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(54) AS-ROLLED TYPE ELECTRIC-RESISTANCE-WELDED STEEL PIPE FOR LINE PIPES

(57) An as-rolled electric resistance welded steel pipe for a line pipe has a base metal portion that includes, in terms of % by mass, 0.01 to 0.10% of C, 0.01 to 0.40% of Si, 0.50 to 2.00% of Mn, 0 to 0.030% of P, 0 to 0.0015% of S, 0.010 to 0.050% of Al, 0.0030 to 0.0080% of N, 0.010 to 0.050% of Nb and 0.005 to 0.020% of Ti, the balance comprising Fe and impurities, and in a metallographic microstructure of the base metal portion, an areal ratio of polygonal ferrite is 80% to 98% and the balance is composed of at least one of bainite or pearlite, a yield strength in a pipe axis direction is 415 to 550 MPa, a tensile strength in the pipe axis direction is 461 to 625 MPa, and a maximum Vickers hardness of an inner surface layer of the base metal portion is 248 HV or less and is smaller than a maximum Vickers hardness of an outer surface layer of the base metal portion by 5 HV or more.

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Description

Technical Field

[0001] The present disclosure relates to an as-rolled electric resistance welded steel pipe for a line pipe.

Background Art

[0002] Crude oil or natural gas produced in recent years includes wet hydrogen sulfide (H_2S). An environment including hydrogen sulfide is referred to as a sour environment.
[0003] A pipeline for transporting drilled crude oil or natural gas is exposed to such a sour environment. Thus, for a steel pipe for a line pipe, which is used in the production of a pipeline, resistance to a sour environment (sour resistance) is required.
[0004] For example, Japanese Patent Application Laid-Open (JP-A) No. 2013-11005 (Patent Document 1) discloses, as a thick-walled high-strength hot-rolled steel sheet for a line pipe, which has excellent sour resistance, a thick-walled high-strength hot-rolled steel sheet for a line pipe, which has a composition including, in terms of % by mass, from 0.01 to 0.07% of C, 0.40% or less of Si, from 0.5 to 1.4% of Mn, 0.015% or less of P, 0.003% or less of S, 0.1% or less of Al, from 0.01 to 0.15% of Nb, 0.1% or less of V, 0.03% or less of Ti, and 0.008% or less of N, such that Nb, V, and Ti satisfy Nb + V + Ti < 0.15, and further Cm satisfies 0.12 or less, and the balance of the composition consists of Fe and inevitable impurities, and has a structure including a bainite phase or a bainitic ferrite phase with an areal ratio of 95% or more, and wherein, in the thick-walled high-strength hot-rolled steel sheet, a maximum hardness in a sheet thickness direction is 220 HV or less, and a yield strength is 450 MPa or more. Here, Cm = C + Si/30 + (Mn + Cu)/30 + Ni/60 + Mo/7 + V/10.
[0005] Patent Document 1: JP-A No. 2013-11005

SUMMARY OF INVENTION

Technical Problem

[0006] The concept of "sour resistance" includes resistance to hydrogen induced cracking (hereinafter also referred to as "HIC") generated mainly in the central portion of the wall thickness of the steel pipe (hereinafter also referred to as "HIC resistance") and resistance to sulfide stress cracking (hereinafter also referred to as "SSC") generated mainly from the inner peripheral surface of the steel pipe as the initiating point (hereinafter also referred to as "SSC resistance").
[0007] Regarding this point, in Patent Document 1, only the HIC resistance is evaluated, and the SSC resistance is not evaluated as the sour resistance. Thus, the high-strength hot-rolled steel sheet for a welded steel pipe for a line pipe of Patent Document 1 may have low SSC resistance.
[0008] From the viewpoint of the improvement in transport efficiency and the improvement in operation efficiency, for an electric resistance welded steel pipe for a line pipe, a certain amount of high strength (for example, a yield strength in a pipe axis direction of 415 MPa or more, and a tensile strength in the pipe axis direction of 461 MPa or more) is required.
[0009] In contrast, from the viewpoint of a bending deformation property and the suppression of buckling in the case of laying a pipeline formed using the electric resistance welded steel pipe for a line pipe, for the electric resistance welded steel pipe for a line pipe, not-too-high strength (for example, the yield strength in the pipe axis direction of 550 MPa or less, and the tensile strength in the pipe axis direction of 625 MPa or less) is also required.
[0010] Therefore, an object of the disclosure is to provide an as-rolled electric resistance welded steel pipe for a line pipe, which has a yield strength in a pipe axis direction of from 415 to 550 MPa, which has a tensile strength in the pipe axis direction of from 461 to 625 MPa, and which has excellent SSC resistance.

Solution to Problem

[0011] Means of solving the problem described above includes the following aspects.

<1> An as-rolled 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:

from 0.01 to 0.10% of C,
from 0.01 to 0.40% of Si,
from 0.50 to 2.00% of Mn,
from 0 to 0.030% of P,

from 0 to 0.0015% of S,
from 0.010 to 0.050% of Al,
from 0.0030 to 0.0080% of N,
from 0.010 to 0.050% of Nb,
from 0.005 to 0.020% of Ti,
from 0 to 0.20% of Ni,
from 0 to 0.20% of Mo,
from 0 to 0.0050% of Ca,
from 0 to 1.00% of Cr,
from 0 to 0.100% of V,
from 0 to 1.00% of Cu,
from 0 to 0.0050% of Mg,
from 0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:

in a metallographic microstructure of the base metal portion, an areal ratio of polygonal ferrite is from 80% to 98%, the balance is composed of at least one of bainite or pearlite,
a yield strength in a pipe axis direction is from 415 to 550 MPa, a tensile strength in the pipe axis direction is from 461 to 625 MPa, and
a maximum Vickers hardness of an inner surface layer of the base metal portion is 248 HV or less and is smaller than a maximum Vickers hardness of an outer surface layer of the base metal portion by 5 HV or more.

<2> The as-rolled electric resistance welded steel pipe for a line pipe according to <1>, wherein the chemical composition of the base metal portion contains, in terms of % by mass, one or more selected from the group consisting of:

more than 0% but equal to or less than 0.20% of Ni,
more than 0% but equal to or less than 0.20% of Mo,
more than 0% but equal to or less than 0.0050% of Ca,
more than 0% but equal to or less than 1.00% of Cr,
more than 0% but equal to or less than 0.10% of V,
more than 0% but equal to or less than 1.00% of Cu,
more than 0% but equal to or less than 0.0050% of Mg, and
more than 0% but equal to or less than 0.0100% of REM.

<3> The as-rolled electric resistance welded steel pipe for a line pipe according to <1> or <2>, wherein the chemical composition of the base metal portion contains, in terms of % by mass, one or more selected from the group consisting of:

from 0.001 to 0.20% of Ni, and
from 0.1 to 0.20% of Mo.

<4> The as-rolled electric resistance welded steel pipe for a line pipe according to any one of <1> to <3>, wherein the chemical composition of the base metal portion contains, in terms of % by mass, from 0.0005 to 0.0050% of Ca.
<5> The as-rolled electric resistance welded steel pipe for a line pipe according to any one of <1> to <4>, wherein a wall thickness is from 10 to 25 mm, and an outer diameter is from 114.3 mm to 660.4 mm.

Advantageous Effects of Invention

[0012] According to the disclosure, an as-rolled electric resistance welded steel pipe for a line pipe, which has a yield strength in a pipe axis direction of from 415 to 550 MPa, which has a tensile strength in the pipe axis direction of from 461 to 625 MPa, and which has excellent SSC resistance, is provided.

BRIEF DESCRIPTION OF DRAWINGS

[0013]

Fig. 1 is a scanning electron micrograph (a magnification of 500 times) showing an example of a metallographic microstructure of a base metal portion in the disclosure.

Fig. 2 is a scanning electron micrograph (a magnification of 2,000 times) obtained by enlarging a part of Fig. 1.

Fig. 3 is a schematic front view of a tensile test specimen used for a tensile test in the disclosure.

Fig. 4 is a schematic perspective view showing an example of a pipe-making step for producing an electric resistance welded steel pipe of the disclosure.

DESCRIPTION OF EMBODIMENTS

[0014] A numerical range expressed by "from x to y" herein includes the values of x and y in the range as the minimum and maximum values, respectively.

[0015] The content of a component (element) expressed by "%" herein means "% by mass".

[0016] The content of C (carbon) in a base metal portion may be herein occasionally expressed as "C content". The content of another element in the base metal portion may be expressed similarly.

[0017] 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.

[0018] Herein, an "as-rolled electric resistance welded steel pipe for a line pipe" may be simply referred to as an "electric resistance welded steel pipe" or an "as-rolled electric resistance welded steel pipe".

[0019] Herein, the as-rolled electric resistance welded steel pipe refers to an electric resistance welded steel pipe which is not subjected to heat treatment other than seam heat treatment after pipe-making.

[0020] Herein, the "pipe-making" refers to a process of making an open pipe by roll-forming of a hot-rolled steel sheet and forming an electric resistance welded portion by electric resistance welding of abutting portions of the obtained open pipe.

[0021] Herein, the "roll-forming" refers to forming of a hot-rolled steel sheet into an open pipe shape by bending work.

[0022] An electric resistance welded steel pipe (i.e., an as-rolled electric resistance welded steel pipe for a line pipe) of the disclosure includes 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: from 0.01 to 0.10% of C, from 0.01 to 0.40% of Si, from 0.50 to 2.00% of Mn, from 0 to 0.030% of P, from 0 to 0.0015% of S, from 0.010 to 0.050% of Al, from 0.0030 to 0.0080% of N, from 0.010 to 0.050% of Nb, from 0.005 to 0.020% of Ti, from 0 to 0.20% of Ni, from 0 to 0.20% of Mo, from 0 to 0.0050% of Ca, from 0 to 1.00% of Cr, from 0 to 0.100% of V, from 0 to 1.00% of Cu, from 0 to 0.0050% of Mg, from 0 to 0.0100% of REM, and the balance being Fe and impurities, wherein: in a metallographic microstructure of the base metal portion, an areal ratio of polygonal ferrite is from 80% to 98%, the balance is composed of at least one of bainite or pearlite, a yield strength in a pipe axis direction (hereinafter also referred to as "YS") is from 415 to 550 MPa, a tensile strength in the pipe axis direction (hereinafter also referred to as "TS") is from 461 to 625 MPa, and a maximum Vickers hardness of an inner surface layer of the base metal portion is 248 HV or less and is smaller than a maximum Vickers hardness of an outer surface layer of the base metal portion by 5 HV or more.

[0023] In the electric resistance welded steel pipe of the disclosure, the base metal portion refers to a portion other than the electric resistance welded portion and a heat affected zone in the electric resistance welded steel pipe.

[0024] 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).

[0025] In the electric resistance welded steel pipe of the disclosure, the maximum Vickers hardness of the inner surface layer of the base metal portion means a value measured as follows.

[0026] First, as measurement points of the Vickers hardness, in a C cross-section of the electric resistance welded steel pipe (i.e., a cross-section perpendicular to the pipe axis direction), nine points at 1 mm pitch, which are arranged on the circumference at a depth of 0.1 mm from an inner peripheral surface of the electric resistance welded steel pipe and centered at a base metal 180° position (i.e., a position shifted from the electric resistance welded portion by 180° in a pipe circumferential direction), are selected. A specimen including the above-described selected nine measurement points is sampled from the electric resistance welded steel pipe. In each of the nine measurement points in the specimen, the Vickers hardness is measured in conformity with JIS Z2244 (2009) under the condition of a test force of 100 gf (= 0.98 N) with the pipe axis direction as a test direction. The maximum value among the obtained nine measurement results is regarded as the maximum Vickers hardness of the inner surface layer of the base metal portion.

[0027] In other words, the maximum Vickers hardness of the inner surface layer of the base metal portion is, approximately speaking, a maximum Vickers hardness in the vicinity of the inner peripheral surface of the base metal portion.

[0028] In the electric resistance welded steel pipe of the disclosure, the maximum Vickers hardness of the outer surface layer of the base metal portion means a value measured in the same way as the maximum Vickers hardness of the inner surface of the base metal portion described above except that the "inner peripheral surface" is read as the "outer peripheral surface".

[0029] In other words, the maximum Vickers hardness of the outer surface layer of the base metal portion is, approximately speaking, a maximum Vickers hardness in the vicinity of the outer peripheral surface of the base metal portion.

[0030] The electric resistance welded steel pipe of the disclosure has a certain amount of strength (i.e., YS and TS in the ranges described above) and has excellent SSC resistance.

[0031] In contrast to the electric resistance welded steel pipe of the disclosure, in a conventional electric resistance welded steel pipe for a line pipe (for example, the electric resistance welded steel pipe for a line pipe described in the above-described Patent Document 1), the HIC resistance as the sour resistance was considered, but the SSC resistance as the sour resistance was not considered.

[0032] However, locations of generation of cracking are different in HIC (hydrogen induced cracking) and SSC (sulfide stress cracking). Specifically, HIC is generated mainly in the central portion of the wall thickness of the electric resistance welded steel pipe, whereas SSC is generated mainly from the inner peripheral surface of the electric resistance welded steel pipe as the initiating point. More specifically, in a state where a fluid containing wet hydrogen sulfide (specifically, crude oil or natural gas; hereinafter also referred to as "sour fluid") is in contact with the inner peripheral surface of the electric resistance welded steel pipe for a line pipe, SSC is generated from the inner peripheral surface as the initiating point.

[0033] Therefore, even if an electric resistance welded steel pipe has excellent HIC resistance, the electric resistance welded steel pipe may have poor SSC resistance.

[0034] In the electric resistance welded steel pipe of the disclosure, the maximum Vickers hardness of the inner surface layer of the base metal portion is 248 HV or less, and the maximum Vickers hardness of the inner surface layer of the base metal portion is smaller than the maximum Vickers hardness of the outer surface layer of the base metal portion by 5 HV or more. As a result, under a state where a sour fluid is in contact with the inner peripheral surface of the electric resistance welded steel pipe, SSC which is cracking generated from the inner peripheral surface as the initiating point is suppressed (i.e., the SSC resistance is improved).

[0035] Moreover, SSC tends to be easily generated as the strength of the electric resistance welded steel pipe becomes higher.

[0036] Regarding this point, in the electric resistance welded steel pipe of the disclosure, the YS is limited to 550 MPa or less, and the TS is limited to 625 MPa or less, respectively. As a result, the SSC resistance is improved.

[0037] In contrast, in the electric resistance welded steel pipe of the disclosure, the maximum Vickers hardness of the inner surface layer of the base metal portion is smaller than the maximum Vickers hardness of the outer surface layer of the base metal portion by 5 HV or more, so that the maximum Vickers hardness of the outer surface layer of the base metal portion is relatively secured to a certain degree.

[0038] As a result, a certain amount of high strength (specifically, YS of 415 MPa or more, and TS of 461 MPa or more) is secured as the entire electric resistance welded steel pipe.

[0039] In contrast to the electric resistance welded steel pipe of the disclosure, in the conventional electric resistance welded steel pipe, the maximum Vickers hardness of the inner surface layer of the base metal portion was almost the same as the maximum Vickers hardness of the outer surface layer of the base metal portion, and the condition that "the maximum Vickers hardness of the inner surface layer of the base metal portion is smaller than the maximum Vickers hardness of the outer surface layer of the base metal portion by 5 HV or more" was not satisfied owing to the following circumstances.

[0040] The electric resistance welded steel pipe is produced by using a hot coil consisting of a hot-rolled steel sheet as a raw material and subjecting the hot-rolled steel sheet, uncoiled from the hot coil, to pipe-making (i.e., roll-forming and electric resistance welding). One of two surfaces of the hot-rolled steel sheet uncoiled from the hot coil (hereinafter also referred to as "first surface") becomes an outer surface of the electric resistance welded steel pipe, and the other of the two surfaces (hereinafter also referred to as "second surface") becomes an inner surface of the electric resistance welded steel pipe. A production process of the hot coil includes respective stages of hot-rolling, cooling, and coiling in this order. From the viewpoint of suppressing warpage of the hot-rolled steel sheet after cooling or from the viewpoint of the productivity, this cooling was conventionally performed by water-cooling the two surfaces of the hot-rolled steel sheet obtained by hot-rolling at cooling rates which are almost the same. Under such a circumstance, in the conventional electric resistance welded steel pipe, the maximum Vickers hardness of the inner surface layer of the base metal portion was almost the same as the maximum Vickers hardness of the outer surface layer of the base metal portion (i.e., the condition that "the maximum Vickers hardness of the inner surface layer of the base metal portion is smaller than the maximum Vickers hardness of the outer surface layer of the base metal portion by 5 HV or more" was not satisfied).

[0041] For the above-described conventional electric resistance welded steel pipe, the present inventors succeeded in making the maximum Vickers hardness of the inner surface layer of the base metal portion smaller than the maximum Vickers hardness of the outer surface layer of the base metal portion by 5 HV or more by providing a difference between the cooling rates for the two surfaces when the two surfaces of the hot-rolled steel sheet obtained by hot-rolling are cooled (specifically, by making the cooling rate of the second surface corresponding to the inner peripheral surface slower than the cooling rate of the first surface corresponding to the outer peripheral surface). Furthermore, the present inventors found that, virtually, the warpage of the hot-rolled steel sheet after cooling is not matter too much because the cooled hot-rolled steel sheet is subsequently coiled.

[0042] The electric resistance welded steel pipe of the disclosure was completed based on the above-described knowledge of the present inventors.

[0043] Not only the maximum Vickers hardness of the inner surface layer of the base metal portion but also the chemical composition of the base metal portion, the metallographic microstructure of the base metal portion, and being the as-rolled electric resistance welded steel pipe contribute to the SSC resistance.

[0044] Moreover, the chemical composition of the base metal portion, the metallographic microstructure of the base metal portion, and being the as-rolled electric resistance welded steel pipe also contribute to the achievement of the YS in the range described above and the TS in the range described above.

[0045] The chemical composition of the base metal portion and the metallographic microstructure of the base metal portion will be described below.

[Chemical Composition of Base Metal Portion]

[0046] The chemical composition of the base metal portion will be described below.

C: from 0.01 to 0.10%

[0047] C enhances the strength of steel. In a case in which a C content is too low, the effect cannot be obtained. Accordingly, the C content is 0.01% or more. The C content is preferably 0.03% or more, and more preferably 0.04% or more.

[0048] In contrast, in a case in which the C content is too high, a carbide is generated, and the toughness and ductility of steel are decreased. Accordingly, the C content is 0.10% or less. The C content is preferably 0.09%, and still more preferably 0.08% or less.

Si: from 0.01 to 0.40%

[0049] Si deoxidizes steel. In a case in which a Si content is too low, the effect cannot be obtained. Accordingly, the Si content is 0.01% or more. The Si content is preferably 0.02% or more, and still more preferably 0.10% or more.

[0050] In contrast, in a case in which the Si content is too high, the toughness of steel is decreased. Accordingly, the Si content is 0.40% or less. The Si content is preferably 0.38% or less, and more preferably 0.35% or less.

Mn: from 0.50 to 2.00%

[0051] Mn enhances the hardenability of steel and enhances the strength of steel. In a case in which a Mn content is too low, the effect cannot be obtained. Accordingly, the Mn content is 0.50% or more. The Mn content is preferably 0.60% or more, and more preferably 0.80% or more.

[0052] In contrast, in a case in which the Mn content is too high, the toughness and SSC resistance of steel are decreased. Accordingly, the Mn content is 2.00% or less. The Mn content is preferably 1.80% or less, and more preferably 1.50% or less.

P: from 0 to 0.030%

[0053] P is an impurity. P segregates in a grain boundary and embrittles the grain boundary. Thus, P decreases the toughness and SSC resistance of steel. Accordingly, a P content is preferably small. Specifically, the P content is 0.030% or less. The P content is preferably 0.021% or less, more preferably 0.015% or less, and still more preferably 0.010% or less.

[0054] In contrast, 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: from 0 to 0.0015%

[0055] S is an impurity. S binds to Mn to form a Mn-based sulfide. The Mn-based sulfide is diffluent. Thus, the toughness and SSC resistance of steel are decreased. Accordingly, a S content is preferably as low as possible. Specifically, the S content is 0.0015% or less. The S content is preferably 0.0010% or less, and more preferably 0.0008% or less.

[0056] In contrast, 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.

Al: from 0.010 to 0.050%

[0057] Al deoxidizes steel. In a case in which an Al content is too low, the effect cannot be obtained. Accordingly, the Al content is 0.010% or more. The Al content is preferably 0.012% or more, and more preferably 0.013% or more.
[0058] In contrast, in a case in which the Al content is too high, an Al nitride is coarsened, and the toughness of steel is decreased. Accordingly, the Al content is 0.050% or less. The Al content is preferably 0.040% or less, more preferably 0.035% or less, and still more preferably 0.030% or less.
[0059] The Al content herein means the content of total Al in the steel.

N: from 0.0030 to 0.0080%

[0060] N enhances the strength of steel by solid-solution strengthening. In a case in which a N content is too low, the effect cannot be obtained. Accordingly, the N content is 0.0030% or more.
[0061] In contrast, in a case in which the N content is too high, a carbonitride is coarsened, and the SSC resistance is decreased. Accordingly, the N content is 0.0080% or less. The N content is preferably 0.0070% or less, more preferably 0.0060% or less, and still more preferably 0.0040% or less.

Nb: from 0.010 to 0.050%

[0062] Nb binds to C and N in the steel to form a fine Nb carbonitride. The fine Nb carbonitride enhances the strength of steel by dispersion strengthening. In a case in which a Nb content is too low, the effect cannot be obtained. Accordingly, the Nb content is 0.010% or more. The Nb content is preferably 0.020% or more, and more preferably 0.030% or more.
[0063] In contrast, in a case in which the Nb content is too high, the Nb carbonitride is coarsened, and the SSC resistance of steel is decreased. Furthermore, in a case in which the Nb content is too high, the toughness of the electric resistance welded portion is decreased. Accordingly, the Nb content is 0.050% or less. The Nb content is preferably 0.045% or less, and more preferably 0.040% or less.

Ti: from 0.005 to 0.020%

[0064] Ti binds to N in the steel to form a Ti nitride and/or Ti carbonitride. The Ti nitride and/or Ti carbonitride refines crystal grains of the steel. In a case in which a Ti content is too low, the effect cannot be obtained. Accordingly, the Ti content is 0.005% or more. The Ti content is preferably 0.007% or more, and more preferably 0.010% or more.
[0065] In contrast, in a case in which the Ti content is too high, a coarse Ti nitride and/or Ti carbonitride is formed. Thus, the SSC resistance of steel is decreased. Accordingly, the Ti content is 0.020% or less. The Ti content is preferably 0.018% or less, and more preferably 0.016% or less.

Ni: from 0 to 0.20%

[0066] Ni is an optional element and may not be contained. In other words, a Ni content may be 0%.
[0067] In a case in which Ni is contained, Ni enhances the strength of steel by solid-solution strengthening. Ni further enhances the toughness of steel. From the viewpoint of the effect, the Ni content is preferably more than 0%, more preferably 0.001% or more, more preferably 0.005% or more, still more preferably 0.01% or more, and still more preferably 0.05% or more.
[0068] In contrast, in a case in which the Ni content is too high, the weldability of steel is decreased. Accordingly, the Ni content is 0.20% or less. The Ni content is preferably 0.18% or less, and still more preferably 0.15% or less.

Mo: from 0 to 0.20%

[0069] Mo is an optional element and may not be contained. In other words, a Mo content may be 0%.
[0070] In a case in which Mo is contained, Mo enhances the hardenability of steel and enhances the strength of steel. Furthermore, since micro segregation of Mo is difficult to be generated, generation of HIC caused by center segregation is suppressed. From the viewpoint of the effect, the Mo content is preferably more than 0%, more preferably 0.10% or more, and still more preferably 0.12% or more.
[0071] In contrast, since Mo is expensive, in a case in which Mo is excessively included, the production cost increases. Accordingly, the Mo content is 0.20% or less. The Mo content is preferably 0.18% or less, and more preferably 0.15% or less.

Ca: from 0% to 0.0050%

[0072] Ca is an optional element and may not be contained. In other words, a Ca content may be 0%.

[0073] In a case in which Ca is contained, Ca makes the form of MnS that becomes a initiating point of generation of SSC into a spherical shape and suppresses the generation of SSC. Ca further forms CaS and suppresses generation of MnS. From the viewpoint of the effect, the Ca content is preferably more than 0%, more preferably 0.0005% or more, still more preferably 0.0010% or more, and still more preferably 0.0020% or more.

[0074] In contrast, in a case in which the Ca content is too high, the effect is saturated, and the production cost increases. Accordingly, the Ca content is 0.0050% or less. The Ca content is preferably 0.0045% or less.

Cr: from 0 to 1.00%

[0075] Cr is an optional element and may not be contained. In other words, a Cr content may be 0%.

[0076] In a case in which Cr is contained, Cr contributes to improvement in hardenability. From the viewpoint of such an effect, the Cr content is preferably more than 0%, and more preferably 0.01% or more.

[0077] In contrast, in a case in which the Cr content is too high, the toughness of the electric resistance welded portion may be deteriorated by Cr-based inclusions generated in the electric resistance welded portion. Accordingly, the Cr content is 1.00% or less. The Cr content is preferably 0.50% or less, more preferably 0.30% or less, and still more preferably 0.20% or less.

V: from 0 to 0.100%

[0078] V is an optional element and may not be contained. In other words, a V content may be 0%.

[0079] In a case in which V is contained, V contributes to improvement in toughness. From the viewpoint of such an effect, the V content is preferably more than 0%, more preferably 0.001% or more, and still more preferably 0.005% or more.

[0080] In contrast, in a case in which the V content is too high, the toughness may be deteriorated by a V carbonitride. Accordingly, the V content is 0.100% or less. The V content is preferably 0.070% or less, more preferably 0.050% or less, and still more preferably 0.030% or less.

Cu: from 0 to 1.00%

[0081] Cu is an optional element and may not be contained. In other words, a Cu content may be 0%.

[0082] In a case in which Cu is contained, Cu contributes to improvement in the strength of the base metal portion. From the viewpoint of such an effect, the Cu content is preferably more than 0%, more preferably 0.01% or more, and still more preferably 0.05% or more.

[0083] In contrast, in a case in which the Cu content is too high, fine Cu particles are generated, and the toughness may be significantly deteriorated. Accordingly, the Cu content is 1.00% or less. The Cu content is preferably 0.70% or less, more preferably 0.50% or less, and still more preferably 0.30% or less.

Mg: from 0 to 0.0050%

[0084] Mg is an optional element and may not be contained. In other words, a Mg content may be 0%.

[0085] In a case in which Mg is contained, Mg functions as a deoxidizer and a desulfurizer. Moreover, Mg forms a fine oxide and also contributes to improvement in the toughness of an HAZ. From the viewpoint of the effect, the Mg content is preferably more than 0%, more preferably 0.0001% or more, and still more preferably 0.0010% or more.

[0086] In contrast, in a case in which the Mg content is too high, the oxide becomes easy to be aggregated or coarsened, and therefore, the decrease in HIC resistance or the decrease in the toughness of the base metal portion or the HAZ may be caused. Accordingly, the Mg content is 0.0050% or less. The Mg content is preferably 0.0030% or less.

REM: from 0 to 0.0100%

[0087] REM is an optional element and may not be contained. In other words, an REM content may be 0%.

[0088] "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.

[0089] In a case in which REM is contained, REM functions as a deoxidizer and a desulfurizer. From the viewpoint of such an effect, the REM content is preferably more than 0%, more preferably 0.0001% or more, and still more preferably 0.0010% or more.

[0090] In contrast, in a case in which REM is too high, a coarse oxide is generated, and therefore, the decrease in the HIC resistance or the decrease in the toughness of the base metal portion or the HAZ may be caused. 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.
[0091] The chemical composition of the base metal portion may contain one or more selected from the group consisting of: more than 0% but equal to or less than 0.20% of Ni, more than 0% but equal to or less than 0.20% of Mo, more than 0% but equal to or less than 0.0050% of Ca, 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 1.00% of Cu, more than 0% but equal to or less than 0.0050% of Mg, and more than 0% but equal to or less than 0.0100% of REM.
[0092] The more preferred content of each optional element has been described above.

Balance: Fe and Impurities

[0093] In the chemical composition of the base metal portion, the balance excluding each element described above is Fe and impurities.
[0094] The impurities refer to components which are contained in a raw material (for example, ore, scrap, and the like) or mixed into in a production step, and which are not intentionally incorporated into a steel.
[0095] 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.
[0096] Examples of the impurities include O, B, Sb, Sn, W, Co, As, Pb, Bi, and H.
[0097] Among the elements described above, O is preferably controlled to have a content of 0.006% or less.
[0098] 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.

[Metallographic Microstructure of Base Metal Portion]

[0099] In the electric resistance welded steel pipe of the disclosure, in the metallographic microstructure of the base metal portion, an areal ratio of polygonal ferrite (hereinafter also referred to as "ferrite fraction") is from 80 to 98%, and the balance is composed of at least one of bainite or pearlite.
[0100] A YS of 550 MPa or less and a TS of 625 MPa or less can be achieved by allowing a ferrite fraction to be 80% or more. The ferrite fraction is preferably 81% or more, and more preferably 82% or more.
[0101] In contrast, a YS of 415 MPa or more and a TS of 461 MPa or more can be achieved by allowing a ferrite fraction to be 98% or less. The ferrite fraction is preferably 97% or less, and more preferably 95% or less.
[0102] The balance in the metallographic microstructure of the base metal portion is composed of at least one of bainite or pearlite. As a result, the SSC resistance is improved compared to a case in which the balance contains, for example, martensite.
[0103] The concept of "bainite" herein includes bainitic ferrite, upper bainite, and lower bainite.
[0104] The concept of "pearlite" herein includes pseudo-pearlite.
[0105] The above-described metallographic microstructure of the base metal portion relates to the electric resistance welded steel pipe of the disclosure being an as-rolled electric resistance welded steel pipe (i.e., not subjected to heat treatment other than seam heat treatment after pipe-making).
[0106] In an electric resistance welded steel pipe formed by being subjected to heat treatment other than seam heat treatment after pipe-making unlike the electric resistance welded steel pipe of the disclosure (as-rolled electric resistance welded steel pipe), martensite may be formed as the metallographic microstructure of the base metal portion. The electric resistance welded steel pipe in this case has poor SSC resistance.
[0107] The measurement of the ferrite fraction and the identification of the balance in the metallographic microstructure of the base metal portion are performed as follows.
[0108] A metallographic microstructure of the central portion of the wall thickness in an L cross-section at a base metal 180° position is nital-etched, and micrographs of the nital-etched metallographic microstructure (hereinafter also referred to as "metallographic micrographs") are observed with a scanning electron microscope (SEM) at a magnification of 500 times. Metallographic micrographs corresponding to ten 500-times visual fields (corresponding to actual cross-sectional area of 0.48 mm^2) are taken. The measurement of the ferrite fraction and the identification of the balance 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.
[0109] Fig. 1 is a scanning electron micrograph (SEM micrograph; a magnification of 500 times) showing an example of a metallographic microstructure of a base metal portion in the disclosure, and Fig. 2 is a SEM micrograph (a magni-

fication of 2,000 times) obtained by enlarging a region of Fig. 1.

[0110] The SEM micrograph (500 times) in Fig. 1 is one (one visual field) of SEM micrographs used in the measurement of the ferrite fraction and the identification of the balance in Test Number 22 described later.

[0111] As shown in Fig. 1 and Fig. 2, the metallographic microstructure according to this example is a metallographic microstructure which is mainly composed of polygonal ferrite and in which the balance is pearlite.

[0112] More specifically, because cementite is not precipitated in a grain boundary of polygonal ferrite and lamellar cementite in pearlite in the balance is not divided, the metallographic microstructure is revealed to be a metallographic microstructure which is not subjected to heat treatment after pipe-making (i.e., a metallographic microstructure of an as-rolled electric resistance welded steel pipe).

[0113] Being an as-rolled electric resistance welded steel pipe can also be confirmed by not observing yield elongation in a case in which a pipe axis direction tensile test is performed.

[0114] In an as-rolled electric resistance welded steel pipe, yield elongation is not observed in a case in which a pipe axis direction tensile test is performed.

[0115] In contrast, in an electric resistance welded steel pipe which is subjected to heat treatment after pipe-making, yield elongation is observed in a case in which a pipe axis direction tensile test is performed.

[Maximum Vickers Hardness of Inner Surface Layer of Base Metal Portion, Maximum Vickers Hardness of Outer Surface Layer of Base Metal Portion]

[0116] In the electric resistance welded steel pipe of the disclosure, a maximum Vickers hardness of an inner surface layer of the base metal portion is 248 HV or less, and the Vickers hardness of the inner surface layer of the base metal portion is smaller than a maximum Vickers hardness of an outer surface layer of the base metal portion by 5 HV or more.

[0117] Each of the maximum Vickers hardness of the inner surface layer of the base metal portion and the maximum Vickers hardness of the outer surface layer of the base metal portion has been described above.

[0118] A difference obtained by subtracting the Vickers hardness of the inner surface layer of the base metal portion from the maximum Vickers hardness of the outer surface layer of the base metal portion (i.e., the maximum Vickers hardness of the outer surface layer of the base metal portion - the Vickers hardness of the inner surface layer of the base metal portion) is hereinafter also referred to as an "outer-inner hardness difference".

[0119] For example, "the Vickers hardness of the inner surface layer of the base metal portion is smaller than the maximum Vickers hardness of the outer surface layer of the base metal portion by 5 HV or more" is hereinafter also referred to as "the outer-inner hardness difference is 5 HV or more".

[0120] In a case in which the maximum Vickers hardness of the inner surface layer of the base metal portion exceeds 248 HV, the toughness of steel is decreased, and the SSC resistance of the electric resistance welded steel pipe is decreased. Accordingly, the maximum Vickers hardness of the inner surface layer is 248 HV or less. The maximum Vickers hardness of the inner surface layer is preferably 245 HV or less, and more preferably 220 HV or less.

[0121] The lower limit of the maximum Vickers hardness of the inner surface layer is not particularly limited. From the viewpoint of more improving the strength of the electric resistance welded steel pipe (i.e., YS and TS), the maximum Vickers hardness of the inner surface layer is preferably 175 HV or more, more preferably 180 HV or more, and still more preferably 185 HV or more.

[0122] In a case in which the outer-inner hardness difference is less than 5 HV, depending on the value of the maximum Vickers hardness of the inner surface layer of the base metal portion, at least one of the deterioration of the SSC resistance, the deficiency of the YS, or the deficiency of the TS occurs. Accordingly, the outer-inner hardness difference is 5 HV or more, and preferably 6 HV or more.

[0123] The upper limit of the outer-inner hardness difference is not particularly restricted. From the viewpoint of the production suitability of the electric resistance welded steel pipe, the outer-inner hardness difference is preferably 20 HV or less, more preferably 15 HV or less, and still more preferably 10 HV or less.

[0124] The maximum Vickers hardness of the outer surface layer of the base metal portion may satisfy the maximum Vickers hardness of the inner surface layer of the base metal portion and the outer-inner hardness difference described above, and others are not particularly restricted.

[0125] The maximum Vickers hardness of the outer surface layer of the base metal portion is preferably from 180 MPa to 250 MPa, and more preferably from 210 MPa to 230 MPa.

[0126] As described above, in the electric resistance welded steel pipe of the disclosure, the Vickers hardness of the inner surface layer of the base metal portion is smaller than the maximum Vickers hardness of the outer surface layer of the base metal portion by 5 HV or more.

[0127] In the electric resistance welded steel pipe of the disclosure, the maximum Vickers hardness of the inner surface layer may be lower than the maximum Vickers hardness of the outer surface layer by 5 HV or more in not only the base metal portion but also the electric resistance welded portion.

[0128] For example, in the case of producing the electric resistance welded steel pipe by production method A described later, the maximum Vickers hardness of the inner surface layer may be lower than the maximum Vickers hardness of the outer surface layer by 5 HV or more also in the electric resistance welded portion.

[Yield Strength in Pipe Axis Direction (YS)]

[0129] The electric resistance welded steel pipe of the disclosure has a yield strength in a pipe axis direction (YS) of from 415 to 550 MPa.
[0130] A YS of 415 MPa or more secures the strength as the electric resistance welded steel pipe for a line pipe. The YS is preferably 430 MPa or more.
[0131] In contrast, a YS of 550 MPa or less (i.e., not-too-high YS) is advantageous in view of the improvement in the SSC resistance or a bending deformation property and the suppression of buckling in the case of laying a pipeline formed using the electric resistance welded steel pipe for a line pipe. The YS is preferably 530 MPa or less.

[Tensile Strength in Pipe Axis Direction (TS)]

[0132] The electric resistance welded steel pipe of the disclosure has a tensile strength in a pipe axis direction (TS) of from 461 to 625 MPa.
[0133] A TS of 461 MPa or more secures the strength as the electric resistance welded steel pipe for a line pipe. The TS is preferably 500 MPa or more, and more preferably 510 MPa or more.
[0134] In contrast, a TS of 625 MPa or less (i.e., not-too-high TS) is advantageous in view of the improvement in the SSC resistance or a bending deformation property and the suppression of buckling in the case of laying a pipeline formed using the electric resistance welded steel pipe for a line pipe. The TS is preferably 620 MPa or less.
[0135] The YS and the TS are measured by the following method.
[0136] A full thickness tensile test specimen is sampled from the base metal 90° position of the electric resistance welded steel pipe. Specifically, the tensile test specimen is sampled such that a longitudinal direction of the tensile test specimen is parallel to the pipe axis direction of the electric resistance welded steel pipe and the shape of a cross-section of the tensile test specimen (i.e., a cross-section parallel to a width direction and a thickness direction of the tensile test specimen) is an arcuate shape.
[0137] Fig. 3 is a schematic front view of a tensile test specimen used for a tensile test.
[0138] A unit of numerical values in Fig. 3 is mm.
[0139] As shown in Fig. 3, the length of a parallel part of the tensile test specimen is set to be 50.8 mm, and the width of the parallel part is set to be 38.1 mm.
[0140] The tensile test is conducted using the tensile test specimen in conformity with standard API, specification 5CT at ordinary temperature. The YS and the TS are determined based on the test result.

[Yield Ratio in Pipe Axis Direction (YR)]

[0141] The electric resistance welded steel pipe of the disclosure has preferably a yield ratio in a pipe axis direction (YR = (YS/TS) $\times$ 100) of 95% or less.
[0142] A YR of 95% or less is advantageous in view of the suppression of buckling in the case of laying a pipeline formed using the electric resistance welded steel pipe for a line pipe.

[Wall Thickness of Electric Resistance Welded Steel Pipe]

[0143] The wall thickness of the electric resistance welded steel pipe of the disclosure is preferably from 10 to 25 mm.
[0144] The wall thickness is more preferably 12 mm or more.
[0145] 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]

[0146] The outer diameter of the electric resistance welded steel pipe of the disclosure is preferably from 114.3 to 660.4 mm (i.e., 4.5 to 26 inches).
[0147] The outer diameter is preferably 152.4 mm (i.e., 6 inches) or more, and more preferably 254 mm (i.e., 10 inches) or more.
[0148] The outer diameter is preferably 609.6 mm (i.e., 24 inches) or less, and more preferably 508 mm (i.e., 20 inches) or less.

[One Example of Production Method]

[0149] One example of a method of producing the electric resistance welded steel pipe of the disclosure is the following production method A.
[0150] The production method A includes:

a preparation step of preparing a slab having the chemical composition described above,
a hot-rolling step of heating the prepared slab and hot-rolling the heated slab, thereby obtaining a hot-rolled steel sheet,
a cooling step of cooling a first surface of the hot-rolled steel sheet at a cooling rate V1 and cooling a second surface which is the opposite side of the first surface of the hot-rolled steel sheet at a cooling rate V2 which is slower than the cooling rate V1,
a coiling step of coiling the cooled hot-rolled steel sheet, 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 in a direction such that the first surface is an outer peripheral surface and the second surface is an inner surface 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 electric resistance welded steel pipe.

[0151] According to the production method A, since the hot-rolled steel sheet in which the hardness of the second surface is lower than the hardness of the first surface is easily produced, the electric resistance welded steel pipe in which the hardness of the inner peripheral surface is lower than the hardness of the outer peripheral surface is easily produced, and therefore, the electric resistance welded steel pipe of the disclosure having an outer-inner hardness difference of 5 HV or more is easily produced.

(Preparation Step)

[0152] In the production method A, the step of preparing a slab is a step of preparing a slab having the chemical composition described above.
[0153] The step of preparing a slab may be a step of producing a slab or a step of simply preparing a slab produced in advance.
[0154] In the case of producing a slab, for example, molten steel having the chemical composition described above is produced, and a slab is produced using the produced molten steel. In this case, the slab may be produced by continuous casting, or the slab may be produced by producing an ingot using molten steel and breaking down the ingot.

(Hot-rolling Step)

[0155] In the production method A, the hot-rolling step is a step of heating the prepared slab described above and hot-rolling the heated slab, thereby obtaining a hot-rolled steel sheet.
[0156] The heating temperature in heating the slab is preferably from 1,100 to 1,250°C.
[0157] In a case in which the heating temperature is 1,100°C or more, refining of crystal grains during hot-rolling and precipitation strengthening after hot-rolling easily proceed, and therefore, the strength of steel is easily improved.
[0158] In a case in which the heating temperature is 1,250°C or less, since coarsening of austenite grains can be more suppressed, crystal grains are easily refined, and therefore, the strength of steel is easily improved.
[0159] The heating of the slab is performed by, for example, a heating furnace.
[0160] In the hot-rolling step, a hot-rolled steel sheet is obtained by hot-rolling the heated slab described above.
[0161] The hot-rolling is preferably performed under the condition that a finish rolling finishing temperature (hereinafter also referred to as "finish rolling temperature") is from 780 to 830°C.
[0162] The hot-rolling is generally performed using a rough rolling mill and a finish rolling mill. Both the rough rolling mill and the finish rolling mill generally include multiple rolling stands in a row, and each of the rolling stands includes a pair of rolls. In this case, the finish rolling temperature (i.e., finish rolling finishing temperature) is a surface temperature of the hot-rolled steel sheet at the exit side of a final stand of the finish rolling mill.
[0163] In a case in which the finish rolling temperature is 780°C or more, since the rolling resistance of the steel sheet can be reduced, the productivity is improved.
[0164] Moreover, in a case in which the finish rolling temperature is 780°C or more, a phenomenon in which rolling is performed in a two-phase region of ferrite and austenite is suppressed, and the formation of a banded structure and the decrease in mechanical properties associated with the phenomenon can be suppressed.
[0165] In contrast, in a case in which the finish rolling temperature is 830°C or less, since a phenomenon in which the

steel becomes too hard is suppressed, a phenomenon in which the YS and/or TS of the electric resistance welded steel pipe to be obtained becomes too high is suppressed.

[0166] In the hot-rolling, the rolling reduction in an austenite non-recrystallization temperature region is preferably from 70 to 80%. In this case, a non-recrystallization structure is refined.

(Cooling Step)

[0167] The cooling step is a step of cooling a first surface of the hot-rolled steel sheet at a cooling rate V1 and cooling a second surface which is the opposite side of the first surface of the hot-rolled steel sheet at a cooling rate V2 which is slower than the cooling rate V1.

[0168] In the cooling step, the first surface may be an upper surface (a surface on the opposite side with respect to the gravity direction, the same shall apply hereinafter) and the second surface may be a lower surface (a surface oriented in the gravity direction, the same shall apply hereinafter), or the first surface may be the lower surface and the second surface may be the upper surface.

[0169] Both the cooling of the first surface and the cooling of the second surface preferably include water-cooling.

[0170] In this case, the hot-rolled steel sheet may be water-cooled immediately after the hot-rolling, or the hot-rolled steel sheet immediately after the hot-rolling may be first air-cooled and then water-cooled.

[0171] The cooling rate V1 and the cooling rate V2 preferably satisfy the following Formula (1). As a result, the hot-rolled steel sheet in which the hardness of the second surface is lower than the hardness of the first surface is more easily produced, and therefore, the electric resistance welded steel pipe of the disclosure having an outer-inner hardness difference of 5 HV or more is more easily produced.

$$V2 \leq V1 - 4.09 \quad \text{Formula (1)}$$

[0172] (In Formula (1), V1 represents the cooling rate V1 (°C/s), and V2 represents the cooling rate V2 (°C/s).)

[0173] The cooling rate V1 is preferably from 5 to 25°C/s.

[0174] The cooling rate V2 is not particularly limited. From the viewpoint of more increasing the strength of the electric resistance welded steel pipe (YS and TS), the cooling rate V2 is preferably 0.5°C/s or more, and more preferably 0.8°C/s or more.

[0175] The cooling rate V1 and the cooling rate V2 can be adjusted by, for example, adjusting a water flow density in a water-cooling apparatus for performing water-cooling. For example, on the presupposition that the water flow density on the second surface side is made smaller than the water flow density on the first surface side (i.e., V2 < V1), in order to satisfy the above Formula (1), the water flow density on the second surface side and the water flow density on the first surface side are respectively independently adjusted.

(Coiling Step)

[0176] The coiling step is a 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.

[0177] The surface temperature of the hot-rolled steel sheet at the start of coiling (hereinafter also referred to as "coiling temperature") is preferably 620°C or less, and more preferably 600°C or less.

[0178] In a case in which the coiling temperature is 620°C or less, since coarsening of crystal grains can be more suppressed, the strength of steel can be more improved.

[0179] The lower limit of the coiling temperature is not particularly limited.

[0180] From the viewpoint of the productivity, the coiling temperature is preferably 500°C or more, and more preferably 530°C or more.

(Pipe-making Step)

[0181] The pipe-making step is a step of uncoiling the hot-rolled steel sheet from the hot coil, roll-forming the uncoiled hot-rolled steel sheet in a direction such that the first surface is an outer peripheral surface and the second surface is an inner surface 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 electric resistance welded steel pipe.

[0182] The pipe-making step can be performed in accordance with a known method except the roll-forming in the direction such that the first surface is an outer peripheral surface and the second surface is an inner surface.

[0183] Fig. 4 is a schematic perspective view showing an example of a pipe-making step.

[0184] As shown in Fig. 4, a hot-rolled steel sheet uncoiled from a hot coil is roll-formed using a forming roll (not shown in the drawing) in a direction such that a first surface is an outer peripheral surface 1 and a second surface is an inner peripheral surface 2, thereby making an open pipe. Abutting portions 3 of the open pipe are subjected to electric resistance welding using a power feed terminal 60 and a welding roll 70, thereby obtaining an electric resistance welded steel pipe 200.

[0185] The production method A may include other steps, if necessary.

[0186] Examples of the other steps include a step of subjecting the electric resistance welded portion of the electric resistance welded steel pipe to seam heat treatment after the pipe-making step, and a step of adjusting the shape of the electric resistance welded steel pipe by a sizing roll after the pipe-making step.

EXAMPLES

[0187] Examples of the disclosure will be described below. However, the disclosure is not limited to the following Examples.

[Test Numbers 1 to 26]

[0188] An electric resistance welded steel pipe of each Test Number was produced in accordance with the production method A described above.

[0189] The details will be described below.

<Production of Slab and Hot Coil>

[0190] Slabs were produced by continuous casting of molten steel having chemical compositions of Steel A to Steel O set forth in Table 1. REM in Steel L is specifically Ce.

[0191] Each of the slabs described above was heated in a heating furnace, the heated slab was hot-rolled using multiple hot rolling mills to obtain a hot-rolled steel sheet, the obtained hot-rolled steel sheet was air-cooled and then water-cooled, and the water-cooled hot-rolled steel sheet was coiled, whereby a hot coil consisting of the hot-rolled steel sheet was obtained.

[0192] The heating temperature in heating the slab, the finish rolling temperature in the hot-rolling, the cooling rates in water-cooling the hot-rolled steel sheet (V1 and V2), and the coiling temperature in coiling the water-cooled hot-rolled steel sheet are respectively set forth in Table 2.

[0193] In the water-cooling of the hot-rolled steel sheet, the upper surface of the hot-rolled steel sheet was set as a first surface, the cooling rate of the first surface was set as V1, the lower surface of the hot-rolled steel sheet was set as a second surface, and the cooling rate of the second surface was set as V2.

[0194] The water-cooling of the hot-rolled steel sheet was performed by spraying the upper surface (i.e., first surface) and the lower surface (i.e., second surface) of the hot-rolled steel sheet, respectively, with a water-cooling shower. In this case, the water flow density of the water-cooling shower for the upper surface and the water flow density of the water-cooling shower for the lower surface were respectively adjusted, so that V1 and V2 were adjusted to be values set forth in Table 2.

[0195] A conventional standard condition of water-cooling is a condition of Test Number 12 (Comparative Example).

<Production of Electric Resistance Welded Steel Pipe>

[0196] The hot-rolled steel sheet was uncoiled from the hot coil described above, the uncoiled hot-rolled steel sheet was roll-formed in a direction such that the first surface is an outer peripheral surface and the second surface is an inner peripheral surface of a pipe to thereby make an open pipe, and abutting portions of the obtained open pipe was subjected to electric resistance welding to form an electric resistance welded portion, thereby obtaining an electric resistance welded steel pipe (hereinafter also referred to as "electric resistance welded steel pipe before shape adjustment"). Then, the electric resistance welded portion of the electric resistance welded steel pipe before shape adjustment was subjected to seam heat treatment, and the shape was then adjusted by a sizing roll, thereby obtaining an electric resistance welded steel pipe (i.e., as-rolled electric resistance welded steel pipe) having an outer diameter of 406.4 mm and a wall thickness of 15.9 mm.

[0197] Only in Test Number 16 (Comparative Example), the electric resistance welded steel pipe after the seam heat treatment (i.e., as-rolled electric resistance welded steel pipe) was further subjected to heat treatment at a heating temperature of 760°C for 30 minutes, and then water-cooled.

[0198] 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 molten steel which is a raw material.

<Measurement and Evaluation>

[0199] The following measurement and evaluation were performed for the electric resistance welded steel pipe after the shape adjustment by a sizing roll in each Test Number.
[0200] The results are set forth in Table 2.

(Measurement of Ferrite Fraction and Confirmation of Kind of Balance)

[0201] By the method described above, the ferrite fraction (hereinafter also referred to as "F fraction") was measured, and the kind of the balance was confirmed.
[0202] In Table 2, "B" means bainite, "P" means pearlite, and "M" means martensite.

(Maximum Vickers Hardness)

[0203] The maximum Vickers hardness of the inner surface layer of the base metal portion (HV) and the maximum Vickers hardness of the outer surface layer of the base metal portion (HV) were respectively measured based on the measurement method described above.
[0204] The outer-inner hardness difference was calculated based on the measurement result by the following Formula.
[0205] Outer-inner Hardness Difference (HV) = Maximum Vickers Hardness of Outer Surface Layer of Base Metal Portion (HV) - Maximum Vickers Hardness of Inner Surface Layer of Base Metal Portion (HV)

(YS, TS)

[0206] The YS (MPa) and the TS (MPa) in the pipe axis direction of the electric resistance welded steel pipe were respectively measured based on the measurement method described above.
[0207] In the tensile test in the pipe axis direction in the measurement of the YS and the TS, yield elongation was observed in Test Number 16 (Comparative Example), but yield elongation was not observed in all the other Test Numbers.

(Evaluation of SSC Resistance)

[0208] A full thickness specimen having a size of 120 mm (pipe circumferential direction) × 25 mm (pipe axis direction) was sampled from the base metal 180° position of the electric resistance welded steel pipe.
[0209] In a state where a load corresponding to 90% of the YS is applied to the sampled specimen in accordance with EFC (European Federation of Corrosion Publications) No. 16 Method B (four-point bend test), the specimen was immersed for 720 hours in the following test bath. As the test bath, a liquid obtained by saturating hydrogen sulfide gas in an aqueous solution including 5% by mass of sodium chloride and 0.4% by mass of sodium acetate was used. The temperature of the test bath during the immersion was ordinary temperature (23°C).
[0210] Whether the specimen was fractured or not was confirmed after a lapse of 720 hours since the start of the immersion. As a result of the confirmation, a case in which a fracture was not observed in the specimen was determined to be "A" (i.e., the SSC resistance of the steel is high), and a case in which a fracture was observed in the specimen was determined to be "B" (i.e., the SSC resistance of the steel is low).

[Table 1]

Steel	Chemical Composition (Unit is % by Mass, Balance is Fe and Impurities)																
	C	Si	Mn	P	S	Al	N	Nb	Ti	Ni	Mo	Ca	Cr	V	Cu	Mg	REM
A	0.06	0.19	1.14	0.009	0.0008	0.027	0.0035	0.034	0.014	-	-	-	-	-	-	-	-
B	0.10	0.38	1.00	0.010	0.0005	0.030	0.0030	0.050	0.015	-	-	-	-	-	-	-	-
C	0.04	0.30	1.20	0.009	0.0003	0.035	0.0040	0.025	0.010	-	-	-	-	-	-	-	-
D	0.03	0.20	1.25	0.010	0.0008	0.030	0.0035	0.025	0.015	0.09	-	-	-	-	-	-	-
E	0.08	0.25	1.30	0.010	0.0006	0.035	0.0032	0.040	0.013	-	0.18	-	-	-	-	-	-
F	0.07	0.18	1.22	0.010	0.0004	0.032	0.0034	0.028	0.015	-	-	0.0038	-	-	-	-	-
G	0.06	0.19	1.25	0.010	0.0005	0.035	0.0035	0.030	0.015	0.08	-	0.0035	-	-	-	-	-
H	0.04	0.14	1.25	0.010	0.0004	0.027	0.0038	0.020	0.012	-	-	-	0.04	-	-	-	-
I	0.05	0.17	1.24	0.015	0.0007	0.022	0.0034	0.034	0.017	-	-	-	-	0.020	-	-	-
J	0.09	0.18	1.30	0.020	0.0008	0.027	0.0032	0.030	0.014	-	-	-	-	-	0.20	-	-
K	0.07	0.19	1.10	0.011	0.0005	0.024	0.0034	0.032	0.015	-	-	-	-	-	-	0.0020	-
L	0.06	0.21	1.14	0.021	0.0003	0.027	0.0035	0.021	0.016	-	-	-	-	-	-	-	0.0020
M	0.05	0.19	1.15	0.010	0.0008	0.027	0.0035	0.036	0.014	0.10	0.18	0.0026	-	-	-	-	-
N	0.06	0.18	1.21	0.010	0.0007	0.025	0.0035	0.030	0.014	-	-	0.0032	-	-	-	-	-
O	0.07	0.14	1.31	0.010	0.0004	0.027	0.0038	0.028	0.014	-	-	0.0042	-	-	-	-	-

[Table 2]

Test Number	Steel	Heating Temperature (°C)	Finish Rolling Temperature (°C)	Cooling Rate (°C/s)		Coiling Temperature (°C)	Heat Treatment after Pipe-making	F Fraction (%)	Kind of Balance	Maximum Vickers Hardness (HV)		Outer-inner Hardness Difference (HV)	YS (MPa)	TS (MPa)	SSC Resistance	Remarks
				Upper Surface (VI)	Lower Surface (V2)					Outer Surface Layer	Inner Surface Layer					
1	A	1200	790	10	5	550	Absence	81	P, B	224	210	14	525	580	A	Example
2	B	1230	780	23	1	540	Absence	82	P, B	210	200	10	550	585	A	Example
3	C	1150	820	24	15	560	Absence	85	P, B	230	220	10	530	570	A	Example
4	D	1120	790	20	10	580	Absence	90	P, B	225	215	10	520	580	A	Example
5	E	1170	795	8	3	570	Absence	82	P, B	212	206	6	540	585	A	Example
6	F	1100	790	17	10	530	Absence	88	P, B	230	220	10	550	585	A	Example
7	G	1120	780	21	12	585	Absence	84	P, B	223	213	10	545	605	A	Example
8	A	1270	790	10	5	550	Absence	83	P, B	224	210	14	530	585	A	Example
9	A	1200	840	18	10	540	Absence	95	P, B	254	240	14	560	630	A	Comparative Example
10	A	1180	780	30	20	560	Absence	95	P, B	250	230	20	562	632	A	Comparative Example
11	A	1170	790	2	1	550	Absence	82	P, B	180	175	5	530	590	A	Example
12	A	1180	790	25	24	540	Absence	76	P, B	253	250	3	560	630	B	Comparative Example
13	A	1150	785	15	8	620	Absence	84	P, B	226	210	16	530	580	A	Example
14	A	1080	792	10	5	550	Absence	87	P, B	210	205	5	545	585	A	Example
15	A	1100	775	17	10	530	Absence	90	P. B	253	240	13	552	628	A	Comparative Example

(continued)

Test Number	Steel	Heating Temperature (°C)	Finish Rolling Temperature (°C)	Cooling Rate (°C/s)		Coiling Temperature (°C)	Heat Treatment after Pipe-making	F Fraction (%)	Kind of Balance	Maximum Vickers Hardness (HV)		Outer-inner Hardness Difference (HV)	YS (MPa)	TS (MPa)	SSC Resistance	Remarks
				Upper Surface (VI)	Lower Surface (V2)					Outer Surface Layer	Inner Surface Layer					
16	A	1120	790	21	10	550	Presence (760°C)	60	B, M	276	256	20	560	630	B	Comparative Example
17	H	1130	790	11	6.2	560	Absence	87	P, B	217	210	7	545	590	A	Example
18	I	1140	780	13	8.1	570	Absence	89	P, B	230	220	10	545	580	A	Example
19	J	1150	820	20	10.1	550	Absence	91	P, B	220	214	6	538	575	A	Example
20	K	1160	810	21	12.1	560	Absence	92	P, B	222	214	8	540	580	A	Example
21	L	1140	800	14	8.1	580	Absence	93	P, B	214	206	8	545	585	A	Example
22	M	1130	810	15	8.6	590	Absence	95	P, B	217	207	10	535	580	A	Example
23	N	1120	800	17	6.3	540	Absence	94	P, B	218	210	8	539	578	A	Example
24	O	1140	810	19	5.4	560	Absence	97	P, B	217	208	9	540	580	A	Example
25	A	1150	800	27	0.3	560	Absence	93	P, B	267	170	97	400	430	A	Comparative Example
26	B	1150	810	12	11	550	Absence	92	P, B	233	230	3	406	438	A	Comparative Example

[0211] As set forth in Table 1 and Table 2, the electric resistance welded steel pipe of each Example, which satisfies the chemical composition and the metallographic microstructure of the base metal portion in the disclosure, satisfies the YS (i.e., from 415 to 550 MPa) and the TS (i.e., from 461 to 625 MPa) in the disclosure, has the maximum Vickers hardness of the inner surface layer of the base metal portion of 248 HV or less, and has the outer-inner hardness difference of 5 HV or more, had excellent SSC resistance.

[0212] In contrast, in Test Number 12 (Comparative Example), the SSC resistance was deteriorated. The reason thereof is considered that the maximum Vickers hardness of the inner surface layer exceeded the upper limit, both the TS and the YS exceeded the upper limit, and the outer-inner hardness difference was less than 5 HV.

[0213] Moreover, also in Test Number 16 (Comparative Example), the SSC resistance was deteriorated. The reason thereof is considered that martensite was contained in the metallographic microstructure of the base metal portion because tempering was performed after pipe-making.

[0214] Test Numbers 9, 10, and 15 are all Comparative Examples in which the TS and the YS exceeded the upper limit, and Test Numbers 25 and 26 are Comparative Examples in which the TS and the YS were lower than the lower limit.

[0215] In Test Number 26 (Comparative Example), since the outer-inner hardness difference was less than 5 HV although the maximum Vickers hardness of the inner surface layer of the base metal portion was 248 HV or less, the SSC resistance was excellent, but the TS and the YS were lower than the lower limit.

[0216] The entire disclosure of Japanese Patent Application No. 2016-068749 is incorporated herein by reference.

[0217] 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 as-rolled 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:

from 0.01 to 0.10% of C,
from 0.01 to 0.40% of Si,
from 0.50 to 2.00% of Mn,
from 0 to 0.030% of P,
from 0 to 0.0015% of S,
from 0.010 to 0.050% of Al,
from 0.0030 to 0.0080% of N,
from 0.010 to 0.050% of Nb,
from 0.005 to 0.020% of Ti,
from 0 to 0.20% of Ni,
from 0 to 0.20% of Mo,
from 0 to 0.0050% of Ca,
from 0 to 1.00% of Cr,
from 0 to 0.100% of V,
from 0 to 1.00% of Cu,
from 0 to 0.0050% of Mg,
from 0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:

in a metallographic microstructure of the base metal portion, an areal ratio of polygonal ferrite is from 80% to 98%, the balance is composed of at least one of bainite or pearl ite,
a yield strength in a pipe axis direction is from 415 to 550 MPa, a tensile strength in the pipe axis direction is from 461 to 625 MPa, and
a maximum Vickers hardness of an inner surface layer of the base metal portion is 248 HV or less and is smaller than a maximum Vickers hardness of an outer surface layer of the base metal portion by 5 HV or more.

2. The as-rolled electric resistance welded steel pipe for a line pipe according to claim 1, wherein the chemical composition of the base metal portion contains, in terms of % by mass, one or more selected from the group consisting of:

more than 0% but equal to or less than 0.20% of Ni,

more than 0% but equal to or less than 0.20% of Mo,
more than 0% but equal to or less than 0.0050% of Ca,
more than 0% but equal to or less than 1.00% of Cr,
more than 0% but equal to or less than 0.10% of V,
more than 0% but equal to or less than 1.00% of Cu,
more than 0% but equal to or less than 0.0050% of Mg, and
more than 0% but equal to or less than 0.0100% of REM.

3. The as-rolled electric resistance welded steel pipe for a line pipe according to claim 1 or 2, wherein the chemical composition of the base metal portion contains, in terms of % by mass, one or more selected from the group consisting of:

from 0.001 to 0.20% of Ni, and
from 0.1 to 0.20% of Mo.

4. The as-rolled electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 3, wherein the chemical composition of the base metal portion contains, in terms of % by mass, from 0.0005 to 0.0050% of Ca.

5. The as-rolled electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 4, wherein a wall thickness is from 10 to 25 mm, and an outer diameter is from 114.3 mm to 660.4 mm.

FIG.1

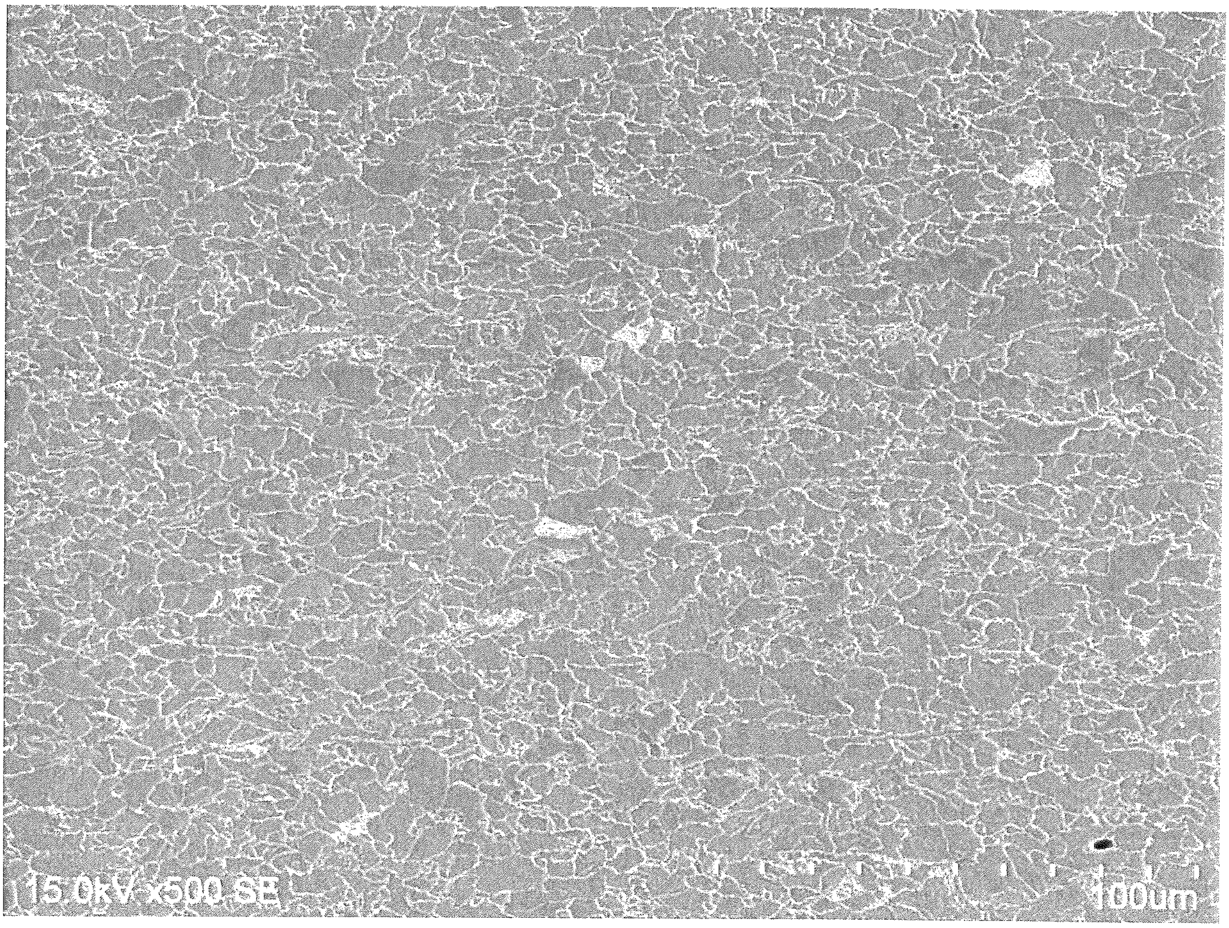


FIG.2

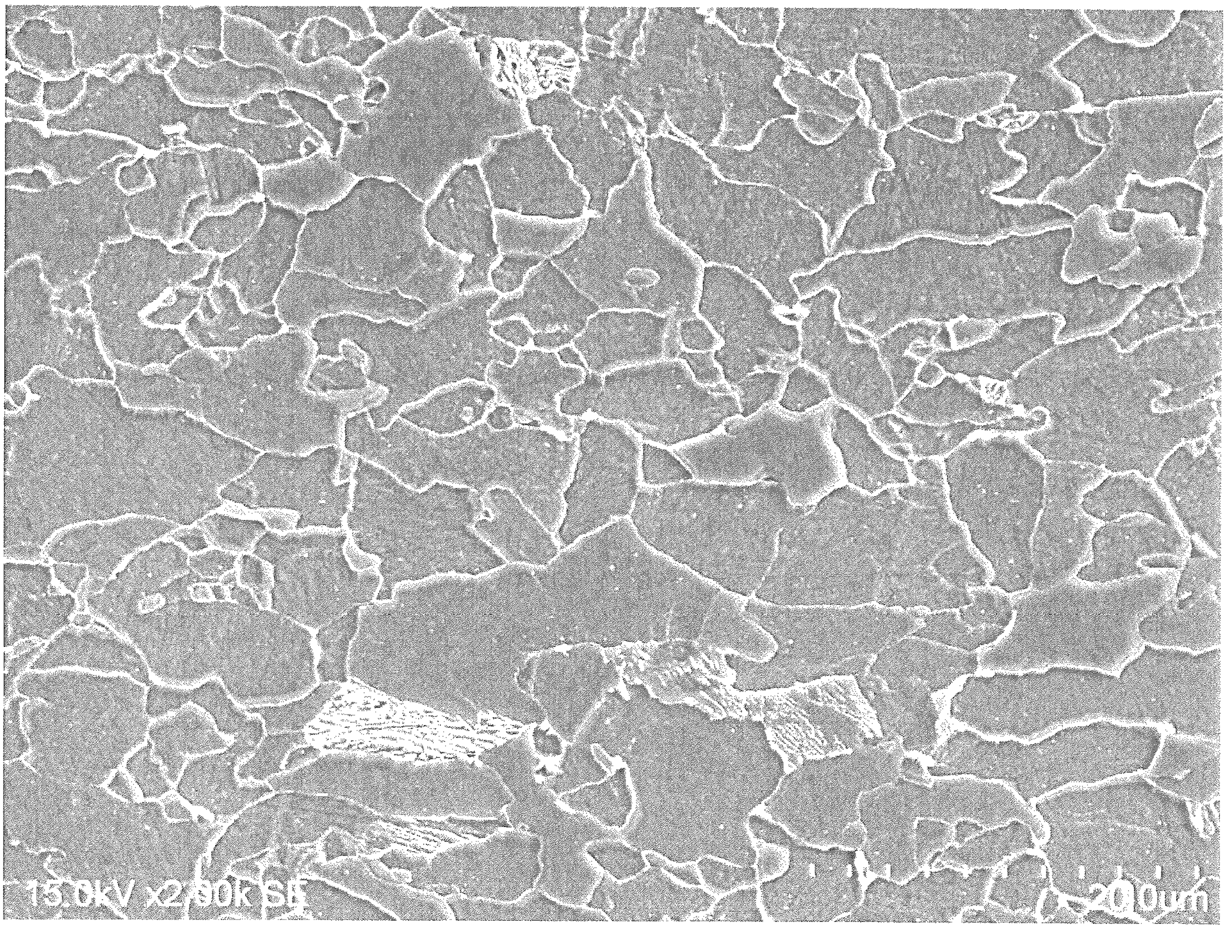


FIG.3

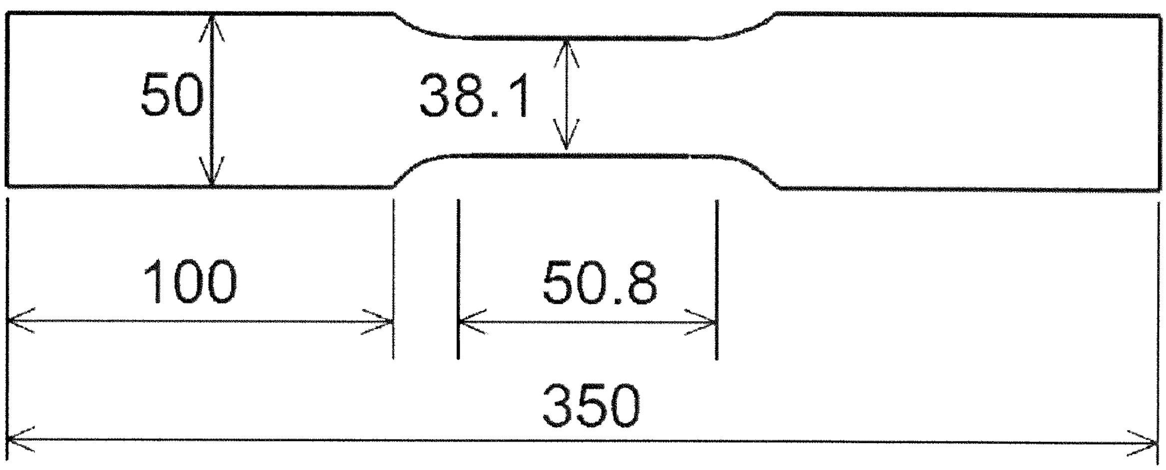
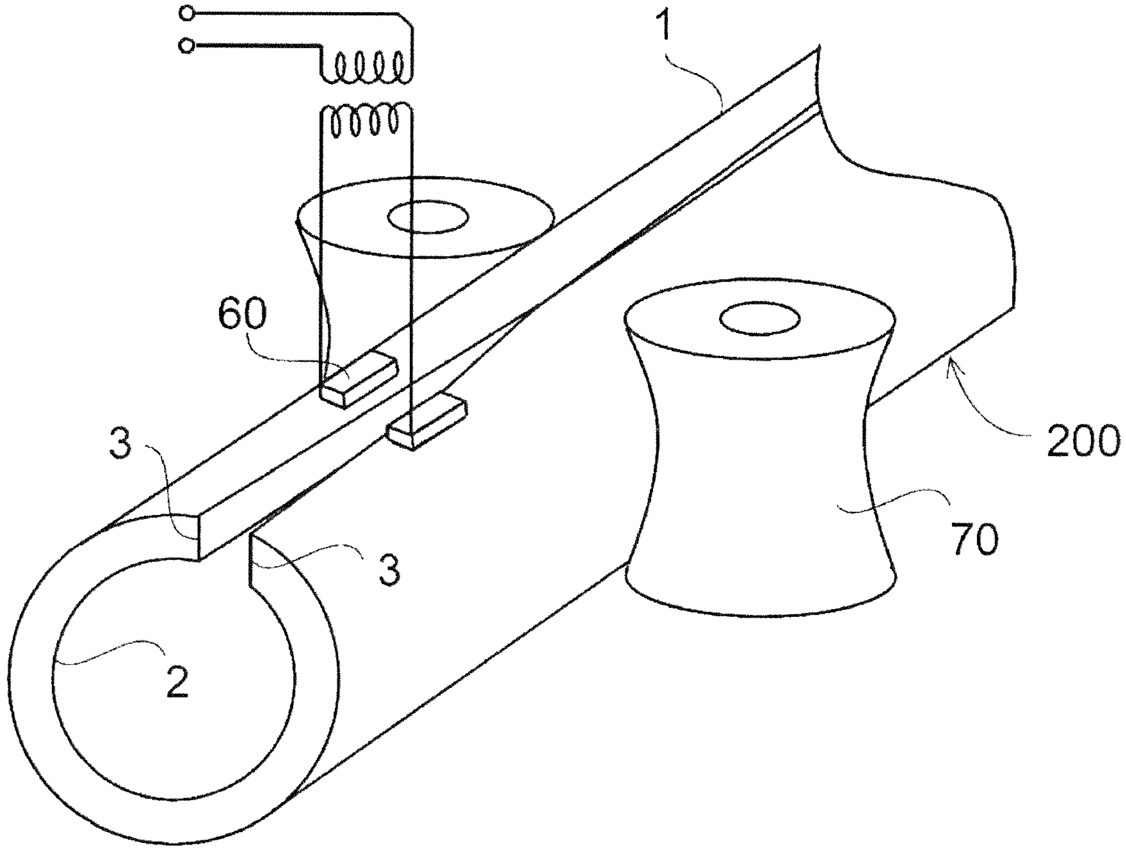


FIG.4



INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2017/013013

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D8/10*(2006.01)i, *C21D9/08*(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)
C22C38/00, C21D8/10, C21D9/08, C22C38/58

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)
JSTPlus/JMEDPlus/JST7580(JDreamIII)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2013/027779 A1 (Nippon Steel & Sumitomo Metal Corp.), 28 February 2013 (28.02.2013), paragraphs [0001], [0008] to [0055], [0082] to [0084] & EP 2752499 A1 paragraphs [0001], [0008] to [0049], [0073] & KR 10-2013-0058074 A & CN 103249854 A & CA 2832021 A1	1-5
Y	JP 2012-241273 A (JFE Steel Corp.), 10 December 2012 (10.12.2012), claims; paragraphs [0004], [0010], [0014], [0020] to [0022], [0053], [0056] to [0058], [0065] to [0072] (Family: none)	1-5

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search: 21 June 2017 (21.06.17)	Date of mailing of the international search report: 04 July 2017 (04.07.17)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/013013

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013/153819 A1 (JFE Steel Corp.), 17 October 2013 (17.10.2013), & US 2015/0083266 A1 & EP 2837708 A1 & CA 2869879 A1 & CN 104220622 A & KR 10-2014-0138942 A & RU 2014145519 A	1-5
A	WO 2016/143270 A1 (JFE Steel Corp.), 15 September 2016 (15.09.2016), (Family: none)	1-5

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2016068749 A **[0216]**