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(54) **ELECTRIC-RESISTANCE-WELDED STEEL PIPE FOR LINE PIPES**

(57) The present invention provides an electric resistance welded steel pipe for a linepipe, in which a base metal portion includes, in terms of % by mass, 0.03% or more and less than 0.10% of C, from 0.30 to 1.00% of Mn, from 0.010 to 0.100% of Nb, from 0.010 to 0.500% of Si, and a balance including Fe and impurities, in which a value of CNeq is from 0.12 to 0.25, a ratio Mn/Si is 2.0 or more, and a value of LR is 0.25 or more; in which the base metal portion has a metallographic microstructure which has a ferrite ratio of from 80 to 98%, with a balance structure including pearlite and/or bainite, and which has a difference in hardness (balance structure - ferrite) of from 50 to 100 Hv; in which the electric resistance welded steel pipe satisfies a YS of 360 MPa or more, a TS of 465 MPa or more, and a YR of 0.90 or less; and in which each of the base metal portion and an electric resistance welded portion has a Charpy absorbed energy at 0°C of 100 J or more.

$$CNeq = C + Mn/6 + Cr/5 + (Ni + Cu)/15 + Nb + Mo + V$$

$$LR = (2.1C + Nb)/Mn$$

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Description

Technical Field

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

Background Art

[0002] In recent years, the importance of pipelines, which are one of the means for transporting mainly crude oil or natural gas, and linepipes used for forming these pipelines, is increasing more than ever.

[0003] In an electric resistance welded steel pipe for a linepipe, there is a case in which a decrease in yield ratio in a pipe axis direction of the electric resistance welded steel pipe is required.

[0004] For example, Patent Document 1 discloses a technique in which a repeated strain is applied to a steel strip as a material, for example, by a bending-unbending process, before pipe-making, to induce Bauschinger effect, thereby achieving a decrease in the yield ratio in the pipe axis direction of the resulting electric resistance welded steel pipe.

[0005] Further, Patent Document 2 discloses a technique in which a metallographic microstructure of a hot-rolled steel sheet for producing an electric resistance welded steel pipe is adjusted to a microstructure composed of a ferrite structure, and martensite having an area ratio of from 1 to 20%, thereby achieving a decrease in the yield ratio in the pipe axis direction of the electric resistance welded steel pipe.

[0006] Patent Document 3 discloses an electric resistance welded steel pipe for a linepipe which has certain degrees of tensile strength and yield strength, which has a decreased yield ratio, and whose base metal portion and electric resistance welded portion have excellent toughness. In this electric resistance welded steel pipe for a linepipe, the base metal portion has a chemical composition including, in terms of % by mass, from 0.080 to 0.120% of C, from 0.30 to 1.00% of Mn, from 0.005 to 0.050% of Ti, from 0.010 to 0.100% of Nb, from 0.001 to 0.020% of N, from 0.010 to 0.450% of Si, from 0.001 to 0.100% of Al, and the balance including Fe and impurities, wherein the value of the following CMeq is from 0.170 to 0.300, the ratio Mn/Si is 2.0 or more, and the value of the following LR is 0.210 or more; wherein the base metal portion contains ferrite in an area ratio of from 60 to 98%, and the balance including tempered bainite; wherein the electric resistance welded steel pipe has a yield strength in the pipe axis direction of from 390 to 562 MPa, a tensile strength in the pipe axis direction of from 520 to 690 MPa, and a yield ratio in the pipe axis direction of 90% or less; and wherein the base metal portion has a Charpy absorbed energy in a pipe circumferential direction at 0°C of 100 J or more, and the electric resistance welded portion has a Charpy absorbed energy in the pipe circumferential direction at 0°C of 80 J or more.

$$\mathrm{CMeq} = \mathrm{C} + \mathrm{Mn}/6 + \mathrm{Cr}/5 + (\mathrm{Ni} + \mathrm{Cu})/15 + \mathrm{Nb} + \mathrm{Mo}/3 + \mathrm{V}$$

$$\mathrm{LR} = (2.1 \times \mathrm{C} + \mathrm{Nb})/\mathrm{Mn}.$$

[0007] Patent Document 4 discloses a thick-walled electric resistance welded steel pipe which has both a low yield ratio of 95% or less, preferably 92% or less, and a low temperature toughness, which is obtained by electric resistance welding a base steel sheet formed in the shape of a pipe, and which has a thickness /outer diameter ratio of from 4.0 to 7.0%. In this thick-walled electric resistance welded steel pipe, the base steel sheet has a component composition including, in terms of % by mass: from 0.06 to 0.15% of C, from 1.00 to 1.65% of Mn, from 0.005 to 0.020% of Ti, from 0.005 to 0.030% of Nb, from 0.001 to 0.006% of N, P limited to 0.02% or less, S limited to 0.005% or less, 0.45% or less of Si, 0.08% or less of Al, less than 0.20% of Mo, 0.50% or less of Cu, 0.50% or less of Ni,1.00% or less of Cr, 0.10% or less of V, 0.0050% or less of Ca, 0.0050% or less of REM, and the balance consisting of Fe and unavoidable impurities, wherein the value of the following Ceq is from 0.32 to 0.43; wherein the base steel sheet has a metallographic microstructure which contains polygonal ferrite in an area ratio of from 50 to 92%, and the polygonal ferrite has an average particle size of 15 μm or less; and wherein an electric resistance welded portion has a hardness of from 160 to 240 Hv, and the structure of the electric resistance welded portion is composed of bainite, fine grained ferrite and pearlite, or composed of fine grained ferrite and bainite.

$$\mathrm{Ceq} = \mathrm{C} + \mathrm{Mn}/6 + (\mathrm{Cr} + \mathrm{Mo} + \mathrm{V})/5 + (\mathrm{Ni} + \mathrm{Cu})/15$$

[0008] Patent Document 5 discloses an as-rolled electric resistance welded steel pipe for a linepipe which has an excellent low temperature toughness as evaluated by DWTT. In this as-rolled electric resistance welded steel pipe for a linepipe, a base metal portion includes, 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 0.010 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, and the balance including Fe and impurities, wherein the value of the following F1 is from 0.300 to 0.350; wherein the metallographic microstructure of a central portion in a thickness direction of the base metal portion has a polygonal ferrite fraction of from 60 to 90%, an average crystal grain size of 15 μm or less, and a coarse crystal grain size, which is the area ratio of crystal grains having a crystal grain size of 20 μm or more, of 20% or less; and wherein the electric resistance welded steel pipe has a yield ratio in the pipe axis direction of from 80 to 95%.

$$F1 = Si/24 + Mn/6 + Ni/40 + Cr/5 + Mo/4 + V/3 + Nb/3$$

Patent Document 1: Japanese Patent Publication (JP-B) No. 4466320
Patent Document 2: Japanese Patent Application Laid-Open (JP-A) No. H10-176239
Patent Document 3: WO 2017/163987
Patent Document 4: WO 2013/027779
Patent Document 5: JP-B No. 6260757

SUMMARY OF INVENTION

Technical Problem

[0009] However, in the technique disclosed in Patent Document 1, the number of steps is increased since a step of applying a strain to the steel strip is required, possibly resulting in an increase in the production cost of the resulting steel pipe.

[0010] In the technique disclosed in Patent Document 2, there is a case in which a further improvement in the toughness of the base metal portion of the steel pipe is required.

[0011] In the technique disclosed in Patent Document 3, a decrease in the yield ratio of the electric resistance welded steel pipe is achieved by subjecting the entirety of the electric resistance welded steel pipe as it has been made (namely, an as-rolled electric resistance welded steel pipe) to a heat treatment at a temperature of 400°C or higher and at an Ac point of 1 or less, after pipe-making, in each case. However, there is a case in which a decrease in the yield ratio of the electric resistance welded steel pipe as well as ensuring the toughness of the base metal portion and the electric resistance welded portion are required, without being limited to the technique of Patent Document 3 (in particular, without performing a heat treatment after pipe-making).

[0012] Further, paragraph 0013 of Patent Document 4 describes that "there has been a finding that it is possible to reduce the precipitation of Nb carbonitrides and to form a multiphase structure, by reducing the content of Nb to a level lower than the conventional one, further optimizing hot rolling conditions and performing a two-stage accelerated cooling after the hot rolling, as a result of which a low Y/T can be ensured. " However, there is a case in which a decrease in the yield ratio of the electric resistance welded steel pipe as well as ensuring the toughness of the base metal portion and the electric resistance welded portion are required, without being limited to the technique (a reduction in Nb content) disclosed in Patent Document 4.

[0013] In addition, Patent Document 5 describes that "an average crystal grain size of 15 μm or less, and a coarse crystal grain size, which is the area ratio of crystal grains having a crystal grain size of 20 μm or more, of 20% or less" was achieved, by restricting the chemical composition of the base metal portion to a specific range and controlling the conditions in the hot rolling step, thereby improving the low temperature toughness as evaluated by DWTT. However, there is a case in which a decrease in the yield ratio of the electric resistance welded steel pipe as well as ensuring the toughness of the base metal portion and the electric resistance welded portion are required, without being limited to the technique disclosed in Patent Document 5.

[0014] An object of the present disclosure is to provide an electric resistance welded steel pipe for a linepipe which has certain degrees of tensile strength and yield strength, which has a decreased yield ratio, and whose base metal portion and electric resistance welded portion have excellent toughness.

Solution to Problem

[0015] Means for solving the problems described above include the following embodiments.

<1> An electric resistance welded steel pipe for a linepipe, the steel pipe including:

a base metal portion; and
an electric resistance welded portion,
wherein the base metal portion has a chemical composition consisting of, in terms of % by mass:

0.03% or more and less than 0.10% of C,
from 0.30 to 1.00% of Mn,
from 0.005 to 0.050% of Ti,
from 0.010 to 0.100% of Nb,
from 0.001 to 0.020% of N,
from 0.010 to 0.500% of Si,
from 0.001 to 0.100% of Al,
from 0 to 0.030% of P,
from 0 to 0.010% of S,
from 0 to 0.50% of Mo,
from 0 to 0.50% of Cu,
from 0 to 0.50% of Ni,
from 0 to 0.50% of Cr,
from 0 to 0.10% of V,
from 0 to 0.0100% of Ca,
from 0 to 0.0100% of REM, and
a balance consisting of Fe and impurities,

wherein CNeq, represented by Formula (1), is from 0.12 to 0.25, a ratio of a content of Mn with respect to a content of Si is 1.8 or more, and LR, represented by Formula (2) is 0.25 or more:

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

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

wherein, in Formulae (1) and (2), each element symbol represents a content of each element in % by mass, wherein the base metal portion has a metallographic microstructure in which:

a first phase composed of ferrite has an area ratio of from 80 to 98%;
a second phase, which is a balance, contains at least one of pearlite or bainite;
an area ratio of martensite with respect to a total area of the second phase is less than 1%; and
a value obtained by subtracting a hardness of the first phase from a hardness of the second phase is from 50 to 100 Hv;

wherein the electric resistance welded steel pipe has:

a yield strength in a pipe axis direction of from 360 to 600 MPa;
a tensile strength in the pipe axis direction of from 465 to 760 MPa; and
a yield ratio in the pipe axis direction of 0.90 or less,

wherein each of the base metal portion and the electric resistance welded portion has a Charpy absorbed energy at 0°C of 100 J or more, and
wherein a yield elongation of the electric resistance welded steel pipe, as measured in a tensile test in the pipe axis direction, is less than 0.2%.

<2> The electric resistance welded steel pipe for a linepipe according to <1>, wherein the chemical composition of the base metal portion includes, in terms of % by mass, at least one selected from the group consisting of:

more than 0% and equal to or less than 0.50% of Mo,
more than 0% and equal to or less than 0.50% of Cu,
more than 0% and equal to or less than 0.50% of Ni,
more than 0% and equal to or less than 0.50% of Cr,

more than 0% and equal to or less than 0.10% of V,
more than 0% and equal to or less than 0.0100% of Ca, and
more than 0% and equal to or less than 0.0100% of REM.

<3> The electric resistance welded steel pipe for a linepipe according to <1> or <2>, wherein the electric resistance welded steel pipe for a linepipe has a thickness of from 10 to 25.4 mm, and an outer diameter of from 254.0 to 660.4 mm.

Advantageous Effects of Invention

[0016] The present disclosure provides an electric resistance welded steel pipe for a linepipe which has certain degrees of tensile strength and yield strength, which has a decreased yield ratio, and whose base metal portion and electric resistance welded portion have excellent toughness.

DESCRIPTION OF EMBODIMENTS

[0017] A numerical range expressed by "from x to y" in the present disclosure includes the values of x and y in the range as the lower limit and upper limit values, respectively.
[0018] The content of a component (element) expressed by "%" in the present disclosure means "% by mass".
[0019] The content of C (carbon) in the present disclosure may sometimes be expressed as "C content". The content of another element may be expressed similarly.
[0020] The term "step" in the present disclosure encompasses not only an independent step but also a step which is not clearly distinguishable from another step as long as the desired object of the step is achieved.
[0021] An electric resistance welded steel pipe for a linepipe according to the present disclosure (hereinafter, also simply referred to as "electric resistance welded steel pipe") includes:

a base metal portion; and
an electric resistance welded portion,
wherein the base metal portion has a chemical composition consisting of, in terms of % by mass:

0.03% or more and less than 0.10% of C,
from 0.30 to 1.00% of Mn,
from 0.005 to 0.050% of Ti,
from 0.010 to 0.100% of Nb,
from 0.001 to 0.020% of N,
from 0.010 to 0.500% of Si,
from 0.001 to 0.100% of Al,
from 0 to 0.030% of P,
from 0 to 0.010% of S,
from 0 to 0.50% of Mo,
from 0 to 0.50% of Cu,
from 0 to 0.50% of Ni,
from 0 to 0.50% of Cr,
from 0 to 0.10% of V,
from 0 to 0.0100% of Ca,
from 0 to 0.0100% of REM, and
the balance consisting of Fe and impurities,

wherein CNeq, represented by Formula (1), is from 0.12 to 0.25, the ratio of the content of Mn with respect to the content of Si is 1.8 or more, and LR, represented by Formula (2) is 0.25 or more:

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

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

wherein, in Formulae (1) and (2), each element symbol represents the content of each element in % by mass, wherein the base metal portion has a metallographic microstructure in which:

- a first phase composed of ferrite has an area ratio of from 80 to 98%;
- a second phase, which is the balance, contains at least one of pearlite or bainite;
- the area ratio of martensite with respect to the total area of the second phase is less than 1%; and
- a value obtained by subtracting the hardness of the first phase from the hardness of the second phase is from 50 to 100 Hv,

wherein the electric resistance welded steel pipe has:

- a yield strength in the pipe axis direction of from 360 to 600 MPa;
- a tensile strength in the pipe axis direction of from 465 to 760 MPa; and
- a yield ratio in the pipe axis direction of 0.90 or less,

wherein each of the base metal portion and the electric resistance welded portion has a Charpy absorbed energy at 0°C of 100 J or more, and
wherein a yield elongation of the electric resistance welded steel pipe, as measured in a tensile test in the pipe axis direction, is less than 0.2%.

[0022] In the present disclosure, the chemical composition (including the fact that each of the value of Ceq, the ratio of the content of Mn with respect to the content of Si, and the value of LR, satisfy each requirement described above) of the base metal portion described above, is also referred to as the chemical composition in the present disclosure.

[0023] The electric resistance welded steel pipe according to the present disclosure includes a base metal portion and an electric resistance welded portion.

[0024] In general, an electric resistance welded steel pipe is produced by: forming (hereinafter, also referred to as "roll forming") a hot-rolled steel sheet in the shape of a pipe to prepare an open pipe; subjecting the abutting portion of the thus prepared open pipe to electric resistance welding to form an electric resistance welded portion (the process up to this point is also referred to as "pipe-making"); and then performing a seam heat treatment on the electric resistance welded portion, if necessary.

[0025] In the electric resistance welded steel pipe according to the present disclosure, the term "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.

[0026] The term "heat affected zone" (hereinafter, also referred to as "HAZ") refers to a zone which has been affected by heat due to electric resistance welding (in the case of performing a seam heat treatment after electric resistance welding, a zone affected by the electric resistance welding and the seam heat treatment).

[0027] A hot-rolled steel sheet, which is the material of the electric resistance welded steel pipe, is produced using a hot strip mill. Specifically, a continuous hot-rolled steel sheet which has been wound in the form of a coil (hereinafter, also referred to as "hot coil") is produced by a hot strip mill.

[0028] A hot-rolled steel sheet, which is the material of the electric resistance welded steel pipe, is different from a steel plate, which is produced using a plate mill, in that the hot-rolled steel sheet is a continuous steel sheet.

[0029] The steel plate is not a continuous steel sheet, and thus cannot be used in roll forming, which is a continuous bending processing.

[0030] The electric resistance welded steel pipe is clearly distinguished from a welded steel pipe (such as a UOE steel pipe) which is produced using a steel plate in that the electric resistance welded steel pipe is produced using a hot-rolled steel sheet.

[0031] In the electric resistance welded steel pipe according to the present disclosure, a yield elongation, as measured in a tensile test in the pipe axis direction, is less than 0.2%. The fact that the yield elongation is less than 0.2% means that the yield elongation is not substantially observed.

[0032] The fact that the yield elongation is less than 0.2% means that the electric resistance welded steel pipe according to the present disclosure is an electric resistance welded steel pipe which has not been subjected to any heat treatment other than the seam heat treatment, after pipe-making (namely, an electric resistance welded steel pipe as it is made (also referred to as "as-rolled electric resistance welded steel pipe")).

[0033] Despite being an electric resistance welded steel pipe as it is made, the electric resistance welded steel pipe according to the present disclosure has certain degrees of tensile strength and yield strength (specifically, a yield strength in the pipe axis direction of from 360 to 600 MPa, and a tensile strength in the pipe axis direction of from 465 to 760 MPa), a decreased yield ratio (specifically, a yield ratio in the pipe axis direction of 0.90 or less), and an excellent toughness (specifically, each of the base metal portion and the electric resistance welded portion has a Charpy absorbed energy at 0°C of 100 J or more).

[0034] Hereinafter, the tensile strength in the pipe axis direction is also referred to as "TS", the yield strength in the pipe axis direction is also referred to as "YS", the yield ratio in the pipe axis direction is also referred to as "YR", and decreasing the YR of the electric resistance welded steel pipe is also referred to as "achieving a decrease in YR".

[0035] As described above, the electric resistance welded steel pipe according to the present disclosure is an electric resistance welded steel pipe as it is made, and has the above-described effects.

[0036] The above-described effects are achieved by the combination of the chemical composition of the base metal portion, and the metallographic microstructure of the base metal portion.

[0037] For example, the fact that the value of LR represented by Formula (2) is 0.25 or more contributes to achieving a decrease in YR (namely, a YR of 0.90 or less). The reason for this is thought to be because an LR value of 0.25 or more allows an improvement in work hardening properties provided by C and an improvement in work hardening properties provided by Nb to be effectively achieved, as a result of which a decrease in YR is achieved.

[0038] Further, the fact that the value obtained by subtracting the hardness of the first phase from the hardness of the second phase (hereinafter, also referred to as "difference in hardness") is 50 Hv or more contributes to achieving a decrease in YR (namely, a YR of 0.90 or less). The reason for this is thought to be because a difference in hardness of 50 Hv or more causes the occurrence of non-uniform deformation due to processing strain during pipe-making, thereby exhibiting anisotropic hardening properties of the steel. As a result, despite being an electric resistance welded steel pipe as it is made, it is thought that a decrease in YR (namely, a YR of 0.90 or less) is achieved. To give further details, means for performing a heat treatment on an electric resistance welded steel pipe as it is made (see, for example, Patent Document 3 described above) can possibly be used, as means for achieving a decrease in YR. In the electric resistance welded steel pipe according to the present disclosure, however, a decrease in YR is achieved, despite being an electric resistance welded steel pipe as it is made.

[0039] Further, the fact that the difference in hardness is 100 Hv or less contributes to an improvement in the toughness of the base metal portion. The reason for this is thought to be because a difference in hardness of 100 Hv or less results in a decrease in internal stress within the metallographic microstructure.

[0040] The metallographic microstructure of the base metal portion is mainly formed during the process of producing a hot-rolled steel sheet, which is the material of the electric resistance welded steel pipe. One example of the method of producing the electric resistance welded steel pipe, including preferred conditions for producing the hot-rolled steel sheet, will be described later.

[0041] Since the electric resistance welded steel pipe according to the present disclosure has a low YR, the effect of allowing a reduction in the occurrence of buckling of the electric resistance welded steel pipe is expected.

[0042] One example of the case in which a reduction in the occurrence of buckling of a steel pipe is required may be, for example, the case of laying a steel pipe for a submarine linepipe by reeling (hereinafter, referred to as "reel-laying"). In the reel-laying, the steel pipe is produced on land in advance, and the produced steel pipe is wound on a spool on a barge ship. Thereafter, while unwinding the wound steel pipe on the sea, the steel pipe is laid on the sea bed. In the reel-laying described above, plastic bending is applied to the steel pipe during the winding and unwinding of the steel pipe, and thus, there is a case in which the steel pipe buckles. When the buckling of the steel pipe occurs, the pipe laying operation has to be stopped, which causes an enormous damage.

[0043] The buckling of the steel pipe can be reduced by decreasing the YR of the steel pipe.

[0044] Therefore, the electric resistance welded steel pipe according to the present disclosure is expected to provide, for example, the effect of allowing a reduction in the occurrence of buckling during the reel-laying, when used as an electric resistance welded steel pipe for a submarine linepipe.

[0045] Further, the electric resistance welded steel pipe according to the present disclosure is expected to provide an excellent effect of stopping crack propagation upon bursting, when used as an electric resistance welded steel pipe for a linepipe, because the base metal portion and the electric resistance welded portion thereof have an excellent toughness.

< Chemical Composition of Base Metal Portion >

[0046] The chemical composition of the base metal portion (namely, the chemical composition in the present disclosure) will now be described.

C: 0.03% or more and less than 0.10%

[0047] C is an element necessary for forming at least one of pearlite or bainite, and to improve the work hardening properties important for achieving a decrease in YR.

[0048] The C content is 0.03% or more, from the viewpoint of obtaining such an effect.

[0049] When the C content is less than 0.03%, the area ratio of the ferrite structure may be excessively increased, failing to improve the work hardening properties. As a result, there is a case in which a decrease in YR cannot be achieved.

[0050] When the C content is 0.10% or more, on the other hand, cementite may be formed in a large amount, possibly resulting in a decrease in the toughness of the base metal portion and the electric resistance welded portion. Accordingly, the C content is less than 0.10%. The C content is preferably 0.09% or less, more preferably less than 0.08%, and still more preferably 0.07% or less.

Mn: from 0.30% to 1.00%

[0051] Mn is an element which improves the hardenability of the steel. Further, Mn is also an element essential for detoxifying S. The Mn content is 0.30% or more, from the viewpoint of obtaining these effects.

[0052] When the Mn content is less than 0.30%, an embrittlement due to S may occur, possibly resulting in a decrease in the toughness of the base metal portion.

[0053] On the other hand, an excessive Mn content may lead to a marked segregation at the central portion in the thickness direction, to cause the formation of MnS or the formation of a hardened phase of coarse martensite and/or bainite, possibly resulting in the impairment of the toughness of the base metal portion and the electric resistance welded portion. Further, an excessive Mn content may lead to a CNeq value of more than 0.25, and as a result, the strength may be excessively increased (specifically, it may result in a failure to achieve at least one of a YS of 600 MPa or less, or a TS of 760 MPa or less). Based on these reasons, the Mn content is 1.00% or less. The Mn content is preferably less than 1.00%, more preferably 0.90% or less, still more preferably 0.80% or less, and yet still more preferably 0.70% or less.

Ti: from 0.005 to 0.050%

[0054] Ti is an element which contributes to the refinement of the crystal grain size by forming carbonitrides, and is an element necessary for ensuring the toughness of the base metal portion and the electric resistance welded portion. The Ti content is 0.005% or more, from the viewpoint of obtaining such effects. The Ti content is preferably 0.010% or more.

[0055] When the Ti content is more than 0.050%, however, coarse TiN may be formed to cause a decrease in the toughness of the base metal portion and the electric resistance welded portion. Accordingly, the Ti content is 0.050% or less.

Nb: 0.010 to 0.100%

[0056] Nb has the effect of increasing the toughness by rolling in a non-recrystallization region at a high temperature. Further, Nb is also an element which improves the work hardening properties by precipitation strengthening (namely, an element which contributes to achieving a decrease in YR). The Nb content is 0.010% or more, preferably 0.020% or more, and more preferably 0.030% or more, from the viewpoint of obtaining these effects.

[0057] When the Nb content is more than 0.100%, however, coarse Nb carbides may be formed to cause a decrease in the toughness. Accordingly, the Nb content is 0.100% or less. The Nb content is preferably 0.080% or less, and more preferably 0.060% or less.

N: from 0.001 to 0.020%

[0058] N is an element which reduces the coarsening of crystal grains by forming metal nitrides, thereby improving the toughness of the base metal portion and the electric resistance welded portion. The N content is 0.001% or more, from the viewpoint of obtaining such an effect.

[0059] When the N content is more than 0.020%, however, the amount of alloy carbides formed may be increased, to cause a decrease in the toughness of the base metal portion and the electric resistance welded portion. Accordingly, the N content is 0.020% or less. The N content is preferably 0.010% or less, and more preferably 0.006% or less.

Si: from 0.010 to 0.500%

[0060] Si is an element which is used as a deoxidizing agent for the steel. Si reduces the formation of coarse oxides in the base metal portion and the electric resistance welded portion, thereby improving the toughness. The Si content is 0.010% or more, from the viewpoint of obtaining such an effect. The Si content is preferably 0.030% or more.

[0061] When the Si content is more than 0.500%, however, inclusions may be formed in the electric resistance welded portion to cause a decrease in the Charpy absorbed energy, possibly resulting in a decrease in the toughness. Accordingly, the Si content is 0.500% or less. The Si content is preferably 0.400% or less, and more preferably 0.350% or less.

Al: from 0.001 to 0.100%

[0062] Al is an element which is used as a deoxidizing agent, in the same manner as Si. The Al content is 0.001% or more, from the viewpoint of improving the toughness of the base material and thus preventing the occurrence of cracks due to free oxygen. The Al content is preferably 0.005% or more, and more preferably 0.010% or more.
[0063] When the Al content is more than 0.100%, however, Al-based oxides may be formed during the electric resistance welding, along with which the toughness of the electric resistance welded portion may be decreased. Accordingly, the Al content is 0.100% or less. The Al content is preferably 0.090% or less.

P: from 0 to 0.030%

[0064] P is an element which can be present in the steel as impurities.
[0065] When the P content is more than 0.030%, P may be segregated at grain boundaries, possibly resulting in the impairment of the toughness of the base metal portion and the electric resistance welded portion. Accordingly, the P content is 0.030% or less.
[0066] The P content may also be 0%. The P content may be more than 0%, or 0.001% or more, from the viewpoint of reducing dephosphorization cost.

S: from 0 to 0.010%

[0067] S is an element which can be present in the steel as impurities.
[0068] When the S content is more than 0.030%, the toughness of the base metal portion and the electric resistance welded portion may be impaired. Accordingly, the S content is 0.030% or less. The S content is preferably 0.020% or less, and more preferably 0.010% or less.
[0069] The S content may also be 0%. The S content may be more than 0%, or 0.001% or more, from the viewpoint of reducing desulfurization cost.

Mo: from 0 to 0.50%

[0070] Mo is an optional element. In other words, the Mo content may be 0%, or more than 0%.
[0071] Mo is an element which has the effect of improving the hardenability of the steel, thereby improving the strength of the steel. The Mo content may be 0.01% or more, from the viewpoint of obtaining such an effect.
[0072] When the Mo content is more than 0.50%, however, Mo carbonitrides may be formed to cause a decrease in the toughness. Accordingly, the Mo content is 0.50% or less. The Mo content may be 0.30% or less, or 0.10% or less.

Cu: from 0 to 0.50%

[0073] Cu is an optional element. In other words, the Cu content may be 0%, or more than 0%.
[0074] Cu is an element effective for improving the strength of the base metal portion. The Cu content may be 0.05% or more, from the viewpoint of obtaining such an effect.
[0075] When the Cu content is more than 0.50%, however, fine Cu particles may be formed to cause a significant decrease in the toughness. Accordingly, the Cu content is 0.50% or less. The Cu content may be 0.40% or less, or 0.30% or less.

Ni: from 0 to 0.50%

[0076] Ni is an optional element. In other words, the Ni content may be 0%, or more than 0%.
[0077] Ni is an element which contributes to improvements in the strength and the toughness. The Ni content may be 0.05% or more, from the viewpoint of obtaining such an effect.
[0078] When the Ni content is more than 0.50%, however, the strength may be excessively increased (specifically, it may result in a failure to achieve at least one of a YS of 600 MPa or less, or a TS of 760 MPa or less). Accordingly, the Ni content is 0.50% or less.

Cr: 0 to 0.50%

[0079] Cr is an optional element. In other words, the Cr content may be 0%, or more than 0%.
[0080] Cr is an element which improves the hardenability. The Cr content may be 0.05% or more, from the viewpoint of obtaining such an effect.

[0081] When the Cr content is more than 0.50%, however, Cr-based inclusions may be formed in the electric resistance welded portion, to cause a decrease in the toughness of the electric resistance welded portion. Accordingly, the Cr content is 0.50% or less. The Cr content may be 0.40% or less.

V: from 0 to 0.10%

[0082] V is an optional element. In other words, the V content may be 0%, or more than 0%.
[0083] V has almost the same effects as Nb. The V content may be 0.010% or more, from the viewpoint of obtaining such effects.
[0084] When the V content is more than 0.10%, however, V carbonitrides may be formed to cause a decrease in the toughness. Accordingly, the V content is 0.10% or less.

Ca: from 0 to 0.0100%

[0085] Ca is an optional element. In other words, the Ca content may be 0%, or more than 0%.
[0086] Ca is an element which controls the form of sulfide-based inclusions, and thereby improving the low temperature toughness. The Ca content may be 0.0001% or more, or 0.0002% or more, from the viewpoint of obtaining such an effect.
[0087] When the Ca content is more than 0.0100%, however, CaO-CaS may form large-sized clusters or inclusions, and there is a risk of adversely affecting the toughness. Accordingly, the Ca content is 0.0100% or less. The Ca content may be 0.0080% or less, or 0.0060% or less.

REM: from 0 to 0.0100%

[0088] REM is an optional element. In other words, the REM content may be 0%.
[0089] The term "REM" as used herein refers to a rare earth element(s), namely, at least one element selected from the group consisting of Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.
[0090] REM has effects as a deoxidizing agent and a desulfurizing agent. The REM content may be 0.0001% or more, from the viewpoint of obtaining such effects.
[0091] When the REM content is more than 0.0100%, however, coarse oxides may be formed to cause a decrease in HIC resistance (resistance to hydrogen cracking during the electric resistance welding) as well as a decrease in the toughness of the base metal portion and HAZ. Accordingly, the REM content is 0.0100% or less.
[0092] The chemical composition of the base metal portion may contain at least one selected from the group consisting of more than 0% and equal to or less than 0.50% of Mo, more than 0% and equal to or less than 0.50% of Cu, more than 0% and equal to or less than 0.50% of Ni, more than 0% and equal to or less than 0.50% of Cr, more than 0% and equal to or less than 0.10% of V, more than 0% and equal to or less than 0.0100% of Ca, and more than 0% and equal to or less than 0.0100% of REM.
[0093] A more preferred content of each of these optional elements is as described above.

Balance: Fe and impurities

[0094] In the chemical composition of the base metal portion, the balance excluding the respective elements described above is Fe and impurities.
[0095] The term "impurities" as used herein refers to components which are contained in raw materials (such as ores and scraps), or components which are mixed-in during production steps, and are not intentionally incorporated into the steel.
[0096] Examples of the impurities include all elements other than the elements described above. Only one kind, or two or more kinds of elements may be contained as the impurities.
[0097] Examples of the impurities include B, Sb, Sn, W, Co, As, Pb, Bi, and H.
[0098] As to the other elements, in general, any of Sb, Sn, W, Co and As can be contained, for example, in a content of 0.1% or less, any of Pb and Bi can be contained, for example, in a content of 0.005% or less, B can be contained, for example, in a content of 0.0003% or less, and H can be contained, for example, in a content of 0.0004% or less, as the impurities. The contents of other elements need not be particularly controlled, as long as the contents are within normal ranges.
[0099] CNeq: from 0.12 to 0.25
[0100] In the chemical composition of the base metal portion, CNeq represented by Formula (1) is from 0.12 to 0.25.

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

[In Formula (1), each element symbol represents the content of each element in % by mass.]

[0101] The value of CNeq positively correlates with the strength of the electric resistance welded steel pipe.

[0102] When the value of CNeq is less than 0.12, it may result in a failure to achieve at least one of a YS of 360 MPa or more or a TS of 465 MPa or more. Accordingly, the value of CNeq is 0.12 or more. The value of CNeq is preferably 0.15 or more, from the viewpoint of improving at least one of YS or TS of the electric resistance welded steel pipe.

[0103] When the value of CNeq is more than 0.25, however, the strength may be excessively increased (specifically, it may result in a failure to achieve at least one of a YS of 600 MPa or less, or a TS of 760 MPa or less). Accordingly, the value of CNeq is 0.25 or less.

Ratio Mn/Si: 1.8 or more

[0104] In the chemical composition of the base metal portion, the ratio Mn/Si (namely, the ratio of the content of Mn with respect to the content of Si; hereinafter also referred to as "Mn/Si") is 1.8 or more.

[0105] When the ratio Mn/Si is less than 1.8, the toughness of the electric resistance welded portion may be decreased, due to the formation of MnSi-based inclusions. The ratio Mn/Si is preferably 1.9 or more, and more preferably 2.0 or more, from the viewpoint of further improving the toughness of the electric resistance welded portion.

[0106] The upper limit of the ratio Mn/Si is not particularly limited. The ratio Mn/Si is preferably 50 or less, more preferably 30 or less, and still more preferably 20 or less, from the viewpoint of further improving the toughness of the base metal portion and the electric resistance welded portion.

LR: 0.25 or more

[0107] In the chemical composition of the base metal portion, the value of LR represented by Formula (2) is 0.25 or more.

[0108] When the value of LR is less than 0.25, there is a case in which a decrease in YR cannot be achieved (namely, the value of YR may be more than 0.90).

[0109] The upper limit of the value of LR is not particularly limited, and may be, for example, 0.90, 0.85 or the like.

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

[In Formula (2), each element symbol represents the content of each element in % by mass.]

[0110] In Formula (2), C and Nb, which improves the work hardening properties and thereby contributes to achieving a decrease in YR, are used as the numerator, and Mn, which has a risk of reducing the work hardening properties to cause an increase in YR, is used as the denominator.

[0111] The upper limit of the value of LR is not particularly limited, and may be, for example, 0.90, 0.80 or the like.

< Metallographic Microstructure of Base Metal Portion >

[0112] The metallographic microstructure of the base metal portion will now be described.

(Area Ratio of First Phase (Ferrite Fraction))

[0113] In the metallographic microstructure of the base metal portion, the area ratio of the first phase composed of ferrite (hereinafter, also referred to as "ferrite fraction") is from 80 to 98%.

[0114] When the ferrite fraction is less than 80%, the degree of carbon enrichment in the second phase may be insufficient. As a result, the difference in hardness between the first phase and the second phase may be excessively decreased, possibly leading to a difference in hardness of less than 50 Hv. Accordingly, the ferrite fraction is 80% or more, and preferably 82% or more.

[0115] When the ferrite fraction is more than 98%, however, the degree of carbon enrichment in the second phase may be increased excessively. As a result, the hardness of the second phase is excessively increased, possibly leading to a difference in hardness of more than 100 Hv. Accordingly, the ferrite fraction is 98% or less, preferably 95% or less, and more preferably 90% or less.

(Second Phase)

[0116] In the metallographic microstructure of the base metal portion, the second phase, which is the balance (namely, the balance excluding the first phase from the metallographic microstructure of the base metal portion), contains at least one of pearlite or bainite, and the area ratio of martensite with respect to the total area of the second phase is less than 1 %.

[0117] When the second phase satisfies the above-described requirements, a difference in hardness (namely, a value obtained by subtracting the hardness of the first phase from the hardness of the second phase) of 100 Hv or less is more easily achieved.

[0118] The fact that the area ratio of martensite with respect to the total area of the second phase is less than 1% means that the second phase does not substantially contain martensite. When the second phase substantially contains martensite (namely, when the second phase contains 1% or more of martensite with respect to the total area of the second phase), the strength may be excessively increased (specifically, it may result in a failure to achieve at least one of a YS of 600 MPa or less, or a TS of 760 MPa or less).

[0119] The concept of "bainite" in the present disclosure encompasses bainitic ferrite, granular bainite, upper bainite and lower bainite.

[0120] The concept of "pearlite" in the present disclosure encompasses a pseudo-pearlite structure.

(Method of Measuring Ferrite Fraction and Method of Identifying Second Phase)

[0121] The measurement of the ferrite fraction and the identification of the second phase, in the metallographic microstructure of the base metal portion, are carried out by performing nital etching on the metallographic microstructure of the central portion in the thickness direction in an L cross section at a base metal 90° position of the electric resistance welded steel pipe, and then observing a photograph of the metallographic microstructure (hereinafter, also referred to as "metallographic micrograph") after the nital etching, captured using a scanning electron microscope (SEM) at a magnification of 1,000 times. At this time, the metallographic micrograph is captured for a region corresponding to 10 fields of view in a field of view of 1,000 times (a region corresponding to 0.12 mm^2 of the actual area of the cross section). The thus captured metallographic micrograph is subjected to image processing, to perform the measurement of the ferrite fraction and the identification of the second phase. The image processing is performed, for example, using a small, general purpose image analysis apparatus, LUZEX AP, manufactured by Nireco Corporation.

[0122] In the present disclosure, the term "base metal 90° position" refers to a position 90 degrees away from the electric resistance welded portion in the pipe circumferential direction; the term "L cross section" refers to a cross section parallel to the pipe axis direction and the thickness direction; and the term "the central portion in the thickness direction" refers to a position corresponding to 1/2 of the thickness.

(Difference in Hardness)

[0123] In the metallographic microstructure of the base metal portion, the difference in hardness (namely, the value obtained by subtracting the hardness of the first phase from the hardness of the second phase) is from 50 to 100 Hv.

[0124] When the difference in hardness is less than 50 Hv, there is a case in which a decrease in YR cannot be achieved. Accordingly, the difference in hardness is 50 Hv or more, and preferably 52 Hv or more, from the viewpoint of achieving a decrease in YR.

[0125] When the difference in hardness is more than 100 Hv, however, the internal stress of the metallographic microstructure may be increased excessively, to cause a decrease in the toughness of the base metal portion. Accordingly, the difference in hardness is 100 Hv or less, preferably 96 Hv or less, and more preferably 90Hv or less.

(Method of Measuring Difference in Hardness)

[0126] The difference in hardness is measured as follows.

[0127] The hardnesses of the first phase and the second phase in the metallographic microstructure of the central portion in the thickness direction (namely, the metallographic microstructure of the central portion in the thickness direction in the L cross section at the base metal 90° position) are respectively measured, and the value obtained by subtracting the hardness of the first phase from the hardness of the second phase is taken as the difference in hardness.

[0128] At this time, the hardness of the first phase is determined as follows.

[0129] Fifty points were selected at random from the first phase, as the measurement points, and a micro-Vickers hardness was measured at each of the thus selected 50 points, by a micro-Vickers hardness test under the condition of a load of 10 gf. Each of the measurement points to be selected may span across the crystal grain boundaries. From the thus obtained 50 measured values, measured values which are obviously too high (specifically, measured values of more than 350 Hv) are excluded, and the arithmetic mean value of the selected remaining measured values is determined. The thus determined arithmetic mean value is taken as the hardness of the first phase.

[0130] The hardness of the second phase is determined in the same manner as the hardness of the first phase.

< Yield Strength (YS) in Pipe Axis Direction >

[0131] The electric resistance welded steel pipe according to the present disclosure has a yield strength (YS) in the pipe axis direction of from 360 to 600 MPa.
[0132] When the YS is 360 MPa or more, the strength required as a steel pipe for a linepipe is ensured. The YS is preferably 380 MPa or more, and more preferably 400 MPa or more.
[0133] When the YS is 600 MPa or less, a bending deformability (namely, ease of bending) at the time of laying the electric resistance welded steel pipe for a linepipe can be ensured, and the buckling of the electric resistance welded steel pipe for a linepipe can be reduced. The YS is preferably 590 MPa or less.
[0134] The "YS" in the electric resistance welded steel pipe according to the present disclosure refers to "0.5% under load proof stress".

< Tensile Strength (TS) in Pipe Axis Direction >

[0135] The electric resistance welded steel pipe according to the present disclosure has a tensile strength (TS) in the pipe axis direction of from 465 to 760 MPa.
[0136] When the TS is 465 MPa or more, the strength required as a steel pipe for a linepipe is ensured. The TS is preferably 470 MPa or more.
[0137] When the TS is 760 MPa or less, the bending deformability (namely, ease of bending) at the time of laying the electric resistance welded steel pipe for a linepipe can be ensured, and the buckling of the electric resistance welded steel pipe for a linepipe can be reduced. Further, the deterioration in the toughness of the base metal portion is further reduced. The TS is preferably 700 MPa or less, and more preferably 680 MPa or less.

< Yield Ratio (YR) in Pipe Axis Direction >

[0138] The electric resistance welded steel pipe according to the present disclosure has a yield ratio in the pipe axis direction (YR = (YS/TS)) of 0.90 or less.
[0139] This enables to reduce the buckling of the electric resistance welded steel pipe, for example, at the time of laying the steel pipe, and the like.
[0140] The lower limit of the YR is not particularly limited, and may be, for example, 0.80, 0.82 or the like.

< Method of Measuring TS, YS and YR>

[0141] In the present disclosure, each of the TS, YS and YR refers to a value measured as described below.
[0142] A test specimen for tensile test is obtained from the base metal 90° position of the electric resistance welded steel pipe, such that the test direction (tensile direction) in the tensile test is the pipe axis direction of the electric resistance welded steel pipe. The test specimen as used above is formed in the shape of a flat plate which is in accordance with The American Petroleum Institute Standard, API 5L (hereinafter, simply referred to as "API 5L").
[0143] Using the thus obtained test specimen, a tensile test in the pipe axis direction (namely, a tensile test in which the pipe axis direction of the electric resistance welded steel pipe is taken as the test direction) is carried out, at room temperature and in accordance with API 5L, to measure each of the TS and YS. The YS as used above refers to the 0.5% under load proof stress, as described above.
[0144] The YR is determined in accordance with the calculation equation "YR = (YS/TS)", based on the thus measured TS and YS.

< Yield Elongation >

[0145] In the electric resistance welded steel pipe according to the present disclosure, a yield elongation, as measured in a tensile test in the pipe axis direction, is less than 0.2% (namely, the yield elongation is not substantially observed).
[0146] The yield elongation described above is determined by the above-described tensile test in the pipe axis direction for determining the TS, YS and YR.

As described above, the fact that the yield elongation is less than 0.2% means that the electric resistance welded steel pipe according to the present disclosure is an electric resistance welded steel pipe as it is made.

[0147] In contrast to the electric resistance welded steel pipe according to the present disclosure, a substantial yield elongation (namely, a yield elongation of 0.2% or more) is observed in a tensile test in the pipe axis direction, in an electric resistance welded steel pipe in which a heat treatment has been performed on the entire pipe, after pipe-making (such as the electric resistance welded steel pipe disclosed in Patent Document 3).

< Charpy Absorbed Energy >

[0148] In the electric resistance welded steel pipe according to the present disclosure, the toughness of the base metal portion and the electric resistance welded portion is ensured.

[0149] Specifically, each of the base metal portion and the electric resistance welded portion has a Charpy absorbed energy at 0°C (hereinafter, also referred to as "vE") of 100 J or more.

[0150] Hereinafter, the Charpy absorbed energy at 0°C is also referred to as "vE".

[0151] The vE of the base metal portion is preferably 150 J or more, more preferably 200 J or more, and still more preferably 250 J or more.

[0152] At the same time, the vE of the base metal portion is preferably 400 J or less.

[0153] The vE of the electric resistance welded portion is preferably 150 J or more, more preferably 190 J or more, and still more preferably 200 J or more.

[0154] At the same time, the vE of the electric resistance welded portion is preferably 400 J or less, and more preferably 350 J or less.

[0155] The vE (namely, the Charpy absorbed energy at 0°C) of the base metal portion refers to a value measured as follows.

[0156] A full-size test specimen with a V-notch (a test specimen for Charpy impact test) is obtained from the base metal 90° position of the electric resistance welded steel pipe. The full-size test specimen with a V-notch is obtained such that the test direction is the pipe circumferential direction (C direction). The thus obtained full-size test specimen with a V-notch is subjected to a Charpy impact test, under the temperature condition of 0°C and in accordance with API 5L, to measure the vE.

[0157] The measurement as described above is carried out five times per one electric resistance welded steel pipe, and the mean value of the measured values of the five tests is taken as the vE of the base metal portion of the electric resistance welded steel pipe.

[0158] The vE of the electric resistance welded portion refers to a value measured as follows.

[0159] The same procedure as in the measurement of the vE of the base metal portion was carried out, except that the position from which the full-size test specimen with a V-notch is obtained is changed to the electric resistance welded portion of the electric resistance welded steel pipe, to determine the vE (namely, the mean value of the measured values of the five tests) of the electric resistance welded portion of the electric resistance welded steel pipe.

< Thickness of Electric Resistance Welded Steel Pipe >

[0160] The electric resistance welded steel pipe according to the present disclosure preferably has a thickness of from 10 to 25.4 mm.

[0161] When the thickness of the electric resistance welded steel pipe is 10 mm or more, it is advantageous in that the YR can be easily decreased utilizing the strain at the time of forming a hot-rolled steel sheet in the shape of a pipe. The thickness is more preferably 12 mm or more.

[0162] When the thickness is 25.4 mm or less, it is advantageous from the viewpoint of production suitability (specifically, formability at the time of forming a hot-rolled steel sheet in the shape of a pipe) of the electric resistance welded steel pipe. The thickness is more preferably 20 mm or less.

< Outer Diameter of Electric Resistance Welded Steel Pipe >

[0163] The electric resistance welded steel pipe according to the present disclosure preferably has an outer diameter of from 254.0 to 660.4 mm (namely, from 10 to 26 inches).

[0164] When the outer diameter of the electric resistance welded steel pipe is 254.0 mm (namely, 10 inches) or more, the steel pipe is more suitable as an electric resistance welded steel pipe for a linepipe. The outer diameter is preferably 304.8 mm (namely, 12 inches) or more.

[0165] When the outer diameter is 660.4 mm (namely, 26 inches) or less, it is advantageous in that the YR can be easily decreased utilizing the strain at the time of forming a hot-rolled steel sheet in the shape of a pipe. The outer diameter is more preferably 508.4 mm (namely, 20 inches).

< One Example of Method of Producing Electric Resistance Welded Steel Pipe (Production Method A) >

[0166] One example (hereinafter, referred to as "production method A") of the method of producing the electric resistance welded steel pipe according to the present disclosure will now be described.

[0167] In the following description, the temperature and cooling rate refer to the temperature and cooling rate at the surface of a steel material (namely, a slab or a hot-rolled steel sheet), respectively, unless otherwise specified.
[0168] The production method A is the method of producing the electric resistance welded steel pipe used in Examples to be described later.
[0169] The production method A includes:

a slab preparation step of preparing a slab having the chemical composition in the present disclosure;
a hot rolling step of heating the prepared slab to a slab heating temperature of from 1100°C to 1350°C, rough rolling the heated slab, and hot rolling the rough-rolled slab under the conditions of a finish rolling start temperature of 950°C or lower, a finish rolling finishing temperature of 820°C or lower, and a cumulative rolling reduction ratio in the finish rolling of 2.5 or more, to obtain a hot-rolled steel sheet;
a first cooling step of subjecting the hot-rolled steel sheet to a first cooling, wherein the time until the start of the first cooling after the completion of the finish rolling is adjusted within 20 s (seconds), and wherein the first cooling is carried out at a first cooling rate of from 10°C/s to 80°C/s, until a first cooling finishing temperature of from 600°C to 700°C is reached;
a second cooling step of subjecting the hot-rolled steel sheet which has been subjected to the first cooling to a second cooling, wherein the second cooling is carried out at a second cooling rate of from 5°C/s to 30°C/s, until a coiling temperature (namely, a second cooling finishing temperature) of from 450°C to 700°C is reached;
a coiling step of coiling the hot-rolled steel sheet which has been subjected to the second cooling, at the coiling temperature, to obtain a hot coil composed of the hot-rolled steel sheet; and
a pipe-making step in which the hot-rolled steel sheet is uncoiled from the hot coil, the uncoiled hot-rolled steel sheet is roll-formed to prepare an open pipe, and the abutting portion in the thus prepared open pipe is subjected to electric resistance welding to form an electric resistance welded portion, thereby obtaining an electric resistance welded steel pipe.

[0170] The production method A enables to produce the electric resistance welded steel pipe according to the present disclosure.
[0171] The respective steps in the production method A will now be described.

(Slab Preparation Step)

[0172] The slab preparation step in the production method A is a step of preparing a slab having the chemical composition in the present disclosure.
[0173] The step of preparing a slab may be a step of producing a slab, or may be a step of simply preparing a slab which has been produced in advance.
[0174] In the case of producing a slab, for example, a molten steel having the chemical composition in the present disclosure is produced, and the thus produced molten steel is used to produce the slab. At this time, the slab may be produced by a continuous casting method, or alternatively, the slab may be produced by forming an ingot using the molten steel, and subjecting the ingot to blooming.

(Hot Rolling Step)

[0175] The hot rolling step in the production method A is a step of heating the slab prepared above to a slab heating temperature of from 1100°C to 1350°C, rough rolling the heated slab, and hot rolling the rough-rolled slab under the conditions of a finish rolling start temperature of 950°C or lower, a finish rolling finishing temperature of 820°C or lower, and a cumulative rolling reduction ratio in the finish rolling of 2.5 or more, to obtain a hot-rolled steel sheet.
[0176] When the slab heating temperature is 1,100°C or higher, the formation of non-solid-solution Nb carbides is reduced, and as a result, the deterioration of toughness is reduced.
[0177] When the slab heating temperature is 1350°C or lower, the coarsening of crystal grains is reduced, and as a result, the deterioration of toughness in the finally obtained electric resistance welded steel pipe can be reduced.
[0178] When the finish rolling start temperature is 950°C or lower, the coarsening of crystal grains is reduced, and as a result, the deterioration of toughness in the finally obtained electric resistance welded steel pipe can be reduced.
[0179] When the finish rolling finishing temperature is 820°C or lower, the coarsening of crystal grains is reduced, and as a result, the deterioration of toughness in the finally obtained electric resistance welded steel pipe can be reduced.
[0180] When the cumulative rolling reduction ratio is 2.5 or more, the coarsening of crystal grains is reduced, and as a result, the deterioration of toughness in the finally obtained electric resistance welded steel pipe can be reduced.

(First Cooling Step)

[0181] The first cooling step in the production method A is a step of subjecting the hot-rolled steel sheet obtained in the hot rolling step described above to the first cooling, wherein the time until the start of the first cooling after the completion of the finish rolling is adjusted within 20 s (seconds), and wherein the first cooling is carried out at a first cooling rate of from 10°C/s to 80°C/s, until a first cooling finishing temperature of from 600°C to 700°C is reached.
[0182] When the time until the start of the first cooling after the completion of the finish rolling is within 20 s (seconds), the coarsening of crystal grains is reduced, and as a result, the deterioration of toughness in the finally obtained electric resistance welded steel pipe can be reduced.
[0183] When the first cooling rate is 10°C/s or more, an excessive formation of ferrite is reduced, and an excessive C enrichment (carbon enrichment) in the second phase is reduced. As a result, a ferrite fraction of 98% or less and a difference in hardness of 100 Hv or less can be achieved, in the finally obtained electric resistance welded steel pipe.
[0184] When the first cooling rate is 80°C/s or less, the formation of ferrite is accelerated, and the C enrichment (carbon enrichment) in the second phase proceeds to a certain degree. As a result, a ferrite fraction of 80% or more and a difference in hardness of 50 Hv or more can be achieved, in the finally obtained electric resistance welded steel pipe.

The first cooling may be water cooling or air cooling.

[0185] In a case in which the first cooling is water cooling, the first cooling rate is controlled by adjusting the water flow density of cooling water.
[0186] In a case in which the first cooling is air cooling, the first cooling rate is controlled by adjusting the amount of cooling air.

(Second Cooling Step)

[0187] The second cooling step in the production method A is a step of subjecting the hot-rolled steel sheet which has been subjected to the first cooling to a second cooling, wherein the second cooling is carried out at a second cooling rate of from 5°C/s to 30°C/s, until a coiling temperature (namely, a second cooling finishing temperature) of from 450°C to 700°C is reached.
[0188] When the second cooling rate is 5°C/s or more, the hardness of the second phase is increased to a certain degree, and as a result, a difference in hardness of 50 Hv or more can be achieved.
[0189] When the second cooling rate is 30°C/s or less, an excessive increase in the hardness of the second phase is reduced, and as a result, a difference in hardness of 100 Hv or less can be achieved.
[0190] When the coiling temperature is 450°C or higher, the formation of martensite is reduced, and as a result, an increase in YS, an increase in YR, and a decrease in the toughness of the base metal portion are reduced in the finally resulting electric resistance welded steel pipe.
[0191] When the coiling temperature is 700°C or lower, an excessive formation of ferrite is reduced, and an excessive C enrichment (carbon enrichment) in the second phase is reduced. As a result, a ferrite fraction of 98% or less and a difference in hardness of 100 Hv or less can be achieved, in the finally obtained electric resistance welded steel pipe.

The second cooling may be water cooling or air cooling.

[0192] In a case in which the second cooling is water cooling, the second cooling rate is controlled by adjusting the water flow density of the cooling water.
[0193] In a case in which the second cooling is air cooling, the second cooling rate is controlled by adjusting the amount of cooling air.

(Coiling Step)

[0194] The coiling step in the production method A is a step of coiling the hot-rolled steel sheet which has been subjected to the second cooling, at the coiling temperature, to obtain a hot coil composed of the hot-rolled steel sheet.
[0195] The coiling step is not particularly limited, and may be carried out under known conditions.

(Pipe-making Step)

[0196] The pipe-making step is a step in which the hot-rolled steel sheet is uncoiled from the hot coil, the uncoiled hot-rolled steel sheet is roll-formed to prepare an open pipe, and the abutting portion in the thus prepared open pipe is subjected to electric resistance welding to form an electric resistance welded portion, thereby obtaining an electric resistance welded steel pipe.

[0197] The pipe-making step is not particularly limited, and may be carried out under known conditions.

[0198] If necessary, the pipe-making step may include:

performing a seam heat treatment on the electric resistance welded portion;
adjusting the shape of the electric resistance welded steel pipe by a sizer, after the formation of the electric resistance welded portion (in the case of performing the seam heat treatment described above, after the seam heat treatment);

and/or the like.

[0199] In the production method A, the electric resistance welded steel pipe is not subjected to any heat treatment (any heat treatment other than the seam heat treatment) after pipe-making.

[0200] Suppose a case in which a heat treatment is performed after pipe-making, a substantial yield elongation (a yield elongation of 0.2% or more) will be observed in the finally resulting electric resistance welded steel pipe, when a tensile test in the pipe axis direction is performed.

[0201] Further, in a case in which a heat treatment is performed after pipe-making, the difference in hardness is decreased, and the effect of achieving a decrease in YR due to anisotropic hardening properties will disappear.

[0202] The respective steps in the production method A described above do not affect the chemical composition of the steel.

[0203] Therefore, the chemical composition of the base metal portion of the electric resistance welded steel pipe produced by the production method A can be regarded as the same as the chemical composition of the raw material (the molten steel or the slab).

EXAMPLES

[0204] Examples of the present disclosure will now be described below. However, the present disclosure is in no way limited to these Examples.

[0205] In the following description, No. 1 to No. 31 are Examples which are within the scope of the present disclosure, and No. 32 to No. 58 are Comparative Examples which are outside the scope of the present disclosure.

< Production of Electric Resistance Welded Steel Pipes >

[0206] The respective electric resistance welded steel pipes of No. 1 to No. 31 (Examples) were obtained in accordance with the production method A.

[0207] Further, the chemical compositions and/or the production conditions in the electric resistance welded steel pipes of Examples were changed, to obtain the respective electric resistance welded steel pipes of No. 32 to No. 58 (Comparative Examples).

[0208] Details will be described below.

[0209] Slabs having the chemical compositions shown in Table 1 were prepared (the slab preparation step).

[0210] In Table 1, numerical values shown in the column of each element are the contents of each element in % by mass.

[0211] In Table 1, blank cells indicate that the corresponding elements are not contained.

[0212] In each of the Examples and Comparative Examples, the balance excluding the elements shown in Table 1 is Fe and impurities.

[0213] In Table 1, "REM" in No. 31 is Ce.

[0214] In Table 1, "CNeq" indicates the value of CNeq represented by Formula (1) described above, "Mn/Si" indicates the ratio of the Mn content with respect to the Si content, and "LR" indicates the value of LR represented by Formula (2) described above.

[0215] Underlined values in Table 1 and Table 2 indicate that the corresponding values are outside the scope of the present disclosure, or outside the ranges of the conditions in the production method A.

[0216] Each of the slabs obtained as described above was heated to the slab heating temperature shown in Table 2, and the heated slab was subjected to hot rolling under the hot rolling conditions (specifically, the finish rolling start temperature, the finish rolling finishing temperature, and the rolling reduction ratio) shown in Table 2, to obtain a hot-rolled steel sheet (the hot rolling step).

[0217] The "rolling reduction ratio" as used herein refers to the "cumulative rolling reduction ratio" in the finish rolling.

[0218] For each hot-rolled steel sheet obtained in the hot rolling step, the time (seconds) until the start of the cooling after the completion of the finish rolling was adjusted as shown in the column of the "Time until the start of cooling" in Table 2, and the first cooling was started at the first cooling rate shown in Table 2.

[0219] The first cooling was carried out until a first cooling finishing temperature of from 600°C to 700°C was achieved.

[0220] Immediately after the completion of the first cooling, the second cooling was carried out at the second cooling rate shown in Table 2 until the coiling temperature (CT) shown in Table 2 was achieved, and then each cooled hot-rolled steel sheet was coiled at the coiling temperature, to obtain a hot coil composed of a hot-rolled steel sheet having a sheet thickness of 17.5 mm (the first cooling step, the second cooling step, and the coiling step).

[0221] Each of the first cooling and the second cooling was carried out by water cooling, and each of the first cooling rate and the second cooling rate was adjusted by adjusting the water flow density of the cooling water.

[0222] The hot rolling step, the first cooling step, the second cooling step and the coiling step described above were carried out using a hot strip mill.

[0223] Subsequently, each hot-rolled steel sheet was uncoiled from each hot coil obtained as described above, the uncoiled hot-rolled steel sheet was roll-formed to prepare an open pipe. Thereafter, the abutting portion of each resulting open pipe was subjected to electric resistance welding to form an electric resistance welded portion. Then a seam heat treatment is performed on the electric resistance welded portion, and the shape of each pipe is adjusted using a sizer, to obtain an as-rolled electric resistance welded steel pipe having an outer diameter of 406 mm and a thickness of 17.5 mm (the pipe-making step).

< Measurements and Identifications >

[0224] For each of the electric resistance welded steel pipes obtained as described above, the following measurements and identifications were carried out.

(Measurement of Ferrite Fraction and Identification of Second Phase Type)

[0225] The measurement of the ferrite fraction (namely, the area ratio of the first phase with respect to the total area of the metallographic microstructure) and the identification of the second phase type (namely, the type of the second phase) were carried out by the methods described above.

[0226] The results are shown in Table 2.

[0227] In Table 2, the description "P, B" in the column of the second phase type indicates that the second phase contains at least one of pearlite or bainite, and does not substantially contain martensite (namely, the area ratio of martensite with respect to the total area of the second phase is less than 1%), and the description "B + M" therein indicates that the second phase is a mixed structure of bainite and martensite (namely, the area ratio of martensite with respect to the total area of the second phase is more than 1% or more).

(Measurement of Difference in Hardness)

[0228] The difference in hardness (namely, the value obtained by subtracting the hardness of the first phase from the hardness of the second phase) was measured by the method described above.

[0229] The results are shown in Table 2.

(Identification of TS, YS, YR and Yield Elongation)

[0230] The TS, YS, YR and the yield elongation were identified by the method described above.

[0231] In the column of "Yield elongation" in Table 2, "N" indicates that the yield elongation was not substantially observed (namely, the yield elongation was less than 0.2%).

[0232] The results are shown in Table 2.

(vE of Base Metal Portion and vE of Electric Resistance Welded Portion)

[0233] The vE (Charpy absorbed energy at 0°C) of each of the base metal portion and the electric resistance welded portion was measured by the method described above.

[0234] The results are shown in Table 2.

[Table 1]

	No	Components (% by mass)										CNeq	Mn /Si	LR
		C	Mn	Ti	Nb	N	Si	Al	P	S	Optional element (s)			
Example	1	0.09	0.30	0.040	0.060	0.005	0.100	0.060	0.018	0.006		0.20	3.0	0.83
	2	0.05	0.38	0.040	0.030	0.003	0.060	0.010	0.014	0.002		0.14	6.3	0.36
	3	0.08	0.37	0.010	0.050	0.002	0.090	0.070	0.006	0.010		0.19	4.1	0.59
	4	0.06	0.61	0.010	0.040	0.003	0.040	0.010	0.003	0.004		0.20	15.3	0.27
	5	0.07	0.54	0.050	0.050	0.002	0.140	0.040	0.004	0.003		0.21	3.9	0.36
	6	0.08	0.43	0.040	0.060	0.002	0.150	0.070	0.011	0.005		0.21	2.9	0.53
	7	0.06	0.32	0.040	0.080	0.002	0.050	0.080	0.028	0.008		0.19	6.4	0.64
	8	0.04	0.58	0.050	0.080	0.003	0.100	0.050	0.024	0.005		0.22	5.8	0.28
	9	0.04	0.31	0.050	0.060	0.003	0.120	0.030	0.029	0.007		0.15	2.6	0.46
	10	0.03	0.33	0.020	0.060	0.004	0.160	0.040	0.024	0.002		0.15	2.1	0.37
	11	0.03	0.46	0.040	0.080	0.003	0.050	0.020	0.005	0.002		0.19	9.2	0.31
	12	0.09	0.34	0.030	0.040	0.002	0.050	0.090	0.020	0.010		0.19	6.8	0.67
	13	0.06	0.53	0.030	0.080	0.004	0.180	0.060	0.030	0.003		0.23	2.9	0.39
	14	0.04	0.51	0.050	0.080	0.002	0.240	0.060	0.017	0.006		0.21	2.1	0.32
	15	0.05	0.40	0.050	0.040	0.004	0.150	0.070	0.016	0.008		0.16	2.7	0.36
	16	0.04	0.45	0.050	0.080	0.004	0.160	0.020	0.013	0.004	Mo: 0.01	0.21	2.8	0.36
	17	0.08	0.37	0.020	0.070	0.002	0.120	0.040	0.019	0.007	Mo: 0.01	0.22	3.1	0.64
	18	0.08	0.50	0.030	0.070	0.003	0.030	0.070	0.016	0.004	Cu: 0.07	0.24	16.7	0.48
	19	0.03	0.45	0.020	0.070	0.004	0.210	0.060	0.021	0.009	Cu: 0.13	0.18	2.1	0.30
	20	0.06	0.51	0.020	0.050	0.003	0.200	0.030	0.010	0.006	Ni: 0.37	0.22	2.6	0.35
	21	0.08	0.37	0.020	0.070	0.002	0.170	0.020	0.016	0.007	Ni: 0.10	0.22	2.2	0.64
	22	0.07	0.49	0.010	0.070	0.002	0.180	0.070	0.009	0.003	Cr: 0.08	0.24	2.7	0.44
	23	0.03	0.35	0.020	0.060	0.003	0.110	0.030	0.013	0.002	Cr: 0.11	0.17	3.2	0.35
	24	0.03	0.40	0.020	0.060	0.002	0.140	0.030	0.024	0.005	Cu: 0.24, Cr: 0.33	0.24	2.9	0.31

(continued)

	No	Components (% by mass)										CNeq	Mn /Si	LR
		C	Mn	Ti	Nb	N	Si	Al	P	S	Optional element (s)			
	25	0.05	0.30	0.020	0.040	0.002	0.100	0.030	0.025	0.003	Cu: 0.11, Cr: 0.17	0.18	3.0	0.48
	26	0.04	0.35	0.050	0.050	0.004	0.050	0.050	0.016	0.005	Cu: 0.26, Ni: 0.14, Cr: 0.08	0.19	7.0	0.38
	27	0.06	0.41	0.050	0.040	0.002	0.180	0.050	0.021	0.002	Cu: 0.11, Ni: 0.41, Cr: 0.06	0.22	2.3	0.40
	28	0.03	0.45	0.030	0.050	0.004	0.200	0.090	0.019	0.001	Cu: 0.12, Ni: 0.05, Cr: 0.14, V: 0.02	0.21	2.3	0.25
	29	0.05	0.40	0.030	0.040	0.004	0.200	0.060	0.026	0.007	Mo: 0.03, V: 0.01	0.20	2.0	0.36
	30	0.05	0.60	0.032	0.060	0.002	0.310	0.060	0.001	0.008	Ca: 0.0057	0.21	1.9	0.28
	31	0.06	0.65	0.045	0.040	0.004	0.160	0.060	0.004	0.004	Ca: 0.0002, REM: 0.0086	0.21	4.1	0.26
	32	0.02	0.43	0.030	0.050	0.003	0.040	0.080	0.020	0.002	Cu: 0.07, Ni: 0.14, Cr: 0.17, V:0.04	0.23	10.8	0.21
	33	0.11	0.48	0.040	0.030	0.003	0.170	0.080	0.005	0.009		0.22	2.8	0.54
	34	0.08	0.24	0.010	0.070	0.004	0.120	0.100	0.005	0.007		0.19	2.0	0.99
	35	0.09	1.05	0.050	0.070	0.004	0.290	0.020	0.029	0.005		0.34	3.6	0.25
	36	0.08	0.61	0.004	0.060	0.004	0.120	0.100	0.003	0.005		0.24	5.1	0.37
	37	0.06	0.44	0.090	0.060	0.002	0.130	0.090	0.000	0.008		0.19	3.4	0.42
	38	0.09	0.78	0.008	0.004	0.002	0.120	0.040	0.029	0.005		0.22	6.5	0.25
	39	0.04	0.30	0.049	0.110	0.002	0.080	0.100	0.020	0.006		0.20	3.8	0.65
	40	0.05	0.61	0.014	0.050	0.003	0.004	0.070	0.021	0.004		0.20	152.5	0.25
Comparative Example	41	0.05	0.39	0.050	0.060	0.004	0.130	0.0004	0.022	0.007		0.18	3.0	0.42
	42	0.07	0.63	0.028	0.050	0.003	0.130	0.130	0.009	0.009		0.23	4.8	0.31
	43	0.07	0.38	0.039	0.080	0.005	0.080	0.020	0.035	0.009		0.21	4.8	0.60
	44	0.05	0.61	0.018	0.050	0.004	0.130	0.100	0.015	0.015		0.20	4.7	0.25
	45	0.06	0.50	0.026	0.060	0.003	0.390	0.010	0.000	0.009		0.20	1.3	0.37
	46	0.03	0.89	0.005	0.040	0.004	0.210	0.030	0.011	0.008		0.22	4.2	0.12
	47	0.08	0.61	0.040	0.080	0.003	0.160	0.080	0.008	0.009		0.26	3.8	0.41
	48	0.03	0.30	0.020	0.030	0.004	0.110	0.100	0.030	0.003		0.11	2.7	0.31

(continued)

	No	Components (% by mass)										CNeq	Mn /Si	LR
		C	Mn	Ti	Nb	N	Si	Al	P	S	Optional element (s)			
	49	0.08	0.53	0.046	0.070	0.002	0.030	0.030	0.007	0.002		0.24	17.7	0.45
	50	0.08	0.59	0.027	0.070	0.003	0.170	0.100	0.020	0.008		0.25	3.5	0.40
	51	0.05	0.52	0.032	0.050	0.003	0.160	0.040	0.015	0.006		0.19	3.3	0.30
	52	0.07	0.49	0.043	0.070	0.004	0.180	0.090	0.025	0.005		0.22	2.7	0.44
	53	0.08	0.68	0.047	0.030	0.005	0.270	0.090	0.022	0.010		0.22	2.5	0.29
	54	0.04	0.33	0.026	0.060	0.002	0.020	0.060	0.010	0.005		0.16	16.5	0.44
	55	0.05	0.59	0.010	0.050	0.002	0.160	0.070	0.028	0.004		0.20	3.7	0.26
	56	0.07	0.66	0.035	0.040	0.004	0.100	0.060	0.010	0.007		0.22	6.6	0.28
	57	0.04	0.55	0.032	0.080	0.004	0.200	0.030	0.008	0.009		0.21	2.8	0.30
	58	0.06	0.52	0.008	0.050	0.003	0.020	0.080	0.011	0.002		0.20	26.0	0.34

[Table 2]

	No	Production conditions							Microstructure			Properties					
		Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)	Rolling reduction ratio	Time until the start of cooling (s)	First cooling rate (°C/s)	Second cooling rate (°C/s)	CT (°C)	Ferrite fraction (%)	Second phase type	Difference in hardness (Hv)	YS (MPa)	TS (MPa)	YR	Yield elongation	vE of base metal portion (J)	vE of electric resistance welded portion (J)
Example	1	926	786	3.0	7	12	10	585	92	B, P	74	512	577	0.89	N	258	231
	2	926	801	3.0	4	68	25	612	92	B, P	77	440	510	0.86	N	345	267
	3	911	797	3.6	10	44	29	621	94	B, P	79	492	567	0.87	N	293	229
	4	913	807	4.8	9	79	24	492	85	B, P	59	504	573	0.88	N	312	283
	5	917	805	4.5	6	70	27	620	83	B, P	66	531	595	0.89	N	287	241
	6	921	784	2.5	6	14	28	580	94	B, P	81	535	601	0.89	N	292	227
	7	944	805	3.5	5	70	27	646	88	B, P	68	500	572	0.87	N	290	215
	8	927	800	2.9	10	76	12	625	93	B, P	89	510	579	0.88	N	256	224
	9	910	815	4.1	6	47	12	553	88	B, P	77	430	495	0.87	N	318	292
	10	949	787	4.9	4	35	14	581	86	B, P	59	420	479	0.88	N	311	291
	11	936	784	3.0	6	13	26	670	95	B, P	96	483	543	0.89	N	294	234
	12	944	789	3.1	5	15	10	590	94	B, P	84	484	553	0.88	N	324	265
	13	900	793	2.7	3	68	13	497	92	B, P	86	555	617	0.90	N	273	236
	14	907	800	3.3	7	26	12	659	94	B, P	85	512	580	0.88	N	250	215
	15	943	780	3.7	7	56	23	499	89	B, P	64	409	475	0.86	N	358	326

(continued)

	No	Production conditions							Microstructure			Properties					
		Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)	Rolling reduction ratio	Time until the start of cooling (s)	First cooling rate (°C/s)	Second cooling rate (°C/s)	CT (°C)	Ferrite fraction (%)	Second phase type	Difference in hardness (Hv)	YS (MPa)	TS (MPa)	YR	Yield elongation	vE of base metal portion (J)	vE of electric resistance welded portion (J)
	16	909	789	5.0	6	63	21	527	87	B, P	67	524	590	0.89	N	301	255
	17	906	796	4.1	5	18	5	523	88	B, P	77	521	588	0.89	N	276	216
	18	931	814	4.4	7	30	17	658	84	B, P	67	550	619	0.89	N	262	205
	19	937	813	4.0	5	43	18	661	88	B, P	74	477	535	0.89	N	321	267
	20	911	792	3.5	5	19	28	527	94	B, P	85	512	587	0.87	N	337	294
	21	915	802	4.7	8	56	23	651	87	B, P	68	524	590	0.89	N	271	194
	22	936	815	2.9	5	65	23	685	87	B, P	73	573	639	0.90	N	279	244
	23	947	811	3.8	10	35	15	695	89	B, P	72	441	493	0.89	N	311	257
	24	914	782	3.9	8	12	6	636	95	B, P	90	588	664	0.88	N	319	275
	25	941	794	5.0	3	62	8	644	82	B, P	61	482	545	0.88	N	373	328
	26	922	781	4.7	10	53	6	676	94	B, P	79	473	544	0.87	N	306	236
	27	943	806	3.1	10	40	8	572	87	B, P	74	552	628	0.88	N	327	259
	28	935	806	4.0	3	67	8	502	84	B, P	52	547	621	0.88	N	313	242
	29	917	788	3.7	4	31	19	628	92	B, P	77	492	566	0.87	N	301	275
	30	949	790	3.5	3	11	28	630	86	B, P	60	546	657	0.83	N	258	227
	31	920	816	3.2	6	52	21	692	90	B, P	69	524	637	0.82	N	328	282
Comparative Example	32	910	794	4.0	10	13	9	620	90	B, P	85	538	585	<u>0.92</u>	N	250	230
	33	906	794	4.1	6	51	9	591	88	B, P	80	529	605	0.87	N	<u>70</u>	<u>40</u>
	34	925	801	5.0	9	12	22	643	87	B, P	63	492	552	0.89	N	<u>65</u>	298
	35	942	815	4.1	9	78	5	639	82	B, P	<u>105</u>	<u>656</u>	736	0.89	N	<u>56</u>	273

(continued)

No	Production conditions							Microstructure			Properties					
	Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)	Rolling reduction ratio	Time until the start of cooling (s)	First cooling rate (°C/s)	Second cooling rate (°C/s)	CT (°C)	Ferrite fraction (%)	Second phase type	Difference in hardness (Hv)	YS (MPa)	TS (MPa)	YR	Yield elongation	vE of base metal portion (J)	vE of electric resistance welded portion (J)
36	913	796	2.8	6	37	23	637	93	B, P	77	572	639	0.89	N	85	50
37	930	808	3.4	8	11	20	534	93	B, P	80	476	538	0.89	N	60	80
38	916	809	5.0	7	29	13	540	87	B, P	64	593	676	0.88	N	50	296
39	933	796	4.0	9	46	7	597	92	B, P	83	511	571	0.90	N	60	168
40	908	801	3.8	4	55	30	667	92	B, P	92	445	518	0.86	N	83	48
41	906	783	2.6	6	14	5	642	96	B, P	89	454	510	0.89	N	50	238
42	903	794	3.0	6	79	28	469	89	B, P	78	520	588	0.88	N	339	40
43	902	803	4.0	4	15	7	672	92	B, P	83	547	615	0.89	N	40	90
44	913	794	3.5	9	80	10	625	93	B, P	95	499	565	0.88	N	40	40
45	920	788	3.2	7	52	15	525	89	B, P	63	519	578	0.90	N	337	25
46	927	810	3.9	5	59	25	554	87	B, P	61	539	567	0.95	N	339	272
47	947	783	2.8	4	15	14	578	87	B, P	69	610	682	0.89	N	241	217
48	924	781	2.5	7	80	7	693	96	B, P	93	350	412	0.85	N	373	304
49	943	816	4.1	5	5	10	643	99	B, P	110	580	699	0.83	N	70	219
50	917	796	5.2	4	100	13	694	40	B, P	30	579	629	0.92	N	250	181
51	933	810	2.6	6	80	3	578	89	B, P	45	520	565	0.92	N	250	200
52	903	783	3.5	8	55	50	525	96	B, P	102	500	575	0.87	N	80	180
53	906	803	5.0	30	55	7	554	92	B, P	80	500	562	0.89	N	60	150
54	980	803	4.1	4	45	27	581	82	B, P	62	411	498	0.83	N	40	250
55	917	830	4.5	5	40	9	540	87	B, P	78	504	604	0.83	N	55	260
56	938	805	1.5	5	24	23	485	89	B, P	84	516	618	0.84	N	68	210
57	913	788	5.0	4	54	15	400	85	B+M	110	630	767	0.82	N	28	219
58	940	797	4.9	5	65	7	720	99	B, P	115	516	632	0.82	N	85	284

[0235] As shown in Table 1 and Table 2, the electric resistance welded steel pipe of each of Examples (No. 1 to No. 31) satisfied a YS of from 360 to 600 MPa, a TS of from 465 to 760 MPa and a YR of 0.90 or less, and showed an excellent toughness of the base metal portion and the electric resistance welded portion, despite being an electric resistance welded steel pipe as it is made. Specifically, each electric resistance welded steel pipe had a toughness satisfying each of a vE of the base metal portion and a vE of the electric resistance welded portion of 100 J or more.

[0236] In contrast to the results of the respective Examples, the results of Comparative Examples were as follows.

[0237] In the electric resistance welded steel pipe of No. 32, the work hardening properties were decreased, because the C content and the value of LR were below the lower limits, resulting in an increase in YR.

[0238] In the electric resistance welded steel pipe of No. 33, a large amount cementite was formed, because the C content was above the upper limit, resulting in the deterioration of the toughness of the base metal portion and the electric resistance welded portion.

[0239] In the electric resistance welded steel pipe of No. 34, an embrittlement due to S occurred, because the Mn content was below the lower limit, resulting in the deterioration of the toughness of the base metal portion.

[0240] In the electric resistance welded steel pipe of No. 35, the segregation of Mn at the central portion in the thickness direction and the formation of MnS or a hardened phase accompanied therewith occurred, because the Mn content was above the upper limit, resulting in the deterioration of the toughness of the base metal portion. Further, the YS exceeded the upper limit, since the value of CNeq was above the upper limit.

[0241] In the electric resistance welded steel pipe of No. 36, the crystal grain size was increased, because the Ti content was below the lower limit, resulting in the deterioration of the toughness of the base metal portion and the electric resistance welded portion.

[0242] In the electric resistance welded steel pipe of No. 37, coarse TiN was formed, because the Ti content was above the upper limit, resulting in the deterioration of the toughness of the base metal portion and the electric resistance welded portion.

[0243] In the electric resistance welded steel pipe of No. 38, the toughness of the base metal portion was deteriorated, because the Nb content and the value of LR were below the lower limits.

[0244] In the electric resistance welded steel pipe of No. 39, coarse Nb carbides were formed, because the Nb content was above the upper limit, resulting in the deterioration of the toughness of the base metal portion.

[0245] In the electric resistance welded steel pipe of No. 40, deoxidation was insufficient to cause the occurrence of cracks due to free oxygen, because the Si content was below the lower limit, resulting in the deterioration of the toughness of the base metal portion and the electric resistance welded portion.

[0246] In the electric resistance welded steel pipe of No. 41, cracks due to free oxygen occurred, because the Al content was below the lower limit, resulting in the deterioration of the toughness of the base metal portion was deteriorated.

[0247] In the electric resistance welded steel pipe of No. 42, Al-based oxides were formed at the electric resistance welded portion, because the Al content was above the upper limit, resulting in the deterioration of the toughness of the electric resistance welded portion was deteriorated.

[0248] In the electric resistance welded steel pipe of No. 43, the segregation of P occurred at the grain boundaries, because the P content was above the upper limit, resulting in the deterioration of the toughness of the base metal portion and the electric resistance welded portion.

[0249] In the electric resistance welded steel pipe of No. 44, coarse inclusions were formed, because the S content was above the upper limit, resulting in the deterioration of the toughness of the base metal portion and the electric resistance welded portion.

[0250] In the electric resistance welded steel pipe of No. 45, MnSi-based oxides were formed at the welded portion, because the ratio Mn/Si was below the lower limit, resulting in the deterioration of the toughness of the electric resistance welded portion.

[0251] In the electric resistance welded steel pipe of No. 46, the YR was increased, because the value of LR was below the lower limit.

[0252] In the electric resistance welded steel pipe of No. 47, the YS exceeded the upper limit, because the value of CNeq was above the upper limit.

[0253] In the electric resistance welded steel pipe of No. 48, the YS and TS were insufficient, because the value of CNeq was below the lower limit.

[0254] In the electric resistance welded steel pipe of No, 49, the ferrite fraction increased above the upper limit, because the first cooling rate was below 10°C/s, and as a result, an excessive carbon enrichment in the second phase occurred, leading to a difference in hardness of above the upper limit. This led to the deterioration of the toughness of the base metal portion.

[0255] In the electric resistance welded steel pipe of No. 50, the ferrite fraction decreased below the lower limit, because the first cooling rate was above 80°C/s, and as a result, the carbon enrichment in the second phase was insufficient, leading to a difference in hardness of below the lower limit. This led to an increase in YR.

[0256] In the electric resistance welded steel pipe of No. 51, the hardness of the second phase was insufficient because the second cooling rate was below 5°C/s, resulting in a difference in hardness of below the lower limit. This led to an increase in YR.

[0257] In the electric resistance welded steel pipe of No. 52, the hardness of the second phase was excessively increased, because the second cooling rate exceeded 30°C/s, resulting in a difference in hardness of above the upper limit. This led to the deterioration of the toughness of the base metal portion.

[0258] In the electric resistance welded steel pipe of No. 53, the toughness of the base metal portion was deteriorated. In No. 53 above, it is thought that the coarsening of crystal grains occurred because the time until the start of the cooling was too long, and as a result, the toughness of the base metal portion was deteriorated.

[0259] In the electric resistance welded steel pipe of No. 54, the toughness of the base metal portion was deteriorated. In No. 54 above, it is thought that the coarsening of crystal grains occurred because the finish rolling start temperature was too high, and as a result, the toughness of the base metal portion was deteriorated.

[0260] In the electric resistance welded steel pipe of No. 55, the toughness of the base metal portion was deteriorated. In No. 55 above, it is thought that the coarsening of crystal grains occurred because the finish rolling finishing temperature was too high, and as a result, the toughness of the base metal portion was deteriorated.

[0261] In the electric resistance welded steel pipe of No. 56, the toughness of the base metal portion was deteriorated. In No. 56 above, it is thought that the coarsening of crystal grains occurred because the rolling reduction ratio was too low, and as a result, the toughness of the base metal portion was deteriorated.

[0262] In the electric resistance welded steel pipe of No. 57, martensite was formed because the coiling temperature (CT) was too low, and as a result, the YS and TS exceeded the upper limits, leading to the deterioration of the toughness of the base metal portion.

[0263] In the electric resistance welded steel pipe of No. 58, the ferrite fraction increased above the upper limit because the coiling temperature (CT) was too high, and as a result, an excessive carbon enrichment in the second phase occurred, leading to a difference in hardness of above the upper limit. This led to the deterioration of the toughness of the base metal portion.

Claims

1. An electric resistance welded steel pipe for a linepipe, the steel pipe comprising:

a base metal portion; and
an electric resistance welded portion,
wherein the base metal portion has a chemical composition consisting of, in terms of % by mass:

0.03% or more and less than 0.10% of C,
from 0.30 to 1.00% of Mn,
from 0.005 to 0.050% of Ti,
from 0.010 to 0.100% of Nb,
from 0.001 to 0.020% of N,
from 0.010 to 0.500% of Si,
from 0.001 to 0.100% of Al,
from 0 to 0.030% of P,
from 0 to 0.010% of S,
from 0 to 0.50% of Mo,
from 0 to 0.50% of Cu,
from 0 to 0.50% of Ni,
from 0 to 0.50% of Cr,
from 0 to 0.10% of V,
from 0 to 0.0100% of Ca,
from 0 to 0.0100% of REM, and
a balance consisting of Fe and impurities,

wherein CNeq, represented by Formula (1), is from 0.12 to 0.25, a ratio of a content of Mn with respect to a content of Si is 1.8 or more, and LR, represented by Formula (2), is 0.25 or more:

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

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

wherein, in Formulae (1) and (2), each element symbol represents a content of each element in % by mass, wherein the base metal portion has a metallographic microstructure in which:

a first phase composed of ferrite has an area ratio of from 80 to 98%;
a second phase, which is a balance, contains at least one of pearlite or bainite;
an area ratio of martensite with respect to a total area of the second phase is less than 1%; and
a value obtained by subtracting a hardness of the first phase from a hardness of the second phase is from 50 to 100 Hv,

wherein the electric resistance welded steel pipe has:

a yield strength in a pipe axis direction of from 360 to 600 MPa;
a tensile strength in the pipe axis direction of from 465 to 760 MPa; and
a yield ratio in the pipe axis direction of 0.90 or less,

wherein each of the base metal portion and the electric resistance welded portion has a Charpy absorbed energy at 0°C of 100 J or more, and
wherein a yield elongation of the electric resistance welded steel pipe, as measured in a tensile test in the pipe axis direction, is less than 0.2%.

2. The electric resistance welded steel pipe for a linepipe according to claim 1, wherein the chemical composition of the base metal portion comprises, in terms of % by mass, at least one selected from the group consisting of:

more than 0% and equal to or less than 0.50% of Mo,
more than 0% and equal to or less than 0.50% of Cu,
more than 0% and equal to or less than 0.50% of Ni,
more than 0% and equal to or less than 0.50% of Cr,
more than 0% and equal to or less than 0.10% of V,
more than 0% and equal to or less than 0.0100% of Ca, and
more than 0% and equal to or less than 0.0100% of REM.

3. The electric resistance welded steel pipe for a linepipe according to claim 1 or 2, wherein the electric resistance welded steel pipe for a linepipe has a thickness of from 10 to 25.4 mm, and an outer diameter of from 254.0 to 660.4 mm.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/033068

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C22C38/50(2006.01)i, C21D8/02(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. C22C38/00-38/60, C21D8/02

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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 2017/163987 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 28 September 2017 & EP 3375900 A1 & KR 10-2018-0077259 A & CN 108368582 A	1-3
A	WO 2018/008194 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 11 January 2018 & EP 3428299 A1 & KR 10-2018-0123519 A & CN 109072379 A	1-3
A	WO 2018/235244 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 27 December 2018 (Family: none)	1-3

☐ 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
13 November 2019 (13.11.2019)	26 November 2019 (26.11.2019)

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- JP H10176239 A **[0008]**
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- WO 2013027779 A **[0008]**
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