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(54) AS-ROLL ELECTRIC RESISTANCE-WELDED STEEL PIPE FOR LINE PIPE, AND HOT-ROLLED STEEL SHEET

(57) An as-rolled electric resistance welded steel pipe for a line pipe, in which a base metal portion includes, in terms of % by mass, 0.030 to 0.120% of C, 0.05 to 0.30% of Si, 0.50 to 2.00% of Mn, 0.010 to 0.035% of Al, 0.0010 to 0.0080% of N, 0.010 to 0.080% of Nb, 0.005 to 0.030% of Ti, 0.001 to 0.20% of Ni, and 0.10 to 0.20% of Mo, and the balance includes Fe and impurities, wherein the following F1 is from 0.300 to 0.350, and wherein in a metallographic microstructure of a wall thickness direction central portion of the base metal portion, a polygonal ferrite fraction is from 60 to 90%, an average crystal grain diameter is 15 μm or less, and a coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, is 20% or less; F1 = C + Si/24 + Mn/6 + Ni/40 + Cr/5 + Mo/4 + V/3 + Nb/3.

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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 and a hot-rolled steel sheet.

Background Art

[0002] Conventionally, various measures have been considered for steel pipes for a line pipe, which are used in the production of a pipeline, and hot-rolled steel sheets used in the production of the steel pipes for a line pipe.

[0003] For example, as a high-strength hot-rolled steel sheet for a spiral line pipe, which has excellent low-temperature toughness, Patent Document 1 discloses a hot-rolled steel sheet including, in terms of % by mass, from 0.02 to 0.08% of C, from 0.05 to 0.5% of Si, from 1 to 2% of Mn, from 0.03 to 0.12% of Nb, from 0.005 to 0.05% of Ti, and the balance being Fe and inevitable impurity elements, in which a pro-eutectoid ferrite fraction is from 3% to 20% and the others are a low-temperature transformation phase and pearlite of 1% or less in a microstructure at a depth of a half thickness of a wall thickness from a steel sheet surface, a number average crystal grain diameter of the whole of the microstructure is from 1 μm to 2.5 μm and an area average grain diameter is from 3 μm to 9 μm, a standard deviation of the area average grain diameter is from 0.8 μm to 2.3 μm, and a reflected X-ray intensity ratio {211}/{111} of a {211} direction and a {111} direction with respect to a plane parallel to the steel sheet surface at the depth of the half thickness of the wall thickness from the steel sheet surface is 1.1 or more.

[0004] Patent Document 1 states that the hot-rolled steel sheet described therein can be used in the production of an electric resistance welded steel pipe or a spiral steel pipe.

[0005] Patent Document 1: WO 2012/002481

SUMMARY OF INVENTION

Technical Problem

[0006] As welded steel pipes among steel pipes for a line pipe, UOE steel pipes produced using heavy plates (for example, heavy plates having a wall thickness of 30 mm or more), or electric resistance welded steel pipes or spiral steel pipes produced using hot coils made of hot-rolled steel sheets are used.

[0007] For the steel pipes for a line pipe, low-temperature toughness evaluated by DWTT (Drop Weight Tear Test) (hereinafter, also simply referred to as "low-temperature toughness") may be required. Specifically, the lower a DWTT guarantee temperature, which is the lowest temperature value at which a percent ductile fracture is 85% or more, is, the more excellent the low-temperature toughness is.

[0008] Generally, the low-temperature toughness tends to be required for the steel pipes for a line pipe, which have a thick wall thickness. This is because the wall thickness of the steel pipes for a line pipe being thick is advantageous in the strength but disadvantageous in the low-temperature toughness.

[0009] Accordingly, in the field of the UOE steel pipes having a relatively thick wall thickness, conventionally, the low-temperature toughness has received attention.

[0010] In contrast, in the field of the electric resistance welded steel pipes having a relatively thin wall thickness, the low-temperature toughness has received little attention.

[0011] As the reason why the low-temperature toughness has received attention in the field of the UOE steel pipes and the low-temperature toughness has received little attention in the field of the electric resistance welded steel pipes, there is the following reason in the production.

[0012] A heavy plate process for producing heavy plates as materials of the UOE steel pipes has a relatively high degree of freedom with respect to production conditions. For example, in the heavy plate process, low-temperature rolling is easily performed, and, for cooling after the rolling, complex controlled cooling is easily performed. Accordingly, in the field of the UOE steel pipes, in order to improve the low-temperature toughness of the UOE steel pipes, in the heavy plate process, fine adjustment of a metallographic microstructure by the low-temperature rolling, the complex controlled cooling, and the like has been generally performed.

[0013] In contrast, a hot-rolling process for producing hot coils (specifically, hot-rolled steel sheets in the form of hot coils) as materials of the electric resistance welded steel pipes has a lower degree of freedom with respect to production conditions compared to the heavy plate process due to limitations of equipment focusing on the productivity. For example, in the hot-rolling process, a hot-rolled steel sheet after rolling is cooled to a coiling temperature (CT) of, for example, about from 400 to 600°C, and then coiled into a coil shape. In the hot-rolling process, low-temperature rolling and complex controlled cooling after the rolling are more difficult to be performed compared to the heavy plate process due to the limitations. Because of these circumstances, in the field of the electric resistance welded steel pipes, the idea itself, of performing fine adjustment of a metallographic microstructure in the hot-rolling process in order to improve the low-temperature toughness of the electric resistance welded steel pipes, was difficult to conceive of.

[0014] In many cases, even if the chemical compositions are the same, the heavy plates and the UOE steel pipes as end products thereof, and the hot-rolled steel sheets and the electric resistance welded steel pipes as end products thereof are totally different in the metallographic microstructure and/or the strength. Because of these circumstances, the problem which receives attention in the UOE steel pipes (i.e., low-temperature toughness) does not necessarily also receive attention in the same manner in the electric resistance welded steel pipes.

[0015] For example, in the heavy plate process, since a heavy plate after the stop of cooling is air-cooled in a state of (not coiled) one heavy plate from the sides of both surfaces, a cooling rate during the air-cooling is relatively fast. In contrast, in the hot-rolling process, since a hot-rolled steel sheet after the stop of cooling is air-cooled in the form of a hot coil, a cooling rate during the air-cooling is relatively slow. In the hot-rolling process, since the cooling rate in the air-cooling in the form of a hot coil is slow, the metallographic microstructure may be substantially tempered during the air-cooling in the form of a hot coil.

[0016] As described above, conventionally, the low-temperature toughness has received attention in the field of the UOE steel pipes for a line pipe, but the low-temperature toughness has received little attention for the electric resistance welded steel pipes for a line pipe.

[0017] However, recently, the low-temperature toughness is likely to be required for the electric resistance welded steel pipes for a line pipe because of a circumstance in which a laying environment of a pipeline becomes more severe, a circumstance in which the production of electric resistance welded steel pipes having a thick wall thickness becomes possible due to the progress of a production technology of electric resistance welded steel pipes, and the like.

[0018] Patent Document 1 described above is one of the few documents focusing on the low-temperature toughness of hot-rolled steel sheets which may be used in the production of electric resistance welded steel pipes.

[0019] However, for the technology disclosed in Patent Document 1, the low-temperature toughness may be required to be further improved.

[0020] The disclosure was made in view of the circumstances described above.

[0021] An object of the disclosure is to provide an as-rolled electric resistance welded steel pipe for a line pipe, which has excellent low-temperature toughness evaluated by DWTT, and a hot-rolled steel sheet suitable for the production of the as-rolled electric resistance welded steel pipe for a line pipe.

Solution to Problem

[0022] 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 0.030 to 0.120% of C,
from 0.05 to 0.30% of Si,
from 0.50 to 2.00% of Mn,
from 0 to 0.030% of P,
from 0 to 0.0100% of S,
from 0.010 to 0.035% of Al,
from 0.0010 to 0.0080% of N,
from 0.010 to 0.080% of Nb,
from 0.005 to 0.030% of Ti,
from 0.001 to 0.20% of Ni,
from 0.10 to 0.20% of Mo,
from 0 to 0.010% of V,
from 0 to 0.0030% of O,
from 0 to 0.0050% of Ca,
from 0 to 0.30% of Cr,
from 0 to 0.30% of Cu,
from 0 to 0.0050% of Mg,
from 0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:

F1 defined by the following Formula (1) is from 0.300 to 0.350,
in a metallographic microstructure of a wall thickness direction central portion of the base metal portion, a polygonal ferrite fraction is from 60 to 90%, an average crystal grain diameter is 15 μm or less, and a coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, is 20% or less, and
a yield ratio in a pipe axis direction is from 80 to 95%.

$$F1 = C + Si/24 + Mn/6 + Ni/40 + Cr/5 + Mo/4 + V/3 + Nb/3 \quad \text{Formula (1)}$$

(In Formula (1), each of C, Si, Mn, Ni, Cr, Mo, V, and Nb represents mass% of a corresponding element.)

<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 0.010% of V,
more than 0% but equal to or less than 0.0030% of Ca,
more than 0% but equal to or less than 0.30% of Cr,
more than 0% but equal to or less than 0.30% 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 a yield strength in the pipe axis direction is from 450 to 540 MPa, and a tensile strength in the pipe axis direction is from 510 to 625 MPa.
<4> The as-rolled electric resistance welded steel pipe for a line pipe according to any one of <1> to <3>, wherein a wall thickness is from 12 to 25 mm, and an outer diameter is from 304.8 to 660.4 mm.
<5> The as-rolled electric resistance welded steel pipe for a line pipe according to any one of <1> to <4>, wherein the yield ratio in the pipe axis direction is from 80 to 93%.
<6> A hot-rolled steel sheet used in the production of the as-rolled electric resistance welded steel pipe for a line pipe according to any one of <1> to <5>,
wherein a chemical composition consists of, in terms of % by mass:

from 0.030 to 0.120% of C,
from 0.05 to 0.30% of Si,
from 0.50 to 2.00% of Mn,
from 0 to 0.030% of P,
from 0 to 0.0100% of S,
from 0.010 to 0.035% of Al,
from 0.0010 to 0.0080% of N,
from 0.010 to 0.080% of Nb,
from 0.005 to 0.030% of Ti,
from 0.001 to 0.20% of Ni,
from 0.10 to 0.20% of Mo,
from 0 to 0.010% of V,
from 0 to 0.0030% of O,
from 0 to 0.0050% of Ca,
from 0 to 0.30% of Cr,
from 0 to 0.30% of Cu,
from 0 to 0.0050% of Mg,
from 0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:

F1 defined by Formula (1) is from 0.300 to 0.350, and
in a metallographic microstructure of a wall thickness direction central portion, a polygonal ferrite fraction

is from 60 to 90%, an average crystal grain diameter is 15 μm or less, and a coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, is 20% or less.

<7> The hot-rolled steel sheet according to <6>, wherein a yield strength in a rolling direction is from 450 to 500 MPa, and a tensile strength in the rolling direction is from 510 to 580 MPa.

Advantageous Effects of Invention

[0023] According to the disclosure, an as-rolled electric resistance welded steel pipe for a line pipe, which has excellent low-temperature toughness evaluated by DWTT, and a hot-rolled steel sheet suitable for the production of the as-rolled electric resistance welded steel pipe for a line pipe are provided.

BRIEF DESCRIPTION OF DRAWINGS

[0024]

Fig. 1 is a KAM map used in measurement of a polygonal ferrite fraction in an example of a metallographic microstructure of a base metal portion in the disclosure.
Fig. 2 is a 15° high angle grain boundary map used in measurement of an average crystal grain diameter and a coarse crystal grain ratio in an example of the metallographic microstructure of the base metal portion in the disclosure.
Fig. 3 is a scanning electron micrograph (SEM micrograph; a magnification of 500 times) showing an example of the metallographic microstructure of the base metal portion in the disclosure.
Fig. 4 is a schematic front view of a tensile test specimen in the disclosure.
Fig. 5 is a continuous cooling transformation diagram (CCT diagram) in the case of producing a hot-rolled steel sheet according to an example of the disclosure.
Fig. 6 is a schematic front view of a DWTT test specimen in the disclosure.

DESCRIPTION OF EMBODIMENTS

[0025] 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.
[0026] The content of a component (element) expressed by "%" herein means "% by mass".
[0027] 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.
[0028] 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.
[0029] 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".
[0030] 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.
[0031] 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.
[0032] Herein, the "roll-forming" refers to forming of a hot-rolled steel sheet into an open pipe shape by bending work.

[As-rolled Electric Resistance Welded Steel Pipe for Line Pipe]

[0033] 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 0.030 to 0.120% of C, from 0.05 to 0.30% of Si, from 0.50 to 2.00% of Mn, from 0 to 0.030% of P, from 0 to 0.0100% of S, from 0.010 to 0.035% of Al, from 0.0010 to 0.0080% of N, from 0.010 to 0.080% of Nb, from 0.005 to 0.030% of Ti, from 0.001 to 0.20% of Ni, from 0.10 to 0.20% of Mo, from 0 to 0.010% of V, from 0 to 0.0030% of O, from 0 to 0.0050% of Ca, from 0 to 0.30% of Cr, from 0 to 0.30% of Cu, from 0 to 0.0050% of Mg, from 0 to 0.0100% of REM, and the balance being Fe and impurities, wherein: F1 defined by the following Formula (1) is from 0.300 to 0.350, in a metallographic microstructure of a wall thickness direction central portion of the base metal portion, a polygonal ferrite fraction is from 60 to 90%, an average crystal grain diameter is 15 μm or less, and a coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, is 20% or less, and a yield ratio in a pipe axis direction is from 80 to 95%.

$$F1=C+Si/24+Mn/6+Ni/40+Cr/5+Mo/4+V/3+Nb/3 \quad \text{Formula (1)}$$

(In Formula (1), each of C, Si, Mn, Ni, Cr, Mo, V, and Nb represents % by mass of a corresponding element.)

[0034] 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.

[0035] 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).

[0036] The electric resistance welded steel pipe of the disclosure has excellent low-temperature toughness (i.e., low-temperature toughness evaluated by DWTT).

[0037] Such an effect is achieved by the chemical composition of the base metal portion described above (including F1 being from 0.300 to 0.350) and the metallographic microstructure of the base metal portion described above (approximately speaking, the metallographic microstructure in which crystal grains are refined).

[0038] The metallographic microstructure of the base metal portion is achieved by a chemical composition and a production condition of a hot-rolled steel sheet as a material. The chemical composition of the base metal portion and the metallographic microstructure of the base metal portion, and a preferred production condition of the hot-rolled steel sheet will be described later.

[0039] As described above, the electric resistance welded steel pipe of the disclosure has excellent low-temperature toughness.

[0040] Thus, the electric resistance welded steel pipe of the disclosure is suitable as, for example, one member for forming a submarine pipeline which undergoes cyclic straining due to waves or one member for forming a line pipe for cold climates.

[0041] The electric resistance welded steel pipe of the disclosure has a yield ratio in a pipe axis direction of from 80 to 95%

[0042] A yield ratio of the electric resistance welded steel pipe of 95% or less secures a plastic deformation allowance required as a steel pipe for a line pipe. A yield ratio of the electric resistance welded steel pipe of 95% or less more suppresses buckling in the case of laying a pipeline formed using the electric resistance welded steel pipe by a reeling method or the like.

[0043] A yield ratio of the electric resistance welded steel pipe of 80% or more has excellent production suitability of the electric resistance welded steel pipe.

<Chemical Composition of Base Metal Portion>

[0044] The chemical composition of the base metal portion in the disclosure will be described.

[0045] Hereinafter, the chemical composition of the base metal portion in the disclosure (including F1 being from 0.300 to 0.350) is referred to as the "chemical composition in the disclosure".

C: from 0.030 to 0.120%

[0046] 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 0.030% or more. The C content is preferably 0.035% or more, and more preferably 0.045% or more.

[0047] In contrast, in a case in which the C content is too high, a carbide is generated, and the low-temperature toughness and the ductility of steel are decreased. Accordingly, the C content is 0.120% or less. The C content is preferably 0.110% or less.

[0048] The mere term "strength" herein means a tensile strength (hereinafter, also referred to as "TS") and/or a yield strength (hereinafter, also referred to as "YS").

Si: from 0.05 to 0.30%

[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 0.05% or more. The Si content is preferably 0.10% or more, and still more preferably 0.15% or more.

[0050] In contrast, in a case in which the Si content is too high, the low-temperature toughness of steel is decreased. Accordingly, the Si content is 0.30% or less. The Si content is preferably 0.25% or less, and more preferably 0.21% 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 0.80% or more, and more preferably 1.00% or more.
[0052] In contrast, in a case in which the Mn content is too high, the strength of steel becomes too high, and the low-temperature toughness of steel is 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 decreases the low-temperature toughness of steel. Accordingly, a P content is preferably small. Specifically, the P content is 0.030% or less. The P content is preferably 0.020% or less, and more preferably 0.015% 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%, may be 0.001% or more, and may be 0.005% or more.

S: from 0 to 0.0100%

[0055] S is an impurity. S binds to Mn to form a Mn-based sulfide. Thus, in a case in which a S content is too high, the low-temperature toughness and the sour resistance of steel are decreased. Accordingly, the S content is 0.0100% or less. The S content is preferably 0.0080% or less, and more preferably 0.0050% 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, may be 0.0010% or more, and may be 0.0020% or more.

Al: from 0.010 to 0.035%

[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 0.015% or more, and more preferably 0.020% or more.
[0058] In contrast, in a case in which the Al content is too high, an Al oxide is coarsened, and the low-temperature 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 0.0010 to 0.0080%

[0060] N forms a nitride to suppress coarsening of austenite grains in a heating step. In this case, the austenite grains are refined in a rolling step, and crystal grains after transformation become fine. Therefore, the low-temperature toughness of steel is enhanced. N further 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 0.0010% or more. The N content is preferably 0.0020% or more, and more preferably 0.0025% or more.
[0061] In contrast, in a case in which the N content is too high, a carbonitride is coarsened, and the low-temperature toughness of steel 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 0.0050% or less.

Nb: from 0.010 to 0.080%

[0062] Nb binds to C and N in the steel to form a fine Nb carbonitride. The Nb carbonitride suppresses coarsening of crystal grains, and the average crystal grain diameter becomes small. Thus, the low-temperature toughness of steel is enhanced. Furthermore, 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 0.015% or more.
[0063] In contrast, in a case in which the Nb content is too high, the Nb carbonitride is coarsened, and the low-temperature toughness of steel is decreased. Accordingly, the Nb content is 0.050% or less. The Nb content is preferably 0.040% or less, and more preferably 0.030% or less.

Ti: from 0.005 to 0.030%

[0064] Ti binds to N in the steel to form a TiN and suppress a decrease in the low-temperature toughness of steel due to a solid solution of N. Furthermore, the dispersion precipitation of the fine TiN suppresses coarsening of crystal grains. As a result, the low-temperature toughness of steel is enhanced. 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, the TiN is coarsened, and a coarse TiC is formed. In this case, the low-temperature toughness of steel is decreased. Accordingly, the Ti content is 0.030% or less. The Ti content is preferably 0.020% or less, and more preferably 0.017% or less.

Ni: from 0.001 to 0.20%

[0066] Ni enhances the hardenability of steel and enhances the strength of steel. In a case in which a Ni content is too low, the effect cannot be obtained. Accordingly, the Ni content is 0.001% or more. The Ni content is preferably 0.01% or more, more preferably 0.05% or more, and still more preferably 0.07% or more.
[0067] In contrast, in a case in which the Ni content is too high, the above-described effect is saturated. Accordingly, the Ni content is 0.20% or less. The Ni content is preferably 0.15% or less.

Mo: from 0.10 to 0.20%

[0068] Mo enhances the hardenability of steel and enhances the strength of steel. Mo further refines austenite grains and enhances the low-temperature toughness of steel. In a case in which a Mo content is too low, the effect cannot be obtained. Accordingly, the Mo content is 0.10% or more. The Mo content is preferably 0.15% or more.
[0069] In contrast, in a case in which the Mo content is too high, the field weldability of steel is decreased. Accordingly, the Mo content is 0.20% or less. The Mo content is preferably 0.19% or less, and more preferably 0.18% or less.

V: from 0 to 0.010%

[0070] V is an optional element. Accordingly, a V content may be 0%.
[0071] V binds to C and N in the steel in a coiling step to form a fine carbonitride and enhance the strength of steel. The fine V carbonitride further suppresses coarsening of crystal grains and enhances the low-temperature toughness of steel. From the viewpoint of the effect, the V content may be more than 0%, may be 0.001% or more, and may be 0.002% or more.
[0072] In contrast, in a case in which the V content is more than 0.010%, the low-temperature toughness is deteriorated by coarsening of the V carbonitride. Accordingly, the V content is 0.010% or less.

O: from 0 to 0.0030%

[0073] O is an impurity. O forms an oxide and decreases the hydrogen induced cracking resistance (hereinafter, also referred to as "HIC resistance") of steel. O further decreases the low-temperature toughness of steel. Accordingly, an O content is 0.0030% or less. The O content is preferably 0.0025% or less. The O content is preferably as low as possible.
[0074] In contrast, the O content may be 0%. From the viewpoint of reducing a deoxidation cost, the O content may be more than 0%, may be 0.0001% or more, may be 0.0010% or more, may be 0.0015% or more, and may be 0.0020% or more.

Ca: from 0 to 0.0050%

[0075] Ca is an optional element. Accordingly, a Ca content may be 0%.
[0076] Ca controls the form of MnS and makes the form into a spherical shape, thereby improving the low-temperature toughness of steel. 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 0.0015% or more, and may be 0.0020% or more.
[0077] In contrast, in a case in which the Ca content is more than 0.0050%, a coarse oxide-based inclusion is formed. Accordingly, the Ca content is 0.0050% or less. The Ca content is preferably 0.0045% or less.

Cr: from 0 to 0.30%

[0078] Cr is an optional element. Accordingly, a Cr content may be 0%.

[0079] Cr is an element that improves the hardenability and enhances the strength of steel. From the viewpoint of such an effect, the Cr content may be more than 0%, and may be 0.01% or more.
[0080] In contrast, in a case in which the Cr content is more than 0.30%, the hardenability becomes too high, and the low-temperature toughness of steel is decreased. Accordingly, the Cr content is 0.30% or less. The Cr content is preferably 0.20% or less, more preferably 0.10% or less, and still more preferably 0.05% or less.

Cu: from 0 to 0.30%

[0081] Cu is an optional element. Accordingly, a Cu content may be 0%.
[0082] Cu enhances the hardenability of steel and enhances the strength of steel. From the viewpoint of such an effect, the Cu content may be more than 0%, may be 0.01% or more, may be 0.05% or more, and may be 0.10% or more.
[0083] In contrast, in a case in which the Cu content is too high, the hardenability becomes too high, and the low-temperature toughness of steel is decreased. Accordingly, the Cu content is 0.30% or less. The Cu content is preferably 0.25% or less, and more preferably 0.20% 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 0.010% of V, more than 0% but equal to or less than 0.0030% of Ca, more than 0% but equal to or less than 0.30% of Cr, more than 0% but equal to or less than 0.30% 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 B, Sb, Sn, W, Co, As, Pb, Bi, and H.
[0097] 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.

F1: from 0.300 to 0.350

[0098] In the chemical composition of the base metal portion, F1 defined by the following Formula (1) is from 0.300 to 0.350.

$$F1 = C + Si/24 + Mn/6 + Ni/40 + Cr/5 + Mo/4 + V/3 + Nb/3 \quad \text{Formula (1)}$$

(In Formula (1), each of C, Si, Mn, Ni, Cr, Mo, V, and Nb represents % by mass of a corresponding element.)

[0099] Needless to say, in a case in which the chemical composition does not contain any element corresponding to an element symbol in Formula (1), "0" is substituted into the corresponding element symbol in Formula (1).

[0100] F1 is correlated to the metallographic microstructure of the base metal portion (in particular, crystal grain diameter).

[0101] In a case in which F1 is less than 0.300, since polygonal ferrite grains (hereinafter, also simply referred to as "ferrite grains") are coarsened, the average crystal grain diameter may become large, and moreover, since the metallographic microstructure becomes a mixed-grain microstructure, the coarse crystal grain ratio may become large. Therefore, the low-temperature toughness may be deteriorated. In a case in which F1 is less than 0.300, since the hardenability is decreased, a sufficient strength may not be obtained. Accordingly, F1 is 0.300 or more. F1 is preferably 0.305 or more.

[0102] In contrast, in a case in which F1 is more than 0.350, since the polygonal ferrite fraction becomes too small, the average crystal grain diameter and/or the coarse crystal grain ratio may become too large. Therefore, the low-temperature toughness may be deteriorated. Accordingly, F1 is 0.350 or less. F1 is preferably 0.345 or less, and more preferably 0.340 or less.

[0103] From the viewpoint of easily achieving F1 of from 0.300 to 0.350, in the chemical composition of the base metal portion, F2 defined by the following Formula (2) is preferably from 0.230 to 0.300, and more preferably from 0.230 to 0.290.

[0104] In a case in which F2 is 0.230 or more, F1 of 0.300 or more is more easily achieved.

[0105] In a case in which F2 is 0.300 or less, F1 of 0.350 or less is more easily achieved.

$$F2 = Si/24 + Mn/6 + Ni/40 + Cr/5 + Mo/4 + V/3 + Nb/3 \qquad \text{Formula (2)}$$

(In Formula (2), each of Si, Mn, Ni, Cr, Mo, V, and Nb represents mass% of a corresponding element.)

[0106] Needless to say, in a case in which the chemical composition does not contain any element corresponding to an element symbol in Formula (2), "0" is substituted into the corresponding element symbol in Formula (2).

[0107] <Metallographic Microstructure of Wall thickness direction central portion of Base Metal Portion>

[0108] The metallographic microstructure of the wall thickness direction central portion of the base metal portion (hereinafter, also referred to as the "metallographic microstructure of the base metal portion") will be described below.

[0109] In the metallographic microstructure of the wall thickness direction central portion of the base metal portion, the polygonal ferrite fraction (hereinafter, also simply referred to as "ferrite fraction") is from 60 to 90%, the average crystal grain diameter is 15 μm or less, and the coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, is 20% or less.

Ferrite Fraction: from 60 to 90%

[0110] In the metallographic microstructure of the wall thickness direction central portion of the base metal portion, the ferrite fraction (i.e., polygonal ferrite fraction) is from 60 to 90%. In other words, the metallographic microstructure of the wall thickness direction central portion of the base metal portion is a metallographic microstructure which is mainly composed of ferrite (i.e., polygonal ferrite).

[0111] In a case in which the ferrite fraction is less than 60%, the average crystal grain diameter and/or the coarse crystal grain ratio becomes too large, and therefore, the low-temperature toughness may be deteriorated. In a case in which the ferrite fraction is 60% or more, the crystal grains are refined (specifically, the average crystal grain diameter and the coarse crystal grain ratio are decreased), and therefore, the low-temperature toughness is enhanced. Accordingly, the ferrite fraction is 60% or more. The ferrite fraction is preferably 65% or more, and more preferably 70% or more.

[0112] In contrast, in the chemical composition containing C in the disclosure, a metallographic microstructure having a ferrite fraction of 90% or less is easily formed. Accordingly, the ferrite fraction in the metallographic microstructure of the wall thickness direction central portion of the base metal portion is 90% or less. The ferrite fraction is preferably 85% or less.

Average Crystal Grain Diameter: 15 μm or less

[0113] In the metallographic microstructure of the wall thickness direction central portion of the base metal portion, the average crystal grain diameter is 15 μm or less.

[0114] In a case in which the average crystal grain diameter is more than 15 μm, the low-temperature toughness is deteriorated. Accordingly, the average crystal grain diameter is 15 μm or less, and preferably 12 μm or less.

[0115] From the viewpoint of the low-temperature toughness, the lower limit of the average crystal grain diameter is not particularly restricted. From the viewpoint of the production suitability of the steel, the average crystal grain diameter is preferably 3 μm or more, more preferably 5 μm or more, and still more preferably 8 μm or more.

Coarse Crystal Grain Ratio: 20% or less

[0116] In the metallographic microstructure of the wall thickness direction central portion of the base metal portion, the coarse crystal grain ratio is 20% or less.

[0117] As described above, the coarse crystal grain ratio herein means an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more.

[0118] In a case in which the coarse crystal grain diameter ratio is more than 20%, the low-temperature toughness is deteriorated. Accordingly, the coarse crystal grain diameter ratio is 20%. The coarse crystal grain diameter ratio is preferably 18% or less, and still more preferably 15% or less.

[0119] From the viewpoint of the low-temperature toughness, the lower limit of the coarse crystal grain diameter ratio is not particularly restricted. From the viewpoint of the production suitability of the steel, the coarse crystal grain diameter ratio is preferably 3% or more, more preferably 5% or more, and still more preferably 8% or more.

[0120] The ferrite fraction (i.e., polygonal ferrite fraction) herein means an areal ratio of ferrite (i.e., polygonal ferrite).

[0121] Confirmation of the metallographic microstructure of the wall thickness direction central portion of the base metal portion herein is performed by confirming the metallographic microstructure of the wall thickness direction central portion in an L cross-section at a base metal 90° position of the electric resistance welded steel pipe.

[0122] The base metal 90° position refers to a position shifted from the electric resistance welded portion by 90° in a pipe circumferential direction.

[0123] The L cross-section refers to a cross-section parallel to a pipe axis direction and a wall thickness direction.

[0124] The ferrite fraction is measured by the following method.

[0125] A sample for observing the wall thickness direction central portion in the L cross-section at the base metal 90° position is sampled from the electric resistance welded steel pipe. An observation surface of the sampled sample is polished by colloidal silica polish for from 30 to 60 minutes. The polished observation surface is analyzed using EBSD-OIM (trademark) (Electron Back Scatter Diffraction Pattern-Orientation Image Microscopy), and an areal ratio of polygonal ferrite in a visual field range of 200 μm (pipe axis direction) × 500 μm (wall thickness direction), centered at the wall thickness direction central portion in the L cross-section at the base metal 90° position, is determined as the ferrite fraction.

[0126] A visual field magnification (observation magnification) of EBSD-OIM is 400 times, and a measurement step is 0.3 μm.

[0127] Specifically, the ferrite fraction is determined by KAM (Kernel Average Misorientation) method equipped in EBSD-OIM.

[0128] Specifically, first, a visual field range is divided into regular hexagonal pixel units, and one regular hexagonal pixel in the visual field range is selected as the central pixel. In a total of 37 pixels composed of the selected central pixel, six pixels located outside of the central pixel, 12 pixels further located outside of the six pixels, and 18 pixels further located outside of the 12 pixels, misorientations between the respective pixels are determined. The average value of the obtained misorientations is determined as a KAM value of the central pixel. In the same manner, a KAM value is determined for each pixel included in the visual field range. The calculating method of these KAM values is a method which is sometimes referred to as "third approximation".

[0129] A KAM map indicating the KAM values of the respective pixels included in the visual field range is produced based on the above result.

[0130] Based on the obtained KAM map, an areal fraction of pixels having a KAM value of 1° or less with respect to the total area of the visual field range is determined as the ferrite fraction.

[0131] A microstructure of pixels having a KAM value of 1° or less is polygonal ferrite, and a microstructure of pixels having a KAM value of more than 1° is at least one of bainite or pearlite.

[0132] Fig. 1 is a KAM map used in measurement of the ferrite fraction in the electric resistance welded steel pipe according to an example of the disclosure.

[0133] Although the KAM map is displayed by gray scale in Fig. 1, a KAM map is typically displayed by color.

[0134] In Fig. 1 displayed by gray scale, black parts are polygonal ferrite. In this example, an areal ratio of the black parts (polygonal ferrite) with respect to the whole of Fig. 1 (the whole of the metallographic microstructure) is the polygonal ferrite fraction.

[0135] The average crystal grain diameter and the coarse crystal grain ratio herein are measured as follows by EBSD-OIM method.

[0136] In the same manner as the above-described measurement of the ferrite fraction, a sample for observing the wall thickness direction central portion in the L cross-section at the base metal 90° position is sampled from the electric resistance welded steel pipe, and an observation surface of the sampled sample is polished by colloidal silica polish for from 30 to 60 minutes.

[0137] The polished observation surface is analyzed using EBSD-OIM, and an area average grain diameter in a visual field range of 200 μm (pipe axis direction) × 500 μm (wall thickness direction), the range is centered at the wall thickness direction central portion in the L cross-section at the base metal 90° position, is determined as the average crystal grain diameter.

[0138] An areal ratio of crystal grains having a crystal grain diameter of 20 μm or more (i.e., coarse crystal grains) with respect to the whole of the visual field range is determined as the coarse crystal grain ratio.

[0139] A visual field magnification (observation magnification) of EBSD-OIM is 400 times, and a measurement step is 0.3 μm.

[0140] More specifically, in the measurement of the average crystal grain diameter, orientation measurement for each measurement step of 0.3 μm is performed, and a 15° large inclination grain boundary map in which a position where a misorientation between adjacent measurement points is more than 15° is regarded as a crystal grain boundary is produced. Here, 15° is a threshold value of a high angle grain boundary and is generally recognized as a crystal grain boundary.

[0141] Based on the produced 15° high angle grain boundary map, a region surrounded by the crystal grain boundaries is regarded as a crystal grain, and a grain diameter and an area of each crystal grain are respectively determined. The grain diameter of each crystal grain is an equivalent circle diameter of each crystal grain.

[0142] Based on the grain diameter and the area of each crystal grain, an area average grain diameter is determined as the average crystal grain diameter.

[0143] An areal ratio of crystal grains having a crystal grain diameter of 20 μm or more (i.e., coarse crystal grains) with respect to the whole of the visual field range is determined as the coarse crystal grain ratio.

[0144] Fig. 2 is a 15° high angle grain boundary map used in measurement of the average crystal grain diameter and the coarse crystal grain ratio in the electric resistance welded steel pipe according to an example of the disclosure.

[0145] Fig. 2 shows the metallographic microstructure at the same part as Fig. 1.

[0146] In Fig. 2, fine (i.e, small area) crystal grains are ferrite grains, and large area crystal grains are bainite grains or pearlite grains.

[0147] In the electric resistance welded steel pipe of the disclosure, the balance in the metallographic microstructure of the base metal portion (i.e., the balance other than polygonal ferrite) is preferably composed of at least one of bainite or pearlite. As a result, the low-temperature toughness is improved compared to a case in which the balance contains, for example, martensite.

[0148] The concept of "bainite" herein includes bainitic ferrite, upper bainite, and lower bainite. The concept of "bainite" herein further includes tempered bainite formed during air-cooling after coiling the hot-rolled steel sheet (i.e., during air-cooling in the form of a hot coil).

[0149] The concept of "pearlite" herein includes pseudo-pearlite.

[0150] The electric resistance welded steel pipe of the disclosure is an as-rolled electric resistance welded steel pipe (i.e., an electric resistance welded steel pipe which is not subjected to heat treatment other than seam heat treatment after pipe-making). Thus, the balance easily becomes at least one of bainite or pearlite.

[0151] 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 tends to have poor low-temperature toughness.

[0152] Fig. 3 is a scanning electron micrograph (SEM micrograph; a magnification of 500 times) showing an example of the metallographic microstructure of the base metal portion in the disclosure.

[0153] Specifically, the SEM micrograph shown in Fig. 3 was measured as follows.

[0154] A test specimen for observing the wall thickness direction central portion in the L cross-section at the base metal 90° position was sampled from the electric resistance welded steel pipe according to an example of the disclosure. The L cross-section in the sampled test specimen was nital-etched, and a micrograph of the nital-etched metallographic microstructure (hereinafter, also referred to as "metallographic micrograph") was taken with a scanning electron microscope (SEM) at a magnification of 500 times.

[0155] According to Fig. 3, the metallographic microstructure according to this example is revealed to be a metallographic microstructure which is mainly composed of ferrite (i.e., polygonal ferrite).

[0156] Being an as-rolled electric resistance welded steel pipe can be confirmed by not observing yield elongation in a case in which a pipe axis direction tensile test is performed.

[0157] 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.

[0158] In contrast, in an electric resistance welded steel pipe which is subjected to heat treatment other than seam heat treatment (for example, tempering) after pipe-making, yield elongation is observed in a case in which a pipe axis direction tensile test is performed.

<Yield Strength in Pipe Axis Direction (YS)>

[0159] The electric resistance welded steel pipe of the disclosure has preferably a yield strength in a pipe axis direction (YS) of from 450 to 540 MPa.

[0160] A YS of 450 MPa or more easily satisfies the strength required as the electric resistance welded steel pipe for a line pipe. The YS is preferably 460 MPa or more, and more preferably 480 MPa or more.

[0161] In contrast, a YS of 540 MPa or less is advantageous in view of a bending deformation property or 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, and more preferably 520 MPa or less.

<Tensile Strength in Pipe Axis Direction (TS)>

[0162] The electric resistance welded steel pipe of the disclosure has preferably a tensile strength in a pipe axis direction (TS) of from 510 to 625 MPa.

[0163] A TS of 510 MPa or more easily satisfies the strength required as the electric resistance welded steel pipe for a line pipe. The TS is preferably 530 MPa or more, more preferably 540 MPa or more, and still more preferably 545 MPa or more.

[0164] In contrast, a TS of 625 MPa or less is advantageous in view of a bending deformation property or 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, more preferably 600 MPa or less, still more preferably 590 MPa or less, and still more preferably 575 MPa or less.

[0165] The YS and the TS are measured by the following method.

[0166] 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 wall thickness direction of the tensile test specimen) is an arcuate shape.

[0167] Fig. 4 is a schematic front view of the tensile test specimen used for a tensile test. A unit of numerical values in Fig. 4 is mm.

[0168] As shown in Fig. 4, 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.

[0169] In the disclosure, the tensile test (i.e., pipe axis direction tensile test) is conducted using the tensile test specimen in conformity with standard API, specification 5CT at ordinary temperature.

[0170] The YS and the TS are determined based on the test result.

<Yield Ratio in Pipe Axis Direction (YR)>

[0171] As described above, the electric resistance welded steel pipe of the disclosure has a yield ratio in a pipe axis direction (YR = (YS/TS) $\times$ 100) of from 80 to 95%.

[0172] From the viewpoint of more effectively suppressing buckling in the case of laying a pipeline formed using the electric resistance welded steel pipe for a line pipe, the YR is preferably 93% or less.

[0173] From the viewpoint of more improving the production suitability of the electric resistance welded steel pipe, the YR is preferably 84% or more.

<Wall Thickness of Electric Resistance Welded Steel Pipe>

[0174] The wall thickness of the electric resistance welded steel pipe of the disclosure is preferably from 12 to 25 mm.

[0175] A wall thickness of the electric resistance welded steel pipe of the disclosure of 12 mm or more improves the strength of the electric resistance welded steel pipe.

[0176] Generally, as the wall thickness becomes thicker, a brittle fracture becomes easy to occur (i.e., the toughness is decreased). However, in the electric resistance welded steel pipe of the disclosure, also in a case in which the wall thickness is 12 mm or more, excellent low-temperature toughness is exhibited.

[0177] Accordingly, in a case in which the wall thickness of the electric resistance welded steel pipe of the disclosure is 12 mm or more, both the strength and the low-temperature toughness are satisfied at a higher level.

[0178] The wall thickness of the electric resistance welded steel pipe of the disclosure is more preferably 14 mm or more, and still more preferably 16 mm or more.

[0179] In contrast, 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 roll-forming of a hot-rolled steel sheet as a material).

[0180] The wall thickness is preferably less than 25 mm, more preferably 22 mm or less, and still more preferably 20 mm or less.

<Outer Diameter of Electric Resistance Welded Steel Pipe>

[0181] The outer diameter of the electric resistance welded steel pipe of the disclosure is preferably from 304.8 to 660.4 mm (i.e., from 12 to 26 inches).

[0182] An outer diameter of 304.8 mm (i.e., 12 inches) or more has excellent transport efficiency of a fluid (for example, natural gas). The outer diameter is preferably 355.6 mm (i.e., 14 inches) or more, and more preferably 406.4 mm (i.e., 16 inches) or more.

[0183] In contrast, an outer diameter of 609.6 mm (i.e., 24 inches) or less has excellent production suitability of the electric resistance welded steel pipe. The outer diameter is more preferably 508 mm (i.e., 20 inches) or less.

[Hot-rolled Steel Sheet]

[0184] Next, a preferred hot-rolled steel sheet as a material of the electric resistance welded steel pipe of the disclosure (hereinafter, also referred to as the "hot-rolled steel sheet of the disclosure") will be described.

[0185] The hot-rolled steel sheet of the disclosure has a chemical composition which is the above-described chemical composition in the disclosure, and, in a metallographic microstructure of a wall thickness direction central portion, has a polygonal ferrite fraction of from 60 to 90%, an average crystal grain diameter of 15 μm or less, and a coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, of 20% or less.

[0186] A preferred embodiment of the chemical composition in the hot-rolled steel sheet of the disclosure is the same as a preferred embodiment of the above-described chemical composition in the disclosure (i.e., the chemical composition in the base metal portion of the electric resistance welded steel pipe of the disclosure).

[0187] A preferred embodiment of each of the polygonal ferrite fraction, the average crystal grain diameter, and the coarse crystal grain ratio in the hot-rolled steel sheet of the disclosure is the same as a preferred embodiment of each of the polygonal ferrite fraction, the average crystal grain diameter, and the coarse crystal grain ratio in the electric resistance welded steel pipe of the disclosure.

[0188] The form of the hot-rolled steel sheet of the disclosure is preferably the form of a hot coil in which the sheet is coiled into a coil shape.

[0189] A preferred range of the wall thickness (i.e., sheet thickness) of the hot-rolled steel sheet of the disclosure is the same as a preferred range of the wall thickness of the electric resistance welded steel pipe of the disclosure.

[0190] Preferably, the hot-rolled steel sheet of the disclosure has a yield strength in a rolling direction (YS) of from 450 to 500 MPa and a tensile strength in the rolling direction (TS) of from 510 to 580 MPa.

[0191] The rolling direction in the hot-rolled steel sheet corresponds to a longitudinal direction in the hot-rolled steel sheet uncoiled from the hot coil.

[0192] Measurement of the YS and the TS of the hot-rolled steel sheet is performed in the same way as the measurement of the TS and the YS of the electric resistance welded steel pipe.

[0193] The YS of the hot-rolled steel sheet is preferably from 465 to 495 MPa.

[0194] The TS of the hot-rolled steel sheet is preferably from 531 to 565 MPa.

[0195] The YR of the hot-rolled steel sheet is preferably from 82 to 92%.

[0196] In the case of producing the electric resistance welded steel pipe of the disclosure using the hot-rolled steel sheet of the disclosure, the YS and the TS (in particular, YS) increase by roll-forming the hot-rolled steel sheet of the disclosure.

[One Example of Production Method of Hot-rolled Steel Sheet]

[0197] Next, a production method A of the hot-rolled steel sheet, which is an example of a preferred production method of the hot-rolled steel sheet of the disclosure, will be described.

[0198] The production method A of the hot-rolled steel sheet includes:

a preparation step of preparing a slab having the chemical composition in the disclosure,

a hot-rolling step of heating the prepared slab to a temperature of from 1060 to 1200°C and hot-rolling the heated slab, thereby obtaining a hot-rolled steel sheet,

a cooling step of strong-cooling the hot-rolled steel sheet subjected to the hot-rolling at a cooling rate V1 of 5°C/s or more to a strong-cooling stop temperature T1 of from 580 to 680°C with a time from the end of the hot-rolling (specifically, the end of finish rolling) to the start of the strong-cooling being set to 20 seconds or less, and then gradual-cooling the hot-rolled steel sheet at a cooling rate V2 of from 2 to 4°C/s to a gradual-cooling stop temperature T2 of from 550 to 670°C (satisfying T1 > T2), and

a coiling step of coiling the gradual-cooled hot-rolled steel sheet at a coiling temperature CT of from 500 to 600°C (satisfying T2 > CT), thereby obtaining a hot-rolled steel sheet in the form of a hot coil.

[0199] In the production method A, the heating temperature of the slab means a surface temperature of the slab.

[0200] In the production method A, the temperature of the hot-rolled steel sheet (FT, T1, T2, CT) means a surface temperature of the hot-rolled steel sheet.

[0201] In the production method A, the cooling rate (VI, V2) means a cooling rate in the wall thickness direction central portion. The cooling rate (VI, V2) is determined by thermal conduction calculation.

[0202] The chemical composition of the hot-rolled steel sheet in the form of a hot coil produced by the production method A can be considered to be the same as the chemical composition of the slab which is a raw material. The reason is that each step in the production method A does not affect the chemical composition of a steel.

[0203] According to the production method A, a metallographic microstructure mainly composed of ferrite and a metallographic microstructure in which crystal grains are refined can be formed.

[0204] Accordingly, according to the production method A, the hot-rolled steel sheet of the disclosure can be produced, in which, in the metallographic microstructure of the wall thickness direction central portion, a ferrite fraction is from 60 to 90%, an average crystal grain diameter is 15 μm or less, and a coarse crystal grain ratio is 20% or less.

[0205] The reason why a metallographic microstructure mainly composed of ferrite and a metallographic microstructure in which crystal grains are refined can be formed by the production method A can be presumed as follows.

[0206] In the production method A, the heating temperature in the hot-rolling step is made to be 1200°C or less, so that coarsening of crystal grains (specifically, austenite grains in a heated stage) is suppressed.

[0207] Furthermore, in the cooling step, the hot-rolled steel sheet formed in the hot-rolling step is strong-cooled at the cooling rate V1 of 5°C/s or more to the strong-cooling stop temperature T1 of from 580 to 680°C with a time from the end of the hot-rolling (specifically, the end of finish rolling) to the start of the strong-cooling being set to 20 seconds or less, so that numerous nucleation sites are generated in a non-recrystallization structure of the hot-rolled steel sheet.

[0208] The strong-cooled hot-rolled steel sheet is gradual-cooled under the above condition, and then coiled under the above condition, so that fine ferrite grains are generated from each of the numerous nucleation sites generated in the strong-cooling, and a metallographic microstructure mainly composed of polygonal ferrite is formed.

[0209] For the above reason, it is considered that, according to the production method A, a metallographic microstructure mainly composed of ferrite and a metallographic microstructure in which crystal grains (specifically, ferrite grains) are refined can be formed.

[0210] In contrast, in a case in which the metallographic microstructure is mainly composed of bainite, although laths (elongated microstructure) are generated in crystal grains directly inherited from prior austenite grains, orientations of these laths are aligned in each block, and each block substantially becomes one crystal grain. Thus, the size of the crystal grains in the metallographic microstructure mainly composed of bainite depends on the size of the prior austenite grains. Thus, in a case in which the metallographic microstructure is mainly composed of bainite, the crystal grains are easily coarsened.

[0211] Next, the reason why fine ferrite grains are generated by the production method A will be described in more detail using a continuous cooling transformation diagram (CCT diagram) of the hot-rolled steel sheet.

[0212] Fig. 5 is the continuous cooling transformation diagram (CCT diagram) of the hot-rolled steel sheet in the production method A.

[0213] In Fig. 5, F indicates a ferrite region, P indicates a pearlite region, B indicates a bainite region, Ar_3 indicates an Ar_3 transformation temperature, and Ms indicates a temperature at which martensite begins to be generated.

[0214] As shown in Fig. 5, the ferrite region exists at a higher temperature position than the pearlite region and the bainite region.

[0215] In this example, a finish rolling temperature (i.e., finish rolling finishing temperature) is a temperature equal to or more than the Ar_3 transformation temperature.

[0216] The hot-rolled steel sheet after the finish rolling is cooled from a temperature equal to or more than the Ar_3 transformation temperature.

[0217] A dashed line C1 in Fig. 5 is a cooling curve in a case in which the hot-rolled steel sheet is cooled under a conventional cooling condition.

[0218] The conventional cooling condition passes through all of the ferrite region, the pearlite region and the bainite region. Thus, the ferrite fraction in the metallographic microstructure is decreased. For example, the metallographic microstructure mainly composed of bainite is obtained.
[0219] In contrast to the conventional cooling condition, in the cooling step in the production method A, the hot-rolled steel sheet is cooled along a cooling curve of a dashed line C2.
[0220] Specifically, in the cooling step in the production method A, the hot-rolled steel sheet is strong-cooled at the cooling rate V1 of 5°C/s or more to the strong-cooling stop temperature T1 of from 580 to 680°C with the time from the end of the hot-rolling (specifically, the end of finish rolling) to the start of the strong-cooling being set to 20 seconds or less (S31 in Fig. 5). The strong-cooling stop temperature T1 is located in the vicinity of a ferrite nose. In a case in which the steel is rapidly cooled by the strong-cooling, numerous strains are generated in the steel, and therefore, numerous nucleation sites are generated in a non-recrystallization structure.
[0221] After the strong-cooling, the hot-rolled steel sheet is gradual-cooled to the gradual-cooling stop temperature T2 of from 550 to 670°C (satisfying T1 > T2) (S32 in Fig. 5). By setting the gradual-cooling stop temperature T2 to the above temperature, the temperature of the steel is maintained in the ferrite region of Fig. 5. As a result, fine ferrite grains are generated from each of the numerous nucleation sites generated in the strong-cooling.
[0222] Therefore, a metallographic microstructure mainly composed of fine ferrite grains (specifically, a metallographic microstructure in which the ferrite fraction is high and crystal grains are refined) is formed.
[0223] F1 defined by the above Formula (1) affects a position of an S curve of each phase of ferrite, pearlite, and bainite in the CCT diagram.
[0224] As described above, in the chemical composition in the disclosure, F1 is from 0.300 to 0.350.
[0225] As a result, as shown in Fig. 5, the S curve of each phase is arranged at an appropriate position in the CCT diagram. Thus, the hot-rolled steel sheet is cooled mainly through the ferrite region as the cooling curve C2 in Fig. 5.
[0226] Therefore, the ferrite fraction in the microstructure is increased, and crystal grains (i.e., ferrite grains) are refined.
[0227] In a case in which F1 is less than 0.300, the S curve of each phase is shifted too much to the left side. In this case, in the cooling step, the temperature of the steel enters the ferrite region before the nucleation sites are sufficiently generated. Thus, ferrite grains are coarsened, and the average crystal grain diameter becomes large. Furthermore, the metallographic microstructure is easy to become a mixed-grain microstructure, and thus, the coarse crystal grain ratio becomes large.
[0228] In contrast, in a case in which F1 is more than 0.350, the S curve of each phase is shifted too much to the right side. In this case, the cooling curve C2 becomes difficult to pass through the ferrite region. Therefore, the amount of the microstructure other than ferrite (pearlite, bainite, and the like) generated is increased, and the ferrite fraction in the microstructure is decreased.
[0229] Each step of the production method A will be described below.

<Preparation Step>

[0230] The preparation step in the production method A is a step of preparing a slab having the chemical composition in the disclosure.
[0231] 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.
[0232] 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.
[0233] The chemical composition of the slab can be considered to be the same as the chemical composition of the molten steel which is a raw material. The reason is that the step of producing a slab does not affect the chemical composition of a steel.

<Hot-rolling Step>

[0234] The hot-rolling step in the production method A is a step of heating the slab to a temperature of from 1060 to 1200°C and hot-rolling the heated slab, thereby obtaining a hot-rolled steel sheet.
[0235] A temperature at which the slab is heated (hereinafter, also referred to as "heating temperature") of 1200°C or less can refine austenite grains. The heating temperature is preferably 1180°C or less.
[0236] A heating temperature of 1060°C or more can realize refining of crystal grains during rolling. A heating temperature of 1060°C or more can realize precipitation strengthening after rolling, and therefore, the strength of the hot-rolled steel sheet can also be improved. From the viewpoint of the effect, the heating temperature is preferably 1100°C or more.
[0237] In the production method A, the heating temperature of the slab means a surface temperature of the slab.

[0238] In the production method A, the temperature of the hot-rolled steel sheet (FT, T1, T2, CT) means a surface temperature of the hot-rolled steel sheet.

[0239] In the production method A, the cooling rate (V1, V2) means a cooling rate in the wall thickness direction central portion, which is determined by thermal conduction calculation.

[0240] The hot-rolling is performed by carrying out rough rolling and finish rolling in this order for the slab heated to the above heating temperature.

[0241] The rough rolling and the finish rolling are performed using a rough rolling mill and a finish rolling mill, respectively. Both the rough rolling mill and the finish rolling mill include multiple rolling stands in a row, and each of the rolling stands includes a pair of rolls.

[0242] The following finish rolling temperature FT (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.

[0243] From the viewpoint of reducing the rolling resistance and improving the productivity, the finish rolling temperature FT (°C) is preferably the Ar_3 transformation temperature or more. In a case in which the finish rolling temperature (°C) is the Ar_3 transformation temperature 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.

[0244] In the chemical composition in the disclosure, the Ar_3 transformation temperature can be 750 or more.

[0245] In the hot-rolling, the rolling reduction in an austenite non-recrystallization temperature region is preferably from 60 to 80%. In this case, a non-recrystallization structure is refined.

<Cooling Step>

[0246] The cooling step in the production method A is a step of strong-cooling the hot-rolled steel sheet obtained in the hot-rolling step at a cooling rate V1 of 5°C/s or more to a strong-cooling stop temperature T1 of from 580 to 680°C with a time from the end of the hot-rolling (specifically, the end of finish rolling) to the start of the strong-cooling being set to 20 seconds or less, and then gradual-cooling the hot-rolled steel sheet to a gradual-cooling stop temperature T2 of from 550 to 670°C (satisfying T1 > T2).

[0247] The cooling step in the production method A is performed on a ROT (Run Out Table).

[0248] Hereinafter, the cooling step in the production method A may be referred to as a "ROT cooling".

[0249] The surface temperature of the steel sheet before the strong-cooling is not particularly limited, and is preferably the Ar_3 transformation temperature or more. In a case in which the surface temperature of the steel sheet just before the strong-cooling is the Ar_3 transformation temperature or more, coarsening of crystal grains and a decrease in the strength caused thereby can be suppressed.

[0250] The strong-cooling is started within 20 seconds (more preferably within 10 seconds) from the end of the hot-rolling (specifically, the end of finish rolling).

[0251] The strong-cooling is performed at the cooling rate V1 of 5°C/s or more.

[0252] The cooling rate V1 is a cooling rate at the wall thickness direction central portion. The cooling rate V1 is a value calculated with thermal conduction.

[0253] A cooling rate V1 of 5°C/s or more makes the degree of supercooling by the cooling sufficient, and therefore, nucleation sites of ferrite are sufficiently obtained.

[0254] The cooling rate V1 is preferably 7°C/s or more, and more preferably 8°C/s or more.

[0255] The strong-cooling is performed to the strong-cooling stop temperature T1 of from 580 to 680°C.

[0256] A strong-cooling stop temperature T1 of 580°C or more can suppress a phenomenon in which the temperature of the hot-rolled steel sheet passes through the ferrite region and reaches the pearlite region and/or the bainite region in the CCT diagram, so that a ferrite fraction of 60% or more is easily achieved. The strong-cooling stop temperature T1 is preferably 600°C or more, and more preferably 610°C or more.

[0257] A strong-cooling stop temperature T1 of 680°C or less can suppress a phenomenon in which Nb precipitation which strengthens pro-eutectoid ferrite is overaged, and therefore, a decrease in the strength of the hot-rolled steel sheet can be suppressed. The strong-cooling stop temperature T1 is preferably 670°C or less, and more preferably 655°C or less.

[0258] The strong-cooling is preferably performed by water-cooling.

[0259] The strong-cooling is performed using, for example, a water-cooling apparatus by making a water flow density in the water-cooling apparatus higher than a usual condition.

[0260] The strong-cooling stop temperature T1 is, in other words, a gradual-cooling start temperature.

[0261] In the cooling step, the strong-cooled hot-rolled steel sheet is gradual-cooled to the gradual-cooling stop temperature T2 of from 550 to 670°C (satisfying T1 > T2).

[0262] The gradual-cooling is preferably performed at a cooling rate V2 of from 2 to 4°C/s.

[0263] In a case in which the cooling rate V2 is 2°C/s or more, since the gradual-cooling stop temperature T2 and a coiling temperature CT can be made lower, coarsening of crystal grains can be suppressed.

[0264] In a case in which the cooling rate V2 is 4°C/s or less, since a phenomenon in which the temperature of the hot-rolled steel sheet passes through the ferrite region and reaches the pearlite region and/or the bainite region in the CCT diagram can be suppressed, a ferrite fraction of 60% or more is easily achieved.

[0265] The gradual-cooling is performed to the gradual-cooling stop temperature T2 of from 550 to 670°C (satisfying T1 > T2).

[0266] In a case in which the gradual-cooling stop temperature T2 is 550°C or more, since a phenomenon in which the temperature of the hot-rolled steel sheet passes through the ferrite region and reaches the pearlite region and/or the bainite region in the CCT diagram can be suppressed, a ferrite fraction of 60% or more is easily achieved. The gradual-cooling stop temperature T2 is preferably 580°C or more, and more preferably 590°C or more.

[0267] In a case in which the gradual-cooling stop temperature T2 is 670°C or less, coarsening of crystal grains can be suppressed. The gradual-cooling stop temperature T2 is preferably 650°C or less, more preferably 635°C or less, and still more preferably 620°C or less.

[0268] The gradual-cooling is preferably performed by water-cooling.

[0269] The gradual-cooling is performed using, for example, a water-cooling apparatus by making a water flow density in the water-cooling apparatus lower than the water flow density in the strong-cooling.

<Coiling Step>

[0270] The coiling step in the production method A is a step of coiling the hot-rolled steel sheet cooled in the cooling step at a coiling temperature CT of from 500 to 600°C (satisfying T2 > CT), thereby obtaining a hot-rolled steel sheet in the form of a hot coil.

[0271] A cooling rate in cooling from the gradual-cooling stop temperature T2 to the coiling temperature CT is preferably from 0.1 to 1.5°C/s, more preferably from 0.3 to 1.5°C/s, and still more preferably from 0.5 to 1.5°C/s.

[0272] The coiling temperature CT is from 500 to 600°C.

[0273] In a case in which the coiling temperature CT is 500°C or more, since a phenomenon in which the temperature of the hot-rolled steel sheet passes through the ferrite region and reaches the pearlite region and/or the bainite region in the CCT diagram can be suppressed, a ferrite fraction of 60% or more is easily achieved. As a result, an average crystal grain diameter of 15 μm or less and a coarse crystal grain ratio of 20% or less are easily achieved. The coiling temperature CT is preferably 510°C or more, and more preferably 520°C or more.

[0274] In a case in which the coiling temperature CT is 580°C or less, coarsening of ferrite grains can be suppressed. As a result, an average crystal grain diameter of 15 μm or less and a coarse crystal grain ratio of 20% or less are easily achieved. The coiling temperature CT is preferably 590°C or less, and more preferably 580°C or less.

[One Example of Production Method of Electric Resistance Welded Steel Pipe]

[0275] Next, a production method X of the electric resistance welded steel pipe, which is an example of a preferred production method of the electric resistance welded steel pipe of the disclosure, will be described.

[0276] The production method X of the electric resistance welded steel pipe includes:

a step of preparing the above-described hot-rolled steel sheet of the disclosure (hereinafter, also referred to as "hot-rolled steel sheet preparation step"), and
a step of making an open pipe by roll-forming of the hot-rolled steel sheet and forming an electric resistance welded portion by electric resistance welding of abutting portions of the obtained open pipe, thereby obtaining an electric resistance welded steel pipe (hereinafter, also referred to as "pipe-making step").

[0277] The pipe-making step in the production method X does not affect the chemical composition, the polygonal ferrite fraction, the average crystal grain diameter, and the coarse crystal grain ratio. Accordingly, the electric resistance welded steel pipe of the disclosure is produced by the production method X using the hot-rolled steel sheet of the disclosure.

[0278] The hot-rolled steel sheet preparation step is preferably a step of preparing the hot-rolled steel sheet of the disclosure in the form of a hot coil.

[0279] In this case, in the pipe-making step, the hot-rolled steel sheet of the disclosure is uncoiled from the hot coil, and the uncoiled hot-rolled steel sheet of the disclosure is roll-formed.

[0280] The hot-rolled steel sheet preparation step may be a step of producing the hot-rolled steel sheet of the disclosure (preferably, the hot-rolled steel sheet of the disclosure in the form of a hot coil) or a step of simply preparing the hot-rolled steel sheet of the disclosure (preferably, the hot-rolled steel sheet of the disclosure in the form of a hot coil) produced in advance.

[0281] In both cases, the hot-rolled steel sheet of the disclosure in the form of a hot coil is preferably produced in accordance with the production method A described above.
[0282] Each operation in the pipe-making step is not particularly limited, and can be performed in accordance with a known method.
[0283] The production method X of the electric resistance welded steel pipe may include other steps, if necessary.
[0284] 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

[0285] Examples of the disclosure will be described below. However, the disclosure is not limited to the following Examples.

[Examples 1 to 13 and Comparative Examples 1 to 8]

<Production of Slab and Hot Coil>

[0286] Slabs were produced by continuous casting of molten steel having chemical compositions of Steel A to Steel O set forth in Table 1.
[0287] REM in Steel J is specifically Ce.
[0288] Each of the slabs described above was heated in a heating furnace.
[0289] The heating temperature (°C) of the slab was set forth in Table 2. The slab after the heating was rolled using a rough rolling mill, and was cooled to 920°C.
[0290] Then, finish rolling was performed by a finish rolling mill. The rolling reduction in a non-recrystallization temperature region was from 60 to 80% in all Examples and Comparative Examples. The finish rolling temperature was the Ar_3 or more (specifically, 750°C or more) in all Examples and Comparative Examples.
[0291] For the steel sheet after the finish rolling, the ROT cooling (i.e., cooling step) was performed.
[0292] For the hot-rolled steel sheet obtained by the finish rolling, the ROT cooling was performed by sequentially carrying out the strong-cooling and the gradual-cooling.
[0293] Time from the end of the finish rolling to the start of the strong-cooling was 10 seconds or less.
[0294] Both the strong-cooling and the gradual-cooling were performed using a water-cooling apparatus. Both the cooling rate V1 in the strong-cooling and the cooling rate V2 in the gradual-cooling were adjusted by adjusting a water flow density in the water-cooling apparatus.
[0295] The cooling rate V1 (°C/s) in the strong-cooling, the strong-cooling stop temperature T1 (°C), and the gradual-cooling stop temperature T2 (°C) were set forth in Table 2.
[0296] The cooling rate V2 (°C/s) in the gradual-cooling was in the range of from 2 to 4°C/s in all examples.
[0297] The hot-rolled steel sheet after the ROT cooling was cooled, and coiled at the coiling temperature CT set forth in Table 2, thereby obtaining a hot coil (i.e., the hot-rolled steel sheet in the form of a hot coil).
[0298] The cooling rate in cooling from the gradual-cooling stop temperature T2 (°C) to the coiling temperature CT was estimated to be from 0.5 to 1.5°C/s in all Examples and Comparative Examples.

<Production of Electric Resistance Welded Steel Pipe>

[0299] The hot-rolled steel sheet was uncoiled from the hot coil described above, the uncoiled hot-rolled steel sheet was roll-formed 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").
[0300] 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 17 mm.
[0301] 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.

<YS, TS, and YR of Hot-rolled Steel Sheet>

[0302] By uncoiling the hot-rolled steel sheet from the hot coil described above and performing a tensile test in a rolling direction for the uncoiled hot-rolled steel sheet, the YS in the rolling direction and the TS in the rolling direction were respectively measured. Furthermore, the YR (%) in the rolling direction was calculated based on the YS in the rolling direction and the TS in the rolling direction.
[0303] The results are set forth in Table 2.
[0304] A full thickness tensile test specimen used in the measurement of the YS and the TS was sampled from a position where a distance from one end of the hot-rolled steel sheet in a sheet width direction is 1/4 of the sheet width (i.e., a position corresponding to the base metal 90° position in the electric resistance welded steel pipe).

<Measurement and Evaluation of Electric Resistance Welded Steel Pipe>

[0305] The following measurement and evaluation were performed for the electric resistance welded steel pipe after the shape adjustment by a sizing roll.
[0306] The results are set forth in Table 2.

(YS, TS, and YR)

[0307] For the electric resistance welded steel pipe after the shape adjustment by a sizing roll, by performing a tensile test in a pipe axis direction, the YS in the pipe axis direction and the TS in the pipe axis direction were measured. The detailed measurement method has been described above. Furthermore, the YR (%) in the rolling direction was calculated based on the YS in the pipe axis direction and the TS in the pipe axis direction.
[0308] In the tensile test in the pipe axis direction in the measurement of the YS and the TS, yield elongation was not observed in all Examples and Comparative Examples. In other words, the electric resistance welded steel pipes of all Examples and Comparative Examples were confirmed to be as-rolled electric resistance welded steel pipes.

(Ferrite Fraction, Average Crystal Grain Diameter, and Coarse Crystal Grain Ratio)

[0309] For the electric resistance welded steel pipe after the shape adjustment by a sizing roll, the ferrite fraction, the average crystal grain diameter, and the coarse crystal grain ratio in the metallographic microstructure of the wall thickness direction central portion of the base metal portion were respectively measured using EBSD-OIM by the method described above.
[0310] As analysis software in EBSD-OIM, "TSL OIM Analysis 7" manufactured by TSL Solutions Ltd. was used.
[0311] In the measurement of the ferrite fraction, the kind of the balance (i.e., microstructure other than polygonal ferrite) in the metallographic microstructure of the wall thickness direction central portion of the base metal portion was confirmed.
[0312] In Table 2, the expression "B, P" means at least one of bainite or pearlite.

(Average Crystal Grain Diameter, Coarse Crystal Grain Ratio)

[0313] The average crystal grain diameter and the coarse crystal grain ratio of the wall thickness direction central portion of the base metal portion in the electric resistance welded steel pipe after the shape adjustment by a sizing roll were measured by the method described above.

(Evaluation of Low-temperature Toughness (Measurement of DWTT Guarantee Temperature))

[0314] By sampling an arcuate member from the electric resistance welded steel pipe after the shape adjustment by a sizing roll and processing the sampled arcuate member into a flat plate shape, a full thickness DWTT test specimen was obtained.
[0315] Fig. 6 is a schematic front view of the obtained DWTT test specimen.
[0316] A unit of numerical values in Fig. 6 is mm.
[0317] The longitudinal direction of the DWTT test specimen (a direction of a length of 300 mm) corresponds to a pipe circumferential direction of the electric resistance welded steel pipe. The central portion of the DWTT test specimen in the longitudinal direction corresponds to the base metal 90° position of the electric resistance welded steel pipe.
[0318] As shown in Fig. 6, in the DWTT test specimen, a notch having a depth of 5 mm was formed at the central portion in the longitudinal direction.
[0319] The DWTT test was performed using the DWTT test specimen in conformity with specification ASTM E 436,

and a DWTT guarantee temperature which is the lowest value of a temperature at which a percent ductile fracture is 85% or more was determined.

[0320] The lower a DWTT guarantee temperature is, the more excellent the low-temperature toughness is.

[Table 1]

Steel	Chemical Composition (% by Mass, Balance is Fe and Impurities)																		F2	F1
	C	Si	Mn	P	S	Al	N	Nb	Ti	Mo	Ni	V	O	Ca	Cr	Cu	Mg	REM		
A	0.040	0.18	1.25	0.011	0.0030	0.027	0.0034	0.030	0.014	0.18	0.10		0.0025	0.0027					0.273	0.313
B	0.080	0.17	1.21	0.010	0.0028	0.025	0.0035	0.015	0.014	0.17	0.09		0.0024	0.0034					0.259	0.339
C	0.065	0.19	1.10	0.010	0.0028	0.024	0.0033	0.021	0.014	0.16	0.11		0.0020	0.0044					0.241	0.306
D	0.035	0.17	1.40	0.011	0.0033	0.027	0.0029	0.024	0.012	0.19	0.14		0.0028	0.0029					0.299	0.334
E	0.110	0.14	1.11	0.014	0.0022	0.024	0.0038	0.011	0.015	0.15	0.07		0.0025	0.0033					0.234	0.344
F	0.052	0.14	1.25	0.008	0.0035	0.023	0.0029	0.024	0.014	0.16	0.12		0.0022						0.265	0.317
G	0.044	0.18	1.25	0.011	0.0030	0.027	0.0055	0.025	0.014	0.17	0.10	0.010	0.0024	0.0033					0.273	0.317
H	0.070	0.19	1.11	0.011	0.0028	0.027	0.0038	0.015	0.011	0.17	0.11		0.0022	0.0033	0.01				0.245	0.315
I	0.045	0.17	1.40	0.011	0.0050	0.030	0.0040	0.025	0.010	0.15	0.10		0.0020			0.20			0.289	0.334
J	0.070	0.21	1.11	0.014	0.0027	0.027	0.0038	0.017	0.017	0.19	0.09		0.0022	0.0044				0.0031	0.249	0.319
K	0.066	0.18	1.27	0.011	0.0027	0.022	0.0039	0.011	0.014	0.15	0.07		0.0022	0.0033			0.0024		0.262	0.328
L	0.020	0.18	1.22	0.020	0.0022	0.027	0.0038	0.022	0.014	0.18	0.11		0.0020	0.0033					0.266	0.286
M	0.130	0.17	1.24	0.011	0.0028	0.029	0.0037	0.017	0.011	0.19	0.08		0.0027	0.0038					0.269	0.399
N	0.040	0.18	1.11	0.010	0.0025	0.024	0.0037	0.012	0.011	0.17	0.08	0.005	0.0024	0.0033	0.01				0.245	0.285
O	0.060	0.21	1.50	0.010	0.0020	0.027	0.0037	0.041	0.014	0.19	0.15	0.005	0.0024	0.0033					0.325	0.385

[Table 2]

	Steel	F1	Production Condition of Hot-rolled Steel Sheet					Hot-rolled Steel Sheet			Electric Resistance Welded Steel Pipe							
			Heating Temp. (°C)	V1 (°C/s)	T1 (°C)	T2 (°C)	CT (°C)	YS (MPa)	TS (MPa)	YR (%)	YS (MPa)	TS (MPa)	YR (%)	F Fraction (%)	Kind of Balance	Average Crystal Grain Diameter (μm)	Coarse Crystal Grain Ratio (%)	DWTT Guarantee Temp. (°C)
Example 1	A	0.313	1130	10	650	600	558	477	549	87	510	562	91	79	P, B	10	8	-20
Example 2	A	0.313	1150	11	630	598	550	472	552	86	500	565	88	77	P, B	12	11	-25
Example 3	A	0.313	1150	12	610	590	550	465	534	87	490	549	89	83	P, B	11	7	-25
Example 4	B	0.339	1130	10	580	550	530	487	558	87	520	575	90	85	P, B	8	10	-10
Example 5	C	0.306	1120	9	630	590	530	480	535	90	505	549	92	82	P, B	9	11	-10
Example 6	D	0.334	1165	12	610	589	500	467	531	88	490	545	90	84	P, B	10	9	-10
Example 7	E	0.344	1145	8	630	589	545	475	535	89	490	545	90	83	P, B	11	12	-5
Example 8	F	0.317	1150	10	610	600	540	468	531	88	490	549	89	64	P, B	12	14	-25
Example 9	G	0.317	1170	14	652	589	525	477	532	90	498	545	91	82	P, B	10	18	-10
Example 10	H	0.315	1150	11	610	580	545	465	565	82	480	570	84	75	P, B	9	10	-10
Example 11	I	0.334	1110	8	610	590	550	495	555	89	520	565	92	68	P, B	10	11	-25
Example 12	J	0.319	1130	14	655	635	580	487	531	92	510	548	93	72	P, B	12	13	-10
Example 13	K	0.328	1140	13	610	600	578	465	534	87	490	550	89	82	P, B	11	8	-5
Comparative Example 1	L	0.286	1150	15	645	620	552	430	480	90	450	490	92	85	P, B	17	21	20
Comparative Example 2	M	0.399	1138	10	642	635	560	480	615	78	510	630	81	58	P, B	18	24	0
Comparative Example 3	A	0.313	1250	11	610	580	545	465	531	88	490	541	91	67	P, B	16	21	5
Comparative Example 4	A	0.313	1040	13	620	590	555	460	519	89	485	532	91	68	P, B	17	22	10
Comparative Example 5	A	0.313	1130	20	520	490	440	500	590	85	530	600	88	59	P, B	16	51	5
Comparative Example 6	A	0.313	1145	4	750	650	600	470	520	90	490	530	92	75	P, B	16	21	10
Comparative Example 7	N	0.285	1140	10	650	630	552	430	485	84	445	495	90	84	P, B	17	20	5
Comparative Example 8	O	0.385	1140	10	650	630	560	522	580	87	555	590	88	57	P, B	18	25	10

[0321] As set forth in Table 1 and Table 2, the electric resistance welded steel pipe of each Example, which satisfies the chemical composition of the base metal portion in the disclosure (including F1 being from 0.300 to 0.350), and, in the metallographic microstructure of the wall thickness direction central portion of the base metal portion, has a F fraction of from 60 to 90%, an average crystal grain diameter of 15 μm or less, and a coarse crystal grain ratio of 20% or less, had a low DWTT guarantee temperature and excellent low-temperature toughness.

[0322] The electric resistance welded steel pipe of each Example had a YR in the range of from 80 to 95%, and was confirmed to secure a plastic deformation allowance required as a steel pipe for a line pipe.

[0323] In contrast to each Example, in Comparative Examples 1 and 7 having F1 of less than 0.300, the average crystal grain diameter was too large, and the DWTT guarantee temperature was too high (i.e., the low-temperature toughness was poor). The reason why the average crystal grain diameter was too large is considered that ferrite grains were coarsened because F1 was less than 0.300.

[0324] In Comparative Examples 2 and 8 having F1 of more than 0.350, the F fraction was too low, and the DWTT guarantee temperature was too high (i.e., the low-temperature toughness was poor).

[0325] In Comparative Examples 2 and 8, the average crystal grain diameter and the coarse crystal grain ratio were too large. The reason thereof is considered that the F fraction became too low because F1 was more than 0.350.

[0326] In Comparative Example 3, the average crystal grain diameter and the coarse crystal grain ratio were too large, and the DWTT guarantee temperature was too high (i.e., the low-temperature toughness was poor).

[0327] The reason why the average crystal grain diameter and the coarse crystal grain ratio were too large in Comparative Example 3 is considered that austenite grains were coarsened in heating the slab because the heating temperature of the slab was too high.

[0328] In Comparative Example 4, the average crystal grain diameter and the coarse crystal grain ratio were too large, and the DWTT guarantee temperature was too high (i.e., the low-temperature toughness was poor).

[0329] The reason why the average crystal grain diameter and the coarse crystal grain ratio were too large in Comparative Example 4 is considered that the effect of refining of crystal grains by rolling was insufficient because the heating temperature of the slab was too low.

[0330] In Comparative Example 5, the F fraction was too low, and the DWTT guarantee temperature was too high (i.e., the low-temperature toughness was poor).

[0331] The reason why the F fraction was too low in Comparative Example 5 is considered that the strong-cooling stop temperature T1, the gradual-cooling stop temperature T2, and the coiling temperature CT were too low.

[0332] In Comparative Example 6, the average crystal grain diameter and the coarse crystal grain ratio were too large, and the DWTT guarantee temperature was too high (i.e., the low-temperature toughness was poor).

[0333] The reason why the average crystal grain diameter and the coarse crystal grain ratio were too large in Comparative Example 6 is considered that the strong-cooling stop temperature T1 and the coiling temperature CT became too high because the cooling rate V1 in the strong-cooling was too low, and therefore, coarse ferrite grains were generated.

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 0.030 to 0.120% of C,
from 0.05 to 0.30% of Si,
from 0.50 to 2.00% of Mn,
from 0 to 0.030% of P,
from 0 to 0.0100% of S,
from 0.010 to 0.035% of Al,
from 0.0010 to 0.0080% of N,
from 0.010 to 0.080% of Nb,
from 0.005 to 0.030% of Ti,
from 0.001 to 0.20% of Ni,
from 0.10 to 0.20% of Mo,
from 0 to 0.010% of V,
from 0 to 0.0030% of O,
from 0 to 0.0050% of Ca,
from 0 to 0.30% of Cr,
from 0 to 0.30% of Cu,

from 0 to 0.0050% of Mg,
from 0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:

F1 defined by the following Formula (1) is from 0.300 to 0.350,
in a metallographic microstructure of a wall thickness direction central portion of the base metal portion, a polygonal ferrite fraction is from 60 to 90%, an average crystal grain diameter is 15 μm or less, and a coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, is 20% or less, and
a yield ratio in a pipe axis direction is from 80 to 95%,

$$F1 = C + Si/24 + Mn/6 + Ni/40 + Cr/5 + Mo/4 + V/3 + Nb/3 \quad \text{Formula (1)}$$

wherein, in Formula (1), each of C, Si, Mn, Ni, Cr, Mo, V, and Nb represents mass% of a corresponding element.

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 0.010% of V,
more than 0% but equal to or less than 0.0030% of Ca,
more than 0% but equal to or less than 0.30% of Cr,
more than 0% but equal to or less than 0.30% 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 a yield strength in the pipe axis direction is from 450 to 540 MPa, and a tensile strength in the pipe axis direction is from 510 to 625 MPa.

4. The as-rolled electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 3, wherein a wall thickness is from 12 to 25 mm, and an outer diameter is from 304.8 to 660.4 mm.

5. The as-rolled electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 4, wherein the yield ratio in the pipe axis direction is from 80 to 93%.

6. A hot-rolled steel sheet used in production of the as-rolled electric resistance welded steel pipe for a line pipe according to any one of claims 1 to 5,
wherein a chemical composition consists of, in terms of % by mass:

from 0.030 to 0.120% of C,
from 0.05 to 0.30% of Si,
from 0.50 to 2.00% of Mn,
from 0 to 0.030% of P,
from 0 to 0.0100% of S,
from 0.010 to 0.035% of Al,
from 0.0010 to 0.0080% of N,
from 0.010 to 0.080% of Nb,
from 0.005 to 0.030% of Ti,
from 0.001 to 0.20% of Ni,
from 0.10 to 0.20% of Mo,
from 0 to 0.010% of V,
from 0 to 0.0030% of O,
from 0 to 0.0050% of Ca,
from 0 to 0.30% of Cr,
from 0 to 0.30% of Cu,
from 0 to 0.0050% of Mg,

from 0 to 0.0100% of REM, and
the balance being Fe and impurities, wherein:

F1 defined by Formula (1) is from 0.300 to 0.350, and
in a metallographic microstructure of a wall thickness direction central portion, a polygonal ferrite fraction is from 60 to 90%, an average crystal grain diameter is 15 μm or less, and a coarse crystal grain ratio, which is an areal ratio of crystal grains having a crystal grain diameter of 20 μm or more, is 20% or less.

7. The hot-rolled steel sheet according to claim 6, wherein a yield strength in a rolling direction is from 450 to 500 MPa, and a tensile strength in the rolling direction is from 510 to 580 MPa.

FIG.1

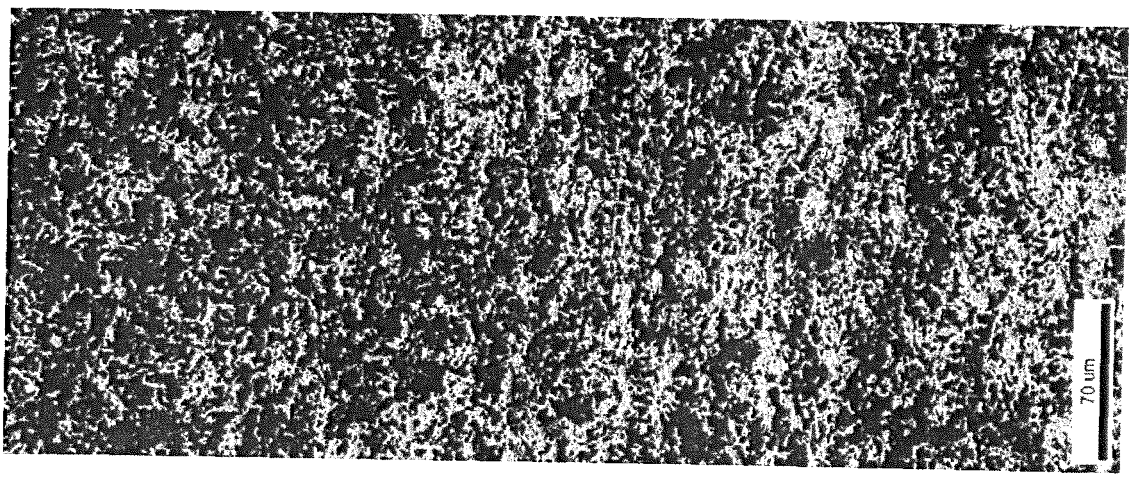


FIG.2

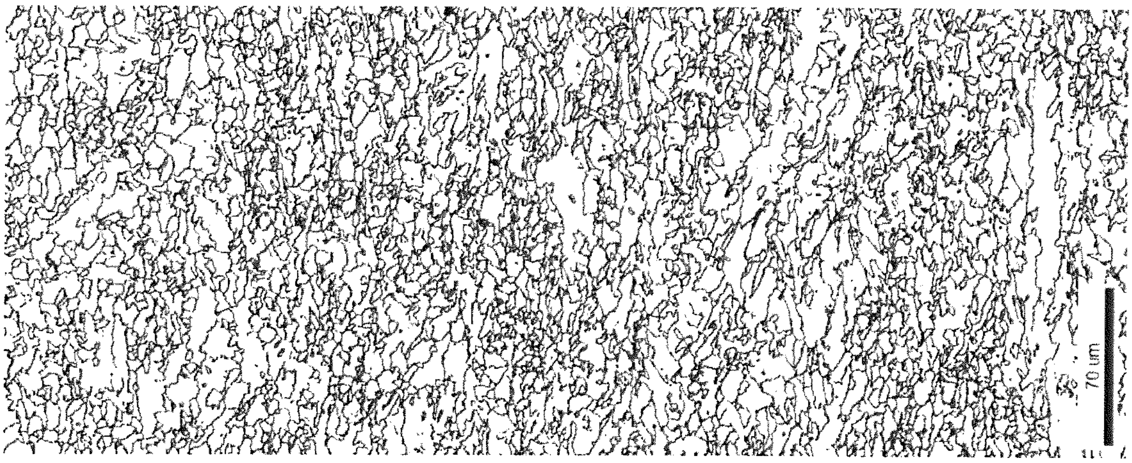


FIG.3

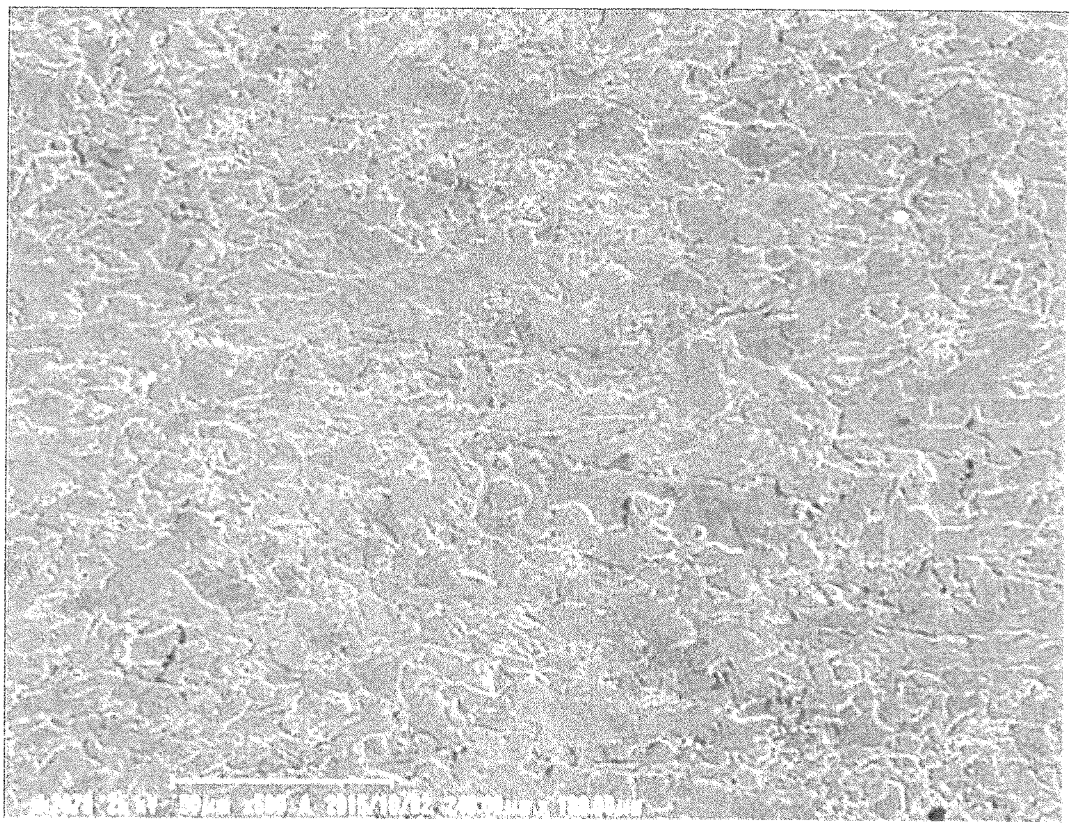


FIG.4

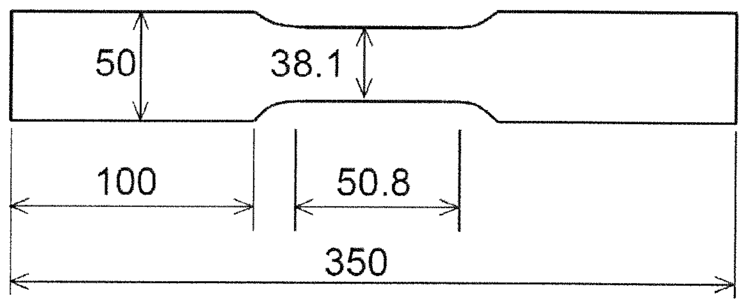


FIG.5

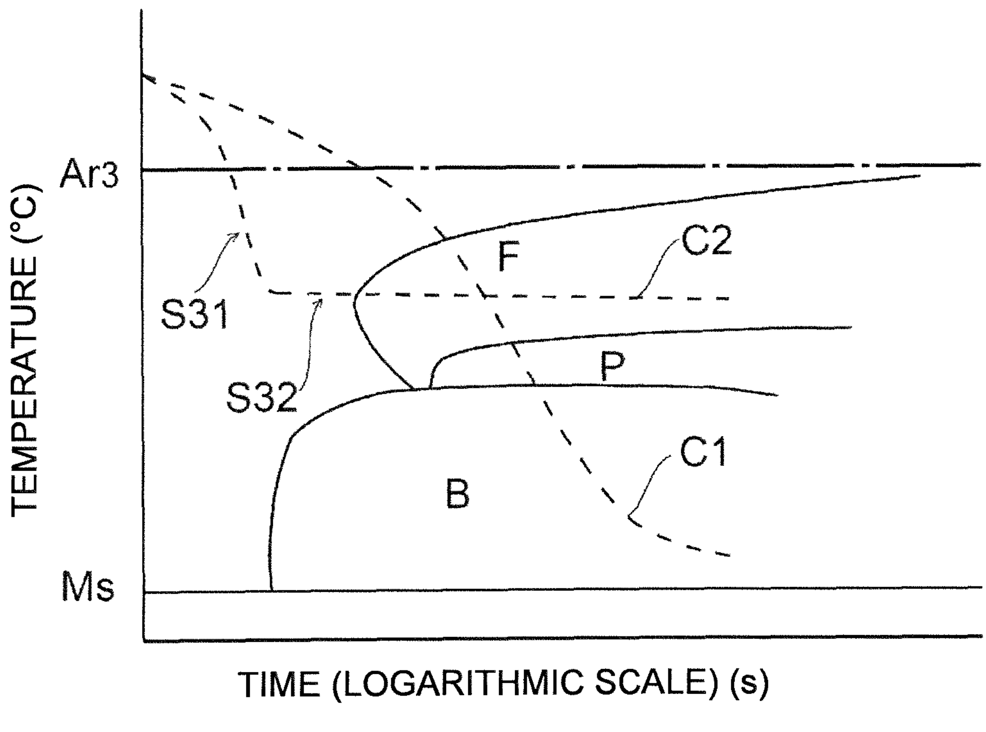
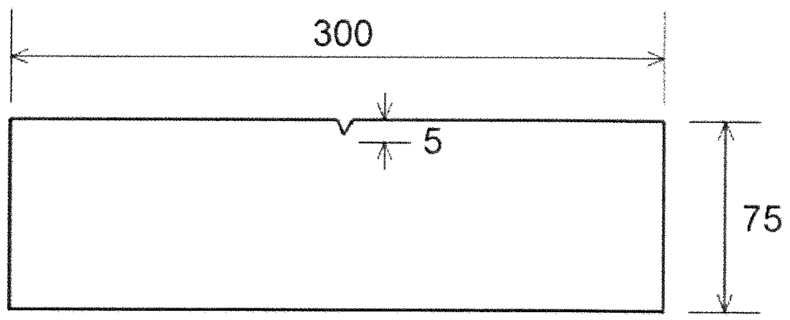

Ar3
TEMPERATURE (°C)
S31
S32
F
C2
P
B
C1
Ms
TIME (LOGARITHMIC SCALE) (s)

FIG.6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/023086

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

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60, C21D8/02, C21D9/08, C21D9/50

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	1-7
A	WO 2014/051119 A1 (Nippon Steel & Sumitomo Metal Corp.), 03 April 2014 (03.04.2014), & US 2015/0219249 A1 & EP 2902519 A1 & CA 2881372 A1 & CN 104350168 A & KR 10-2015-0002871 A	1-7
A	JP 10-298645 A (Sumitomo Metal Industries, Ltd.), 10 November 1998 (10.11.1998), (Family: none)	1-7

☒ 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
05 September 2017 (05.09.17)	12 September 2017 (12.09.17)

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/023086

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 2016-33236 A (JFE Steel Corp.), 10 March 2016 (10.03.2016), (Family: none)	1-7

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

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