Strength in Pipe Axis Direction (YS)]

[0149] The electric resistance welded steel pipe of the present disclosure has a yield strength in a pipe axis direction (YS) of from 390 to 562 MPa.

[0150] YS in the pipe axis direction is preferably 410 MPa or more, more preferably 450 MPa or more, still more preferably 470 MPa or more, and particularly preferably 500 MPa or more.

[0151] YS in the pipe axis direction is preferably 550 MPa or less, more preferably 540 MPa or less, and particularly preferably 530 MPa or less.

[0152] A YS in the pipe axis direction of 562 MPa or less can be achieved by performing tempering after pipe-making.

The reason thereof can be considered to be because the tempering after pipe-making results in a decrease in pipe-making strain and dislocation density.

[Tensile Strength in Pipe Axis Direction (TS)]

[0153] The electric resistance welded steel pipe of the present disclosure has a tensile strength in a pipe axis direction (TS) of from 520 to 690 MPa.
[0154] TS in the pipe axis direction is preferably 550 MPa or more, and more preferably 580 MPa or more.
[0155] TS in the pipe axis direction is preferably 680 MPa or less, more preferably 660 MPa or less, and particularly preferably 650 MPa or less.

[Yield Ratio in Pipe Axis Direction]

[0156] The electric resistance welded steel pipe of the present disclosure has a yield ratio in a pipe axis direction (YR = (YS/TS) $\times$ 100) of 93% or less.
[0157] As a result, the buckling of the electric resistance welded steel pipe in laying or the like is suppressed.
[0158] A YR in the pipe axis direction of 93% or less can be achieved by performing tempering after pipe-making. The reason thereof can be considered to be because YS is decreased by decreasing a dislocation density, and because work hardening is increased (i.e., TS is increased) by precipitating cementites on a dislocation.

[Wall Thickness of Electric Resistance Welded Steel Pipe]

[0159] The wall thickness of the electric resistance welded steel pipe of the present disclosure is preferably from 10 to 25 mm.
[0160] A wall thickness of 10 mm or more is advantageous in view of facilitating a decrease in YR by using a strain caused by forming a hot-rolled steel sheet into a pipe shape. The wall thickness is more preferably 12 mm or more.
[0161] A wall thickness of 25 mm or less is advantageous in view of the production suitability of the electric resistance welded steel pipe (specifically, formability in formation of a hot-rolled steel sheet into a pipe shape). The wall thickness is more preferably 20 mm or less.

[Outer Diameter of Electric Resistance Welded Steel Pipe]

[0162] The outer diameter of the electric resistance welded steel pipe of the present disclosure is preferably from 114.3 to 609.6 mm (i.e., from 4.5 to 24 inches).
[0163] An outer diameter of 114.3 mm or more is more preferred as the electric resistance welded steel pipe for a line pipe. The outer diameter is preferably 139.7 mm (i.e., 5.5 inches) or more, and more preferably 177.8 mm (i.e., 7 inches) or more.
[0164] An outer diameter of 609.6 mm or less is advantageous in view of facilitating a decrease in YR by using a strain caused by forming a hot-rolled steel sheet into a pipe shape. The outer diameter is preferably 406.4 mm (i.e., 16 inches) or less, and more preferably 304.8 mm (i.e., 12 inches) or less.

[One Example of Production Method]

[0165] One example of a method of producing an electric resistance welded steel pipe of the present disclosure is the following production method A.
[0166] The production method A includes:

a step of producing an as-rolled electric resistance welded steel pipe by using a hot-rolled steel sheet having the chemical composition described above, and
a tempering step of obtaining an electric resistance welded steel pipe by tempering the as-rolled electric resistance welded steel pipe.

[0167] According to the production method A, the inclusion of the tempering step facilitates the production of an electric resistance welded steel pipe having a YR of 93% or less by the reasons described above.
[0168] A tempering temperature (i.e., a retention temperature in the tempering) is preferably from 400°C to an Ac1 point.
[0169] A tempering temperature of 400°C or more further facilitates precipitation of cementite and a specific precipitate (precipitate having an equivalent circle diameter of 100 nm or less), and therefore further facilitates achievement of a YR of 93% or less. The tempering temperature is more preferably 420°C or more.

[0170] A tempering temperature of an Ac1 point or less results in suppression of coarsening of a metallographic microstructure, as a result of which toughness is improved. Although tempering temperature depends on the Ac1 point of a steel, it is also preferably 720°C or less, also preferably 710°C or less, and also preferably 700°C or less.
[0171] The Ac1 point means a temperature at which transformation to austenite is started in the case of increasing the temperature of a steel.
[0172] The Ac1 point is calculated by the following formula:

$$\text{Ac1 point (°C)} = 750.8 - 26.6\,\text{C} + 17.6\,\text{Si} - 11.6\,\text{Mn} - 22.9\,\text{Cu} - 23\,\text{Ni} + 24.1\,\text{Cr} + 22.5\,\text{Mo} - 39.7\,\text{V} - 5.7\,\text{Ti} + 232.4\,\text{Nb} - 169.4\,\text{Al}$$

[0173] [where C, Si, Mn, Ni, Cu, Cr, Mo, V, Ti, Nb, and Al represent % by mass of the respective elements, respectively. Ni, Cu, Cr, Mo, and V are optional elements. Among the optional elements, an element that is not contained in a slab is set at 0% by mass, and the Ac1 point is calculated.]
[0174] A tempering time (i.e., a retention time at the tempering temperature) in the tempering step is preferably 5 minutes or more from the viewpoint of facilitating a more decrease in YR due to precipitation of cementite and a specific precipitate.
[0175] In the production method A, the as-rolled electric resistance welded steel pipe refers to an electric resistance welded steel pipe which is produced by roll-forming (i.e., forming into a pipe shape) a hot-rolled steel sheet, and which is not subjected to heat treatment other than seam heat treatment after the roll-forming.
[0176] A preferred aspect of the step of producing the as-rolled electric resistance welded steel pipe in the production method A will be described later.
[0177] The production method A preferably includes a sizer step of adjusting the shape of the as-rolled electric resistance welded steel pipe by a sizer under a condition in which the change in ovality before and after adjustment (hereinafter also referred to as "change in ovality (%) by sizer step") is 1.0% or more, between the step of producing an as-rolled electric resistance welded steel pipe and the tempering step.
[0178] In a case in which the production method A includes the sizer step, the electric resistance welded steel pipe having the specific precipitate areal ratio of from 0.100 to 1.000% described above can be more easily produced.
[0179] The reason thereof can be considered to be because a dislocation of which the amount is equal to or more than a certain amount is introduced into the as-rolled electric resistance welded steel pipe by the sizer step under the condition in which the change in ovality by sizer step is 1.0% or more, and the as-rolled electric resistance welded steel pipe is then tempered at a temperature of from 400°C to an Ac1 point, thereby facilitating precipitation of fine specific precipitates on the dislocation.
[0180] The ovality of the as-rolled electric resistance welded steel pipe is determined as described below.
[0181] First, four measurement values are obtained by measuring the outer diameter of the as-rolled electric resistance welded steel pipe in the circumferential direction of the pipe with a 45° pitch. Each of the maximum value, minimum value, and average value of the four measurement values is determined. The ovality of the as-rolled electric resistance welded steel pipe is determined by the following formula on the basis of the maximum value, the minimum value, and the average value.

$$\text{Ovality of as-rolled electric resistance welded steel pipe} = (\text{maximum value} - \text{minimum value})/\text{average value}$$

[0182] The change in ovality (%) by sizer step is determined by the following formula on the basis of the ovality of the as-rolled electric resistance welded steel pipe before the adjustment of the shape by the sizer and the ovality of the as-rolled electric resistance welded steel pipe after the adjustment of the shape by the sizer.

$$\text{Change in ovality (\%) before and after sizer step} = (|\text{ovality of as-rolled electric resistance welded steel pipe after adjustment of shape by sizer} - \text{ovality of as-rolled electric resistance welded steel pipe before adjustment of shape by sizer}|/\text{ovality of as-rolled electric resistance welded steel pipe before adjustment of shape by sizer}) \times 100$$

[0183] The step of producing an as-rolled electric resistance welded steel pipe in the production method A preferably includes:

a hot-rolling step of heating a slab having the chemical composition described above and hot-rolling the heated slab, thereby obtaining a hot-rolled steel sheet,
a cooling step of cooling the hot-rolled steel sheet obtained in the hot-rolling step,
a coiling step of coiling the hot-rolled steel sheet cooled in the cooling step, thereby obtaining a hot coil consisting of the hot-rolled steel sheet, and
a pipe-making step of uncoiling the hot-rolled steel sheet from the hot coil, roll-forming the uncoiled hot-rolled steel sheet to thereby make an open pipe, and subjecting abutting portions of the obtained open pipe to electric resistance welding to form an electric resistance welded portion, thereby obtaining an as-rolled electric resistance welded steel pipe.

[0184] In the pipe-making step, the electric resistance welded portion may be subjected to seam heat treatment after the electric resistance welding, if necessary.
[0185] In the hot-rolling step, the slab having the chemical composition described above is preferably heated to a temperature of from 1150°C to 1350°C.
[0186] In a case in which the temperature to which the slab is heated is 1150°C or more, the toughness of the base metal portion of the electric resistance welded steel pipe can be further improved. The reason thereof can be considered to be because generation of an insoluble Nb carbide can be suppressed in a case in which the temperature to which the slab is heated is 1150°C or more.
[0187] In a case in which the temperature to which the slab is heated is 1350°C or less, the toughness of the base metal portion of the electric resistance welded steel pipe can be further improved. The reason thereof can be considered to be because coarsening of a metallographic microstructure can be suppressed in a case in which the temperature to which the slab is heated is 1350°C or less.
[0188] In the hot rolling step, the slab heated, for example, to a temperature of 1150°C to 1350°C is preferably hot-rolled at a temperature that is equal to or more than Ar3 point + 100°C. As a result, the hardenability of the hot-rolled steel sheet can be improved. As a result, the sour resistance of the finally obtained electric resistance welded steel pipe (i.e., the tempered electric resistance welded steel pipe) can be improved.
[0189] The Ar3 point is determined from the chemical composition of the base metal portion by the following formula:

$$\mathrm{Ar3}\ (^\circ\mathrm{C}) = 910 - 310\ \mathrm{C} - 80\ \mathrm{Mn} - 55\ \mathrm{Ni} - 20\ \mathrm{Cu} - 15\ \mathrm{Cr} - 80\ \mathrm{Mo}$$

[where C, Mn, Ni, Cu, Cr, and Mo represent % by mass of the respective elements, respectively. Ni, Cu, Cr, and Mo are optional elements. Among the optional elements, an element that is not contained in the slab is set at 0% by mass, and the Ar3 point is calculated.]
[0190] The cooling step is a step of cooling the hot-rolled steel sheet obtained in the hot-rolling step.
[0191] In the cooling step, the hot-rolled steel sheet obtained in the hot-rolling step is preferably cooled at a cooling start temperature set at the Ar3 point or more. As a result, the strength and toughness of the base metal portion can be further improved. The reason thereof can be considered to be because generation of coarse ferrite is suppressed by setting the cooling start temperature at the Ar3 point or more.
[0192] The cooling in the cooling step is preferably started within ten seconds after the end of the rolling in the hot-rolling step (i.e., after the end of the final rolling in the hot-rolling step). As a result, the ferrite fraction of the finally obtained electric resistance welded steel pipe is easily adjusted to 80% or less.
[0193] In the cooling step, the hot-rolled steel sheet obtained in the hot-rolling step is preferably cooled at a cooling rate of from 5°C/s to 80°C/s.
[0194] In a case in which the cooling rate is 5°C/s or more, the degradation of the toughness of the base metal portion is further suppressed. The reason thereof can be considered to be because generation of coarse ferrite is suppressed by setting the cooling rate in the cooling step at 5°C/s or more.
[0195] In a case in which the cooling rate is 80°C/s or less, the degradation of the toughness of the base metal portion is suppressed. The reason thereof can be considered to be because an excessive second phase fraction (i.e., a ferrite fraction of less than 40%) is suppressed by setting the cooling rate in the cooling step at 80°C/s or less.
[0196] In the coiling step, the hot-rolled steel sheet cooled in the cooling step is preferably coiled at a coiling temperature of from 450 to 650°C.
[0197] A coiling temperature of 450°C or more results in suppression of the degradation of the toughness of the base metal portion. The reason thereof can be considered to be because a coiling temperature of 450°C or more results in suppression of generation of martensite.
[0198] A coiling temperature of 650°C or less may result in suppression of an increase in YR. The reason thereof can be considered to be because a coiling temperature of 650°C or less results in suppression of excessive generation of a Nb carbonitride, thereby resulting in suppression of an increase in YS.

EXAMPLES

[0199] Examples of the present disclosure will be described below. However, the present disclosure is not limited to the following Examples.

[Examples 1 to 26, and Comparative Examples 1 to 31]

<Production of Hot Coil>

[0200] Slabs having chemical compositions set forth in Table 1 and Table 2 were prepared.
[0201] The slab of Comparative Example 28 (S: 0.0015%) was produced under usual conditions.
[0202] In processes of producing the slabs of Examples 1 to 26, and Comparative Examples 1 to 27 and 29 to 31, the contents of S in the slabs were controlled to 0.0010% or less by using a technology of optimizing the composition of a slag used in smelting and a technology of exchanging the slag in the course of the smelting.
[0203] Each of the slabs was heated to 1250°C, the heated slab was hot-rolled to obtain a hot-rolled steel sheet, the obtained hot-rolled steel sheet was cooled at a cooling rate of 50°C/s, and the cooled hot-rolled steel sheet was coiled at a coiling temperature of 550°C, whereby a hot coil including the hot-rolled steel sheet was obtained.
[0204] Times from the end of final rolling to the start of the cooling in the hot rolling were set at times set forth in Table 3.
[0205] In each Example and each Comparative Example, the balance excluding the elements set forth in Table 1 and Table 2 is Fe and impurities.
[0206] In Table 2, REM in Examples 18 and 19 is Ce, REM in Examples 23 and 24 is Nd, and REM in Example 25 is La.
[0207] In Table 1 to Table 3, the underlined numerical values show numerical values that fall outside the scope of the present disclosure.

<Production of As-Rolled Electric Resistance Welded Steel Pipe>

[0208] A hot-rolled steel sheet was uncoiled from the hot coil, the uncoiled hot-rolled steel sheet was roll-formed to thereby make an open pipe, abutting portions of the obtained open pipe was subjected to electric resistance welding to form a welded portion, and the welded portion was then subjected to seam heat treatment, thereby obtaining an as-rolled electric resistance welded steel pipe.

<Production of Electric Resistance Welded Steel Pipe (Sizer and Tempering)>

[0209] The shape of the as-rolled electric resistance welded steel pipe was adjusted by a sizer under conditions achieving each of changes in ovality (%) by sizer step set forth in Table 3.
[0210] The as-rolled electric resistance welded steel pipe of which the shape had been adjusted was tempered at each tempering temperature and for each tempering time set forth in Table 3, thereby obtaining an electric resistance welded steel pipe.
[0211] The outer diameter of the obtained electric resistance welded steel pipe was 219 mm, and the wall thickness of this electric resistance welded steel pipe was 15.9 mm.
[0212] The above production step does not affect the chemical composition of a steel. Accordingly, the chemical composition of the base metal portion of the obtained electric resistance welded steel pipe can be considered to be the same as the chemical composition of the slab which is a raw material.

<Measurement>

[0213] The following measurement was performed for the obtained electric resistance welded steel pipe.
[0214] The results are set forth in Table 3.

(Measurement of Ferrite Fraction and Confirmation of Structure of Second Phase)

[0215] By the method described above, the ferrite fraction was measured, and the kind of a second phase was confirmed.
[0216] In Table 3, TB means tempered bainite, and P means pearlite.

(Measurement of YS, TS, and YR)

[0217] A specimen for a tensile test was sampled in a direction where the test direction (tensile direction) in a tensile test corresponds to the pipe axis direction (hereinafter also referred to as "L-direction") of the electric resistance welded steel pipe from the base metal 90° position of the electric resistance welded steel pipe. The shape of the specimen was allowed to be a flat plate shape conforming to an American Petroleum Institute standard API 5L (hereinafter simply referred to as "API 5L").

[0218] A tensile test in which a test direction was the L-direction of the electric resistance welded steel pipe was conducted using the sampled specimen in conformity with API 5L at room temperature, and TS in the L-direction of the electric resistance welded steel pipe and YS in the L-direction of the electric resistance welded steel pipe were measured.

[0219] YR (%) in the L-direction of the electric resistance welded steel pipe was determined based on a calculation formula "(YS/TS) × 100".

(Measurement of vE (J) (Charpy Absorbed Energy at 0°C) of Base Metal Portion)

[0220] A full-size specimen with a V-notch (a specimen for a Charpy impact test) was sampled from the base metal 90°C position of the electric resistance welded steel pipe. The full-size specimen with a V-notch was sampled so that a test direction was the circumferential direction of the pipe (C-direction). The sampled full-size specimen with a V-notch was subjected to a Charpy impact test in conformity with API 5L under a temperature condition of 0°C to measure vE (J).

[0221] The above measurement was performed five times per one electric resistance welded steel pipe, and the average value of five measurement values was regarded as vE (J) of the base metal portion of the electric resistance welded steel pipe.

(Measurement of vE (J) (Charpy Absorbed Energy at 0°C) of Welded Portion)

[0222] The same operation as the measurement of vE (J) of the base metal portion was performed except that a position from which a full-size specimen with a V-notch was sampled was changed to the welded portion of the electric resistance welded steel pipe.

(Measurement of Specific Precipitate Areal Ratio)

[0223] The specific precipitate areal ratio (i.e., the areal ratio of precipitates having an equivalent circle diameter of 100 nm or less, simply referred to as "precipitate areal ratio (%)"in Table 3) was measured by the method described above.

(CLR (%) in HIC Test; and Sour Resistance)

[0224] An HIC test was conducted according to NACE-TM0284.

[0225] A full thickness specimen for an HIC test was sampled from the base metal 90°C position of the electric resistance welded steel pipe, and the sampled full thickness specimen was immersed for 96 hours in a test liquid obtained by saturating 100% of H_2S gas in Solution A (i.e., aqueous solution including 5 mass% of NaCl and 0.5 mass% of glacial acetic acid). The presence or absence of HIC in the specimen immersed for 96 hours was measured by an ultrasonic flaw detector. Based on this measurement result, CLR (%) was determined by the following formula.

[0226] Lower CLR means superior sour resistance.

$$\text{CLR (\%)} = (\text{total length of cracks/length of specimen}) \times 100\ (\%)$$

[Table 1]

	Component (% by mass)								
	C	Mn	Ti	Nb	N	Si	Al	P	S
Example 1	0.058	0.52	0.049	0.050	0.002	0.057	0.0612	0.007	0.0007
Example 2	0.067	0.66	0.012	0.016	0.002	0.107	0.0979	0.030	0.0009
Example 3	0.067	0.89	0.048	0.089	0.001	0.306	0.0843	0.022	0.0008
Example 4	0.054	0.85	0.030	0.081	0.002	0.070	0.0501	0.002	0.0006
Example 5	0.044	0.70	0.016	0.090	0.001	0.251	0.0255	0.026	0.0006
Example 6	0.065	0.54	0.035	0.053	0.001	0.226	0.0866	0.002	0.0009

(continued)

	Component (% by mass)								
	C	Mn	Ti	Nb	N	Si	Al	P	S
Example 7	0.048	0.50	0.012	0.016	0.001	0.150	0.0448	0.012	0.0006
Example 8	0.030	0.31	0.031	0.030	0.002	0.100	0.0366	0.025	0.0006
Example 9	0.077	0.43	0.019	0.088	0.002	0.203	0.0318	0.010	0.0008
Example 10	0.042	0.64	0.047	0.095	0.002	0.117	0.0806	0.004	0.0007
Example 11	0.060	0.76	0.036	0.055	0.002	0.307	0.0742	0.024	0.0005
Example 12	0.031	0.58	0.015	0.062	0.002	0.064	0.0490	0.005	0.0009
Example 13	0.057	0.62	0.034	0.023	0.002	0.177	0.0158	0.029	0.0008
Example 14	0.045	0.54	0.032	0.073	0.001	0.205	0.0479	0.006	0.0006
Example 15	0.033	0.37	0.037	0.077	0.001	0.075	0.0806	0.024	0.0006
Example 16	0.065	0.66	0.035	0.044	0.001	0.068	0.0352	0.019	0.0006
Example 17	0.041	0.62	0.014	0.071	0.001	0.232	0.0300	0.021	0.0006
Example 18	0.064	0.61	0.014	0.045	0.001	0.190	0.0085	0.017	0.0007
Example 19	0.069	0.77	0.027	0.059	0.002	0.078	0.0136	0.021	0.0009
Example 20	0.048	0.61	0.013	0.041	0.001	0.018	0.0399	0.025	0.0009
Example 21	0.062	0.35	0.049	0.043	0.002	0.100	0.0120	0.017	0.0009
Example 22	0.051	0.55	0.016	0,017	0.002	0.221	0.0856	0.030	0.0006
Example 23	0.064	0.72	0.035	0.031	0.001	0.282	0.0295	0.012	0.0006
Example 24	0.065	0.47	0.043	0.032	0.002	0.152	0.0637	0.027	0.0009
Example 25	0.037	0.48	0.047	0.033	0.001	0.219	0.0692	0.007	0.0008
Example 26	0.064	0.62	0.014	0.023	0.002	0.282	0.0120	0.007	0.0006
Comparative Example 1	0.090	0.60	0.032	0.083	0.001	0.090	0.0219	0.002	0.0005
Comparative Example 2	0.020	0.60	0.046	0.095	0.001	0.030	0.0446	0.018	0.0007
Comparative Example 3	0.060	1.00	0.024	0.090	0.002	0.480	0.0336	0.007	0.0009
Comparative Example 4	0.045	0.65	0.041	0.092	0.002	0.005	0.0214	0.012	0.0005
Comparative Example 5	0.076	0.20	0.037	0.090	0.002	0.100	0.0086	0.016	0.0009
Comparative Example 6	0.075	1.10	0.035	0.060	0.002	0.199	0.0718	0.021	0.0006
Comparative Example 7	0.052	0.35	0.001	0.096	0.002	0.075	0.0909	0.006	0.0006
Comparative Example 8	0.033	0.65	0.070	0.078	0.001	0.134	0.0156	0.016	0.0008
Comparative Example 9	0.075	0.67	0.029	0.005	0.002	0.136	0.0529	0.004	0.0007
Comparative Example 10	0.030	0.47	0.032	0.110	0.002	0.102	0.0880	0.021	0.0008
Comparative Example 11	0.035	0.46	0.021	0.099	0.002	0.076	0.0005	0.008	0.0009
Comparative Example 12	0.060	0.89	0.047	0.063	0.002	0.367	0.1500	0.017	0.0009
Comparative Example 13	0.070	0.90	0.014	0.080	0.001	0.193	0.0525	0.026	0.0005
Comparative Example 14	0.030	0.30	0.005	0.064	0.001	0.020	0.0736	0.000	0.0008
Comparative Example 15	0.030	1.00	0.030	0.073	0.002	0.225	0.0794	0.000	0.0006
Comparative Example 16	0.074	0.62	0.025	0.013	0.001	0.218	0.0288	0.004	0.0008
Comparative Example 17	0.079	0.55	0.026	0.076	0.001	0.068	0.0351	0.026	0.0006

(continued)

	Component (% by mass)								
	C	Mn	Ti	Nb	N	Si	Al	P	S
Comparative Example 18	0.055	0.73	0.045	0.061	0.002	0.158	0.0513	0.023	0.0005
Comparative Example 19	0.052	0.87	0.041	0.080	0.002	0.272	0.0546	0.013	0.0009
Comparative Example 20	0.072	0.65	0.009	0.088	0.002	0.101	0.0644	0.004	0.0005
Comparative Example 21	0.052	0.91	0.019	0.087	0.001	0.249	0.0626	0.022	0.0007
Comparative Example 22	0.074	0.92	0.007	0.056	<u>0.0005</u>	0.274	0.0809	0.007	0.0008
Comparative Example 23	0.074	0.92	0.007	0.056	<u>0.030</u>	0.274	0.0809	0.007	0.0009
Comparative Example 24	0.058	0.52	0.049	0.050	0.002	0.400	0.0612	0.007	0.0005
Comparative Example 25	0.045	0.54	0.032	0.073	0.001	0.205	0.0479	0.006	0.0009
Comparative Example 26	0.069	0.77	0.027	0.059	0.002	0.078	0.0136	0.021	0.0005
Comparative Example 27	0.077	0.74	0.030	0.055	0.001	0.083	0.0748	0.006	0.0009
Comparative Example 28	0.058	0.52	0.049	0.050	0.002	0.057	0.0612	0.007	<u>0.0015</u>
Comparative Example 29	0.045	0.85	0.032	0.020	0.001	0.219	0.0399	0.024	0.0006
Comparative Example 30	0.040	0.88	0.073	0.020	0.002	0.282	0.0352	0.024	0.0009
Comparative Example 31	0.031	0.78	0.027	0.040	0.001	0.075	0.0806	0.017	0.0006

[Table 2]

	Component (% by mass) (continued from Table 1)								Mn/Si	LR	CNeq	Ac1 (°C)
	Mo	Cu	Ni	Cr	V	Ca	Mg	REM				
Example 1						0.0024			9.1	0.331	0.195	745
Example 2						0.0028			6.2	0.236	0.193	730
Example 3						0.0024			2.9	0.259	0.304	750
Example 4									12.2	0.229	0.277	751
Example 5									2.8	0.261	0.252	762
Example 6						0.0029			2.4	0.352	0.207	744
Example 7	0.11								3.3	0.233	0.253	745
Example 8	0.20								3.1	0.300	0.312	753
Example 9		0.41				0.0021			2.1	0.575	0.264	753
Example 10		0.70				0.0021			5.5	0.289	0.290	736
Example 11			0.16						2.5	0.237	0.252	742
Example 12				0.46		0.0020			9.0	0.220	0.281	761
Example 13				0.63		0.0026			3.5	0.231	0.308	763
Example 14					0.030				2.6	0.311	0.238	755
Example 15					0.073				5.0	0.396	0.244	748
Example 16						0.0051			9.7	0.272	0.218	747
Example 17						0.0044			2.7	0.255	0.215	758
Example 18						0.0023		0.0053	3.2	0.295	0.211	754
Example 19						0.0026		0.0078	9.9	0.264	0.257	753
Example 20	0.02		0.52			0.0022			33.5	0.232	0.246	734
Example 21	0.11				0.023	0.0020			3.5	0.502	0.292	756
Example 22		0.27		0.47					2.5	0.227	0.272	741
Example 23				0.27				0.0052	2.6	0.229	0.270	754
Example 24		0.26				0.0023		0.0094	3.1	0.361	0.193	737

(continued)

	Component (% by mass) (continued from Table 1)								Mn/Si	LR	CNeq	Ac1 (°C)
	Mo	Cu	Ni	Cr	V	Ca	Mg	REM				
Example 25		0.13			0.098	0.0025		0.0088	2.2	0.231	0.257	737
Example 26						0.0027	0.0075		2.2	0.257	0.190	750
Comparative Example 1									6.7	0.456	0.272	758
Comparative Example 2						0.0028			20.0	0.228	0.215	758
Comparative Example 3						0.0025			2.1	0.216	0.317	761
Comparative Example 4									129	0.291	0.245	760
Comparative Example 5						0.0022			2.0	1.246	0.199	767
Comparative Example 6						0.0026			5.5	0.198	0.318	741
Comparative Example 7						0.0028			4.7	0.579	0.206	753
Comparative Example 8						0.0022			4.8	0.228	0.220	760
Comparative Example 9						0.0025			4.9	0.244	0.191	735
Comparative Example 10						0.0020			4.6	0.373	0.218	757
Comparative Example 11						0.0023			6.1	0.374	0.212	769
Comparative Example 12						0.0022			2.4	0.211	0.272	734
Comparative Example 13	0.08								4.7	0.252	0.380	753
Comparative Example 14						0.0022			15.0	0.424	0.144	749
Comparative Example 15						0.0023			4.4	0.136	0.269	746
Comparative Example 16						0.0025			2.8	0.272	0.190	744
Comparative Example 17						0.0021			8.0	0.443	0.246	755
Comparative Example 18									4.6	0.244	0.238	749
Comparative Example 19						0.0030			3.2	0.217	0.277	753
Comparative Example 20									6.5	0.366	0.268	753
Comparative Example 21						0.0022			3.6	0.216	0.290	753
Comparative Example 22						0.0029			3.3	0.232	0.284	742

(continued)

	Component (% by mass) (continued from Table 1)								Mn/Si	LR	CNeq	Ac1 (°C)
	Mo	Cu	Ni	Cr	V	Ca	Mg	REM				
Comparative Example 23						0.0027			3.3	0.232	0.284	742
Comparative Example 24									1.3	0.331	0.195	751
Comparative Example 25					0.030	0.0021			2.6	0.311	0.238	755
Comparative Example 26								0.0078	9.9	0.264	0.257	753
Comparative Example 27		0.58	0.62	0.51	0.051	0.0030			8.9	0.292	0.488	724
Comparative Example 28						0.0022			9.1	0.331	0.195	745
Comparative Example 29									3.9	0.134	0.206	741
Comparative Example 30						0.0020			3.1	0.118	0.207	743
Comparative Example 31						0.0029			10.4	0.135	0.201	738

[Table 3]

	Time(s) from end of rolling to start of cooling	Change in ovality (%) by sizer step	Tempering temp. (°C)	Tempering time (min)	Electric resistance welded steel pipe								
					YR (%)	YS (MPa)	TS (MPa)	vE (J)		F fraction (%)	Kind of second phase	Precipitate areal ratio (%)	CLR (%)
								Base metal portion	Welded portion				
Example 1	6	2.5	520	27	86	477	558	389	339	74	TB	0.800	0
Example 2	4	5.0	540	12	82	482	591	362	308	62	TB+P	0.740	0
Example 3	5	1.1	490	12	82	562	685	358	329	61	TB+P	0.560	2
Example 4	7	1.3	670	24	85	553	652	393	326	62	TB+P	0.380	0
Example 5	5	4.8	580	9	81	525	645	429	399	64	TB+P	0.450	0
Example 6	3	3.7	550	10	81	503	617	376	308	69	TB	0.860	0
Example 7	7	2.1	400	20	81	534	662	414	339	65	TB	0.640	0
Example 8	6	4.3	700	25	82	557	683	410	380	78	TB	0.480	0
Example 9	6	1.2	410	13	80	542	678	339	319	59	TB+P	0.900	2
Example 10	9	2.0	590	7	83	548	657	495	421	64	TB+P	0.110	0
Example 11	4	4.7	540	28	82	536	657	433	399	55	TB+P	0.300	0
Example 12	3	2.4	670	12	84	541	641	420	390	56	TB+P	0.260	0
Example 13	6	4.4	420	15	85	549	648	387	317	44	TB+P	0.840	0
Example 14	7	3.2	610	9	81	515	640	420	400	74	TB	0.860	0
Example 15	4	2.3	460	29	85	505	596	410	390	75	TB	0.340	0
Example 16	5	3.0	600	11	83	496	595	333	313	59	TB+P	0.340	0
Example 17	4	3.4	420	30	81	487	598	472	392	74	TB	0.310	0
Example 18	7	2.0	690	6	84	484	580	386	309	66	TB+P	0.860	0
Example 19	5	4.7	690	23	84	536	635	318	255	64	TB+P	0.360	0
Example 20	9	3.1	715	10	85	511	603	469	399	67	TB+P	0.470	0
Example 21	6	4.8	440	12	82	543	663	382	344	72	TB	0.910	0
Example 22	5	4.3	590	24	82	536	655	437	354	49	TB+P	0.900	0

(continued)

	Time(s) from end of rolling to start of cooling	Change in ovality (%) by sizer step	Tempering temp. (°C)	Tempering time (min)	Electric resistance welded steel pipe								
					YR (%)	YS (MPa)	TS (MPa)	vE (J)		F fraction (%)	Kind of second phase	Precipitate areal ratio (%)	CLR (%)
								Base metal portion	Welded portion				
Example 23	6	1.5	410	23	82	525	642	360	288	51	TB+P	0.480	0
Example 24	4	2.8	600	6	83	484	580	369	306	68	TB+P	0.590	0
Example 25	9	3.3	600	20	82	526	643	420	499	70	TB	0.460	0
Example 26	8	3.5	650	20	81	480	595	354	330	65	TB	0.350	0
Comparative Example 1	4	4.9	680	27	86	533	618	219	188	58	TB+P	0.820	15
Comparative Example 2	8	2.2	630	11	<u>94</u>	510	543	619	557	71	TB	0.120	0
Comparative Example 3	5	1.4	410	20	82	554	679	351	<u>10</u>	56	TB+P	0.570	0
Comparative Example 4	3	1.8	590	26	81	530	651	<u>10</u>	<u>10</u>	71	TB	0.490	0
Comparative Example	8	2.2	660	19	81	476	588	15	<u>12</u>	79	TB	0.670	3
Comparative Example 6	7	3.3	510	15	84	559	661	<u>12</u>	<u>9</u>	53	TB+P	0.760	12
Comparative Example 7	4	3.0	750	7	83	495	596	<u>17</u>	446	70	TB	0.860	0
Comparative Example 8	7	2.5	640	22	85	495	583	<u>13</u>	<u>15</u>	73	TB	0.600	0
Comparative Example 9	5	1.8	740	22	82	478	579	<u>11</u>	368	59	TB+P	0.590	1
Comparative Example	9	1.3	490	19	84	496	588	<u>15</u>	430	73	TB	0.850	15

(continued)

	Time(s) from end of rolling to start of cooling	Change in ovality (%) by sizer step	Tempering temp. (°C)	Tempering time (min)	Electric resistance welded steel pipe								
					YR (%)	YS (MPa)	TS (MPa)	vE (J)		F fraction (%)	Kind of second phase	Precipitate areal ratio (%)	CLR (%)
								Base metal portion	Welded portion				
Comparative Example	5	4.0	710	27	83	481	576	12	10	80	TB	0.640	0
Comparative Example	5	3.1	610	12	86	539	624	12	15	53	TB+P	0.410	0
Comparative Example 13	7	3.4	640	16	91	603	663	344	320	49	TB+P	0.240	2
Comparative Example 14	7	1.3	650	25	95	440	465	460	450	84	TB	0.630	15
Comparative Example 15	3	4.6	500	14	95	520	547	531	478	56	TB+P	0.320	0
Comparative Example 16	9	2.0	350	6	95	486	510	315	286	62	TB+P	0.002	0
Comparative Example 17	7	4.8	780	7	85	529	621	10	274	65	TB+P	0.280	5
Comparative Example 18	8	0.1	700	9	94	517	550	443	364	63	TB+P	0.080	0
Comparative Example 19	5	0.2	660	16	95	548	577	456	374	61	TB+P	0.004	0
Comparative Example 20	7	0.2	500	19	94	549	584	353	293	61	TB+P	0.015	0
Comparative Example 21	4	0.1	420	15	96	549	572	477	415	63	TB+P	0.075	0
Comparative Example 22	5	1.4	400	23	91	555	610	15	14	57	TB+P	0.590	0
Comparative Example 23	8	4.1	670	19	91	539	592	18	16	53	TB+P	0.760	0

(continued)

	Time(s) from end of rolling to start of cooling	Change in ovality (%) by sizer step	Tempering temp. (°C)	Tempering time (min)	Electric resistance welded steel pipe								
					YR (%)	YS (MPa)	TS (MPa)	vE (J)		F fraction (%)	Kind of second phase	Precipitate areal ratio (%)	CLR (%)
								Base metal portion	Welded portion				
Comparative Example 24	4	1.9	710	18	81	497	617	380	<u>10</u>	65	TB	0.830	0
Comparative Example 25	15	3.2	610	30	81	515	640	450	420	<u>90</u>	TB	0.860	15
Comparative Example 26	5	4.7	690	3	<u>95</u>	536	565	318	255	64	TB+P	0.050	0
Comparative Example 27	8	2.3	610	15	82	<u>677</u>	<u>821</u>	318	320	40	TB	0.830	0
Comparative Example 28	6	2.5	520	15	84	470	560	390	320	72	TB	0.750	18
Comparative Example 29	8	3.5	650	10	<u>95</u>	480	<u>505</u>	350	330	75	TB	0.470	0
Comparative Example 30	5	4.7	600	15	<u>96</u>	490	<u>510</u>	380	380	67	TB	0.480	0
Comparative Example 31	4	4.1	615	16	<u>95</u>	475	<u>501</u>	360	315	68	TB	0.460	0

[0227] As set forth in Table 1 to Table 3, it is found that the electric resistance welded steel pipe of each Example has excellent sour resistance, has a certain amount of tensile strength and yield strength, has a decreased yield ratio, and has the excellent toughness of a base metal portion and a welded portion.

[0228] In contrast to each Example, the results of each Comparative Example were as follows.

[0229] Comparative Example 1 in which a C content was more than the upper limit resulted in the deterioration of sour resistance.

[0230] Comparative Example 2 in which a C content was less than the lower limit resulted in an increase in YR. The reason thereof can be considered to be because the work hardenability of steel was deteriorated.

[0231] Comparative Example 3 in which a Si content was more than the upper limit resulted in the deterioration of the toughness of a welded portion.

[0232] Comparative Example 4 in which a Si content was less than the lower limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because deoxidization became insufficient, thereby generating a coarse oxide.

[0233] Comparative Example 5 in which a Mn content was less than the lower limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because embrittlement due to S occurred.

[0234] Comparative Example 6 in which a Mn content was more than the upper limit resulted in the deterioration of the toughness of a base metal portion and a welded portion and in the deterioration of sour resistance. The reason thereof can be considered to be because cracking due to MnS occurred.

[0235] Comparative Example 7 in which a Ti content was less than the lower limit resulted in the deterioration of the toughness of a base metal portion. The reason thereof can be considered to be because a crystal grain became coarse.

[0236] Comparative Example 8 in which a Ti content was more than the upper limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because coarse TiN was generated.

[0237] Comparative Example 9 in which Nb was less than the lower limit resulted in the deterioration of the toughness of a base metal portion. The reason thereof can be considered to be because rolling in the region of nonrecrystallization temperature became insufficient.

[0238] Comparative Example 10 in which Nb was more than the upper limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because a coarse Nb carbonitride was generated.

[0239] Comparative Example 11 in which Al was less than the lower limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because deoxidization became insufficient.

[0240] Comparative Example 12 in which Al was more than the upper limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because a large amount of Al-based inclusion was generated.

[0241] In Comparative Example 13 in which CNeq was more than the upper limit, YS was more than the upper limit.

[0242] In Comparative Example 14 in which CNeq was less than the lower limit, TS was less than the lower limit.

[0243] In Comparative Example 15 in which LR was less than 0.210, YR was more than the upper limit.

[0244] In Comparative Example 16, TS was less than the lower limit, and YR was more than the upper limit. The reason thereof can be considered to be because a tempering temperature was too low, thereby resulting in the insufficient effect of reducing a pipe-making strain by tempering (i.e., the effect of reducing a dislocation density) and in insufficient precipitation on a dislocation.

[0245] In Comparative Example 17, the toughness of a base metal portion was deteriorated (i.e., the base metal portion showed vE less than the lower limit). The reason thereof can be considered to be because a tempering temperature was too high, transformation to austenite therefore occurred, a metallographic microstructure was coarsened, and the toughness of the base metal portion was deteriorated.

[0246] In each of Comparative Examples 18 to 21, YR was more than the upper limit. The reason thereof can be considered to be because a change in ovality by sizer step was small, and therefore, neither the introduction of a sufficient dislocation nor the precipitation on the dislocation occurred.

[0247] Comparative Example 22 in which a N content was less than the lower limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because crystal grains became coarse.

[0248] Comparative Example 23 in which a N content was more than the upper limit resulted in the deterioration of the toughness of a base metal portion and a welded portion. The reason thereof can be considered to be because the amount of generated nitride was increased.

[0249] Comparative Example 24 in which a Mn/Si ratio was less than the lower limit resulted in the deterioration of the toughness of a welded portion.

[0250] Comparative Example 25 in which a ferrite fraction was more than the upper limit resulted in the deterioration of sour resistance.

[0251] In Comparative Example 26, YR was more than the upper limit. The reason thereof can be considered to be because a tempering time was short, thereby resulting in the insufficient effect of reducing a pipe-making strain by tempering (i.e., the effect of reducing a dislocation density) and in insufficient precipitation on a dislocation.

[0252] In Comparative Example 27 in which CNeq was more than the upper limit, both YS and TS are more than the upper limit.

[0253] Comparative Example 28 in which a S content was more than the upper limit resulted in the deterioration of sour resistance.

[0254] In Comparative Examples 29 to 31 in which LR was less than 0.210, YR was more than the upper limit.

[0255] The entire disclosure of Japanese Patent Application No. 2016-134289 is incorporated herein by reference.

[0256] All documents, patent applications, and technical standards described in this specification are herein incorporated by reference to the same extent as if each individual document, patent application, or technical standard was specifically and individually indicated to be incorporated by reference.

Claims

1. An electric resistance welded steel pipe for a line pipe, the steel pipe comprising a base metal portion and an electric resistance welded portion,
wherein a chemical composition of the base metal portion consists of, in terms of % by mass:

0.030 to less than 0.080% of C,
0.30 to 1.00% of Mn,
0.005 to 0.050% of Ti,
0.010 to 0.100% of Nb,
0.001 to 0.020% of N,
0.010 to 0.450% of Si,
0.0010 to 0.1000% of Al,
0 to 0.030% of P,
0 to 0.0010% of S,
0 to 0.50% of Mo,
0 to 1.00% of Cu,
0 to 1.00% of Ni,
0 to 1.00% of Cr,
0 to 0.100% of V,
0 to 0.0100% of Ca,
0 to 0.0100% of Mg,
0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:

CNeq, expressed by the following Formula (1), is from 0.190 to 0.320,
a ratio of % by mass of Mn to % by mass of Si is 2.0 or more, LR, expressed by the following Formula (2), is 0.210 or more,
in a case in which a metallographic microstructure of the base metal portion is observed using a scanning electron microscope at a magnification of 1,000 times, an areal ratio of a first phase that is ferrite is from 40 to 80%, and a second phase, which is the balance, comprises tempered bainite,
a yield strength in a pipe axis direction is from 390 to 562 MPa,
a tensile strength in the pipe axis direction is from 520 to 690 MPa,
a yield ratio in the pipe axis direction is 93% or less,
a Charpy absorbed energy in a circumferential direction of the pipe in the base metal portion is 100 J or more at 0°C, and
a Charpy absorbed energy in the circumferential direction of the pipe in the electric resistance welded portion is 80 J or more at 0°C;

$$CNeq = C + Mn/6 + Cr/5 + (Ni + Cu)/15 + Nb + Mo + V \qquad \text{Formula (1)}$$

$$LR = (2.1 \times C + Nb)/Mn \quad \text{Formula (2)}$$

wherein, in Formula (1) and Formula (2), C, Mn, Cr, Ni, Cu, Nb, Mo, and V represent % by mass of respective elements.

2. The electric resistance welded steel pipe for a line pipe according to claim 1, wherein the chemical composition of the base metal portion comprises, in terms of % by mass, one or more of:

more than 0% but equal to or less than 0.50% of Mo,
more than 0% but equal to or less than 1.00% of Cu,
more than 0% but equal to or less than 1.00% of Ni,
more than 0% but equal to or less than 1.00% of Cr,
more than 0% but equal to or less than 0.100% of V,
more than 0% but equal to or less than 0.0100% of Ca,
more than 0% but equal to or less than 0.0100% of Mg, or
more than 0% but equal to or less than 0.0100% of REM.

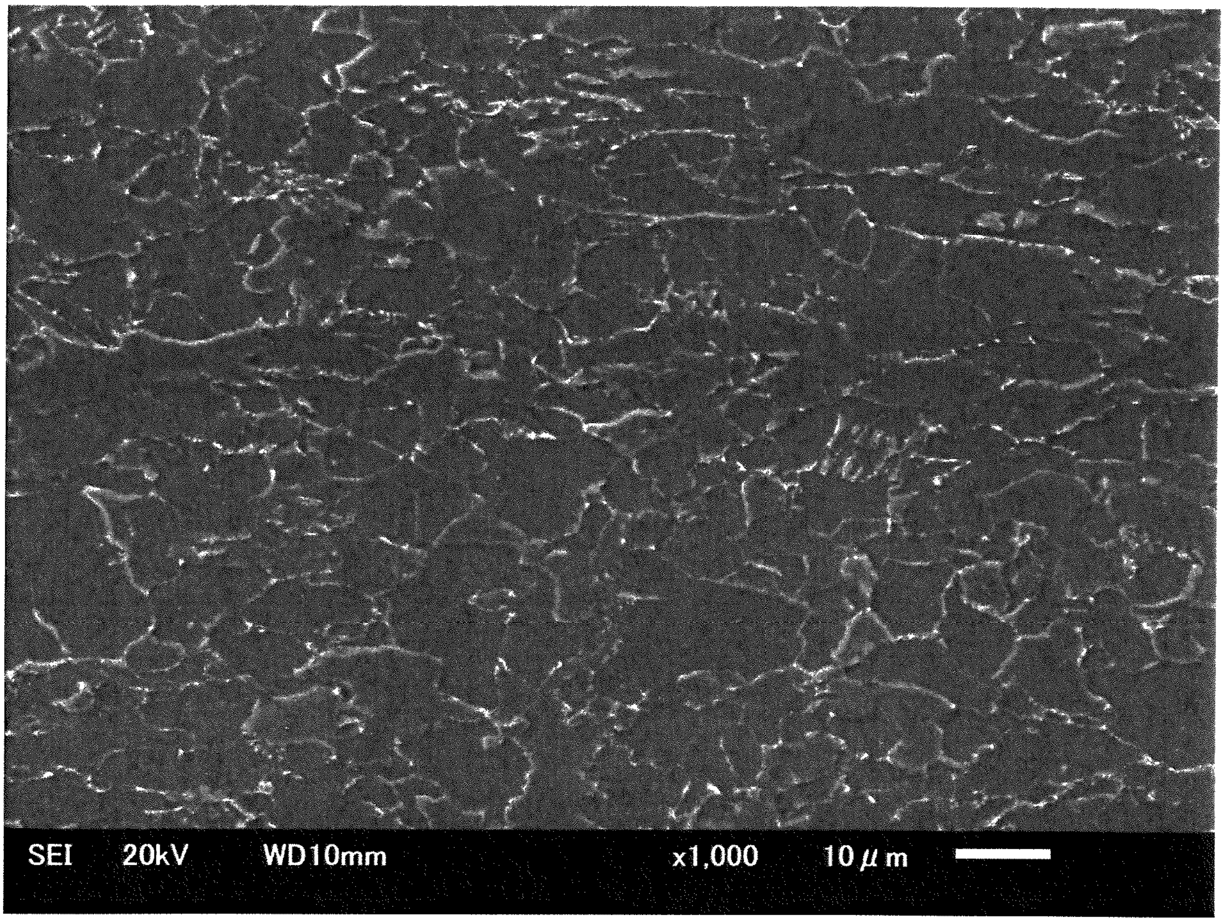
3. The electric resistance welded steel pipe for a line pipe according to claim 1 or 2, wherein an areal ratio of a precipitate having an equivalent circle diameter of 100 nm or less is from 0.100 to 1.000% in a case in which the metallographic microstructure of the base metal portion is observed using a transmission electron microscope at a magnification of 100,000 times.

4. The electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 3, wherein a content of Nb in the chemical composition of the base metal portion is, in terms of % by mass, 0.020% or more.

5. The electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 4, wherein the electric resistance welded steel pipe for a line pipe has a wall thickness of from 10 to 25 mm and an outer diameter of from 114.3 to 609.6 mm.

6. The electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 5, wherein, in a case in which a hydrogen-induced cracking test is conducted on a specimen sampled from the base metal portion, CLR, which is a percentage of a total length of a crack with respect to a length of the specimen, is 8% or less.

FIG.1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/010024

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D9/08*(2006.01)i, *C22C38/14*(2006.01)i, *C22C38/50*(2006.01)i, *C21D8/02*(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60, C21D9/08, C21D8/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013/027779 A1 (Nippon Steel & Sumitomo Metal Corp.), 28 February 2013 (28.02.2013), & EP 2752499 A1 & KR 10-2013-0058074 A & CN 103249854 A & CA 2832021 A1	1-6
A	JP 2014-189808 A (Kobe Steel, Ltd.), 06 October 2014 (06.10.2014), (Family: none)	1-6
A	JP 2010-506044 A (ExxonMobil Upstream Research Co.), 25 February 2010 (25.02.2010), & US 2009/0301613 A1 & WO 2008/045631 A2 & KR 10-2009-0078807 A & CN 101611163 A	1-6

☒ 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
01 June 2017 (01.06.17)	13 June 2017 (13.06.17)

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INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2017/010024

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 2002-302716 A (Sumitomo Metal Industries, Ltd.), 18 October 2002 (18.10.2002), (Family: none)	1-6
A	JP 2007-15008 A (JFE Steel Corp.), 25 January 2007 (25.01.2007), (Family: none)	1-6

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 4305216 B **[0007]**
- JP 4466320 B **[0007]**
- WO 2012133558 A **[0007] [0114]**
- JP 2016134289 A **[0255]**