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(54) Titre : TUBE D'ACIER EPAIS SOUDE PAR RESISTANCE ELECTRIQUE HAUTEMENT RESISTANT POUR TUBE CONDUCTEUR DE PUITS PROFOND AINSI QUE PROCEDE DE FABRICATION DE CELUI-CI, ET TUBE CONDUCTEUR EPAISHAUTEMENT RESISTANT DE PUITS PROFOND
(54) Title: HIGH-STRENGTH THICK-WALLED ELECTRIC-RESISTANCE-WELDED STEEL PIPE FOR DEEP-WELL CONDUCTOR CASING, METHOD FOR MANUFACTURING THE SAME, AND HIGH-STRENGTH THICK-WALLED CONDUCTOR CASINGFOR DEEP WELLS

(57) **Abrégé/Abstract:**

A high-strength high-toughness electric-resistance-welded steel pipe having high resistance to post-weld heat treatment is provided. A hot-rolled steel plate serving as a material is subjected to roll forming so as to have a generally circular cross section and is subjected to electric resistance welding to form an electric-resistance-welded steel pipe. The electric-resistance-welded portion of the electric-resistance-welded steel pipe is then subjected to in-line heat treatment. The electric-resistance-welded steel pipe is then subjected to reducing rolling such that the circularity of an end portion of the steel pipe is 0.6% or less. The hot-rolled steel plate serving as a material has a composition containing C: 0.01% to 0.12%, Si: 0.05% to 0.50%, Mn: 1.0% to 2.2%, P: 0.03% or less, S: 0.005% or less, Al: 0.001% to 0.10%, N: 0.006% or less, Nb: 0.010% to 0.100%, and Ti: 0.001% to 0.050% and has a structure composed of 90% or more by volume of a bainitic ferrite phase and 10% or less (including 0%) by volume of a second phase, the bainitic ferrite phase having an average grain size of 10 µm or less, the structure containing fine Nb precipitates having a particle size of less than 20 nm dispersed in a base material portion, the ratio (%) of the fine Nb precipitates to the total amount of Nb being 75% or less a Nb equivalent basis. The electric-resistance-welded steel pipe can have high strength and toughness and maintain strength through post-weld heat treatment including heating to a temperature of 600°C or more. The electric-resistance-welded steel pipe is less likely to be broken while placed as a deep-well conductor casing.

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ABSTRACT

A high-strength high-toughness electric-resistance-welded steel pipe having high resistance to post-weld heat treatment is provided.

A hot-rolled steel plate serving as a material is subjected to roll forming so as to have a generally circular cross section and is subjected to electric resistance welding to form an electric-resistance-welded steel pipe. The electric-resistance-welded portion of the electric-resistance-welded steel pipe is then subjected to in-line heat treatment. The electric-resistance-welded steel pipe is then subjected to reducing rolling such that the circularity of an end portion of the steel pipe is 0.6% or less. The hot-rolled steel plate serving as a material has a composition containing C: 0.01% to 0.12%, Si: 0.05% to 0.50%, Mn: 1.0% to 2.2%, P: 0.03% or less, S: 0.005% or less, Al: 0.001% to 0.10%, N: 0.006% or less, Nb: 0.010% to 0.100%, and Ti: 0.001% to 0.050% and has a structure composed of 90% or more by volume of a bainitic ferrite phase and 10% or less (including 0%) by volume of a second phase, the bainitic ferrite phase having an average grain size of 10 μm or less, the structure containing fine Nb precipitates having a particle size of less than 20 nm dispersed in a base material portion, the ratio (%) of the fine Nb precipitates to the total amount of Nb being 75% or less on

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a Nb equivalent basis. The electric-resistance-welded steel pipe can have high strength and toughness and maintain strength through post-weld heat treatment including heating to a temperature of 600°C or more. The electric-resistance-welded steel pipe is less likely to be broken while placed as a deep-well conductor casing.

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DESCRIPTION

Title of Invention: HIGH-STRENGTH THICK-WALLED ELECTRIC-RESISTANCE-WELDED STEEL PIPE FOR DEEP-WELL CONDUCTOR CASING, METHOD FOR MANUFACTURING THE SAME, AND HIGH-STRENGTH THICK-WALLED CONDUCTOR CASING FOR DEEP WELLS

Technical Field

[0001]

The present invention relates to an electric-resistance-welded steel pipe suitable for a conductor casing used as a retaining wall in oil or gas well drilling and more particularly to a high-strength thick-walled electric-resistance-welded steel pipe suitable for a conductor casing for wells in deep-water oil or gas field development at a depth of 3,000 m or more (hereinafter also referred to as deep wells) and to a method for manufacturing the high-strength thick-walled electric-resistance-welded steel pipe.

Background Art

[0002]

Conductor casings are used as retaining walls in wells at an early stage of oil or gas well drilling and protect oil well pipes from external pressure. Conductor casings are conventionally manufactured by joining a UOE steel pipe to a connector (threaded forged member).

[0003]

When placed into wells, conductor casings are

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repeatedly subjected to bending deformation. When placed into deep wells, conductor casings are also subjected to stress loading due to their own weights. Thus, deep-well conductor casings are particularly required

(1) not to be broken by repeated bending deformation during placement, and

(2) to have strength to bear their own weights.

In order to prevent conductor casings from being broken by bending deformation, it is particularly necessary to reduce stress concentration, for example, caused by linear misalignment in a joint. Linear misalignment may be reduced by improving the circularity of a steel pipe to be used.

[0004]

In general, conductor casings are sometimes subjected to post-weld heat treatment at a temperature of 600°C or more in order to relieve the residual stress of a joint between a steel pipe and a forged member or to prevent hydrogen cracking. Thus, there is a demand for a steel pipe that suffers a smaller decrease in strength due to post-weld heat treatment, can maintain desired strength even after post-weld heat treatment, and has high resistance to post-weld heat treatment.

[0005]

For example, Patent Literature 1 describes a high-strength riser steel pipe having good high-temperature

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stress relief (SR) characteristics to meet the demand. In the technique described in Patent Literature 1, a riser steel pipe having good high-temperature SR characteristics has a steel composition containing C: 0.02% to 0.18%, Si: 0.05% to 0.50%, Mn: 1.00% to 2.00%, Cr: 0.30% to 1.00%, Ti: 0.005% to 0.030%, Nb: 0.060% or less, and Al: 0.10% or less by weight. In the technique described in Patent Literature 1, in addition to these components, a riser steel pipe may further contain one or two or more of Cu: 0.50% or less, Ni: 0.50% or less, Mo: 0.50% or less, and V: 0.10% or less, and further Ca: 0.0005% to 0.0050% and/or B: 0.0020% or less by weight. In the technique described in Patent Literature 1, inclusion of a predetermined amount of Cr retards softening of the base material ferrite and increases resistance to softening, which can suppress the decrease in toughness and strength caused by post-weld heat treatment (SR treatment) and improve high-temperature SR characteristics.

[0006]

Patent Literature 2 describes, as a technique for improving the circularity of a steel pipe, a method for expanding a UOE steel pipe by using a pipe expander in which each die of all mounted on the pipe expander has a grooved outer surface, and changing the dies mounted on the pipe expander for each steel pipe to be expanded, each of the dies facing a piece of excess weld metal inside a steel pipe

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weld portion. Patent Literature 2 states that the technique can uniformize the wear loss of the dies mounted on the pipe expander and improve the circularity of a steel pipe.

Citation List

Patent Literature

[0007]

PTL 1: Japanese Patent No. 3558198

PTL 2: Japanese Unexamined Patent Application

Publication No. 2006-289439

Summary of Invention

Technical Problem

[0008]

In order to prevent a conductor casing from being broken by repeated bending deformation during placement, it is important to reduce stress concentration. Thus, a steel pipe to which a connector is to be joined should have a certain degree of circularity. However, Patent Literature 1 does not describe a measure to improve circularity, for example, by reducing linear misalignment. The technique described in Patent Literature 1 includes no measure to improve circularity, and a steel pipe will have insufficient circularity at its end portion, particularly when used as a deep-well conductor casing. When a steel pipe manufactured by the technique described in Patent Literature 1 is used as a deep-well conductor casing, an additional step is

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necessary to improve the circularity of an end portion of the steel pipe by cutting or straightening. Thus, there is a problem in the technique described in Literature 1 that the productivity of manufacturing conductor casings is decreased.

[0009]

The technique described in Patent Literature 2 also cannot ensure sufficient circularity particularly for deep-well conductor casings, which is a problem.

[0010]

The present invention solves such problems of the related art and aims to provide a high-strength high-toughness thick-walled electric-resistance-welded steel pipe having high resistance to post-weld heat treatment suitable for a deep-well conductor casing and a method for manufacturing the steel pipe. The present invention also aims to provide a conductor casing including the electric-resistance-welded steel pipe as a component thereof.

[0011]

The term "high-strength thick-walled electric-resistance-welded steel pipe", as used herein, refers to a thick-walled electric-resistance-welded steel pipe having a thickness of 15 mm or more in which both a base material portion and an electric-resistance-welded portion have high strength of at least the API X80 grade. The base material

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portion has a yield strength YS of 555 MPa or more and a tensile strength TS of 625 MPa or more, and the electric-resistance-welded portion has a tensile strength TS of 625 MPa or more. The term "high toughness", as used herein, means that the absorbed energy vE_{-40} in a Charpy impact test at a test temperature of -40°C is 27 J or more. For placement in deep water, the thickness is preferably 20 mm or more.

[0012]

The phrase "high resistance to post-weld heat treatment", as used herein, means that the base material maintains the strength of at least the API X80 grade even after post-weld heat treatment performed at 600°C or more.

Solution to Problem

[0013]

In order to achieve the objects, the present inventors have intensively studied the characteristics of a steel pipe suitable for a deep-well conductor casing. As a result, the present inventors have found that in order to prevent a conductor casing from being broken by bending deformation during placement, it is necessary to use a steel pipe having a circularity of 0.6% or less. The present inventors have found that if a steel pipe to be used has a circularity of 0.6% or less, linear misalignment between a threaded member and a joint (an end portion of the steel pipe) can be

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reduced to prevent the steel pipe from being broken by repeated bending deformation, without a particular additional process, such as cutting or straightening.

[0014]

The present inventors have considered that such a steel pipe is preferably an electric-resistance-welded steel pipe rather than a UOE steel pipe. Electric-resistance-welded steel pipes have a cylindrical shape formed by continuous forming with a plurality of rolls and have higher circularity than UOE steel pipes formed by press forming and pipe expanding. The present inventors have found from their study that forming by reducing rolling with sizer rolls finally performed after electric resistance welding is effective in order to manufacture an electric-resistance-welded steel pipe having circularity suitable for a deep-well conductor casing. The present inventors have also found that in roll forming in pipe manufacturing, in addition to roll forming with a cage roll group and a fin pass forming roll group, pressing two or more portions of an inner wall of a hot-rolled steel plate being subjected to the forming process with an inner roll disposed downstream of the cage roll group is effective in further improving circularity, and further this can reduce the load of fin pass forming.

[0015]

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The present inventors have also intensively studied the effects of the composition of a hot-rolled steel plate used as a steel pipe material and the hot-rolling conditions on the steel pipe strength after post-weld heat treatment. As a result, the present inventors have found that in order that an electric-resistance-welded steel pipe maintains the strength of at least the API X80 grade even after post-weld heat treatment performed at 600°C or more and preferably at less than 750°C, a hot-rolled steel plate used as a steel pipe material should contain fine Nb precipitates (precipitated Nb) having a particle size less than 20 nm in an amount of 75% or less of the Nb content on a Nb equivalent basis. The present inventors have found that when the amount of fine Nb precipitates (precipitated Nb) is more than 75% of the Nb content, the decrease in yield strength YS due to post-weld heat treatment performed at a temperature of 600°C or more cannot be suppressed.

[0016]

The present invention has been accomplished on the basis of these findings after further consideration. The present invention is summarized as described below.

[1] A high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing,

the steel pipe having a composition containing, on a mass percent basis:

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C: 0.01% to 0.12%, Si: 0.05% to 0.50%,

Mn: 1.0% to 2.2%, P: 0.03% or less,

S: 0.005% or less, Al: 0.001% to 0.10%,

N: 0.006% or less, Nb: 0.010% to 0.100%, and

Ti: 0.001% to 0.050%,

the remainder being Fe and incidental impurities,

the steel pipe having a structure composed of 90% or more by volume of a bainitic ferrite phase as a main phase and 10% or less (including 0%) by volume of a second phase, the bainitic ferrite phase having an average grain size of 10 μm or less, the structure containing fine Nb precipitates having a particle size of less than 20 nm dispersed in a base material portion, a ratio (%) of the fine Nb precipitates to the total amount of Nb being 75% or less on a Nb equivalent basis, and

the circularity of an end portion of the steel pipe defined by the following formula (1) being 0.6% or less.

Circularity (%) = {(maximum outer diameter mm ϕ of steel pipe) - (minimum outer diameter mm ϕ of steel pipe)} / (nominal outer diameter mm ϕ) x 100 (1)

[2] The high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to [1], wherein the composition further contains one or two or more selected from V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B:

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0.0030% or less on a mass percent basis.

[3] The high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to [1] or [2], wherein the composition further contains one or two selected from Ca: 0.0050% or less and REM: 0.0050% or less on a mass percent basis.

[4] A method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing, including: continuously rolling a hot-rolled steel plate with a roll forming machine to form an open pipe having a generally circular cross section; butting edges of the open pipe; electric-resistance-welding a portion where the edges being butted while pressing the butted edges to controll by squeeze rolls to form an electric-resistance-welded steel pipe; subjecting the electric-resistance-welded portion of the electric-resistance-welded steel pipe to in-line heat treatment; and reducing the diameter of the electric-resistance-welded steel pipe by rolling,

wherein the hot-rolled steel plate is manufactured by heating to soak a steel at a heating temperature in the range of 1150°C to 1250°C for 60 minutes or more,

the steel having a composition containing, on a mass percent basis,

C: 0.01% to 0.12%, Si: 0.05% to 0.50%,

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Mn: 1.0% to 2.2%, P: 0.03% or less,
S: 0.005% or less, Al: 0.001% to 0.10%,
N: 0.006% or less, Nb: 0.010% to 0.100%, and
Ti: 0.001% to 0.050%,
the remainder being Fe and incidental impurities, and
hot-rolling the steel with a finishing delivery
temperature of 750°C or more,

after completion of the hot rolling, subjecting the
hot-rolled steel plate to accelerated cooling such that the
average cooling rate in a temperature range of 750°C to 650°C
at the center of plate thickness ranges from 8°C/s to 70°C/s,
and

coiling the hot-rolled steel plate at a coiling
temperature in the range of 580°C to 400°C.

[5] The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to [4], wherein the roll forming machine includes a cage roll group composed of a plurality of rolls and a fin pass forming roll group composed of a plurality of rolls.

[6] The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to [5], wherein two or more portions of an inner wall of the hot-rolled steel plate are pressed with an inner roll disposed downstream of the cage

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roll group during a forming process.

[7] The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of [4] to [6], wherein the in-line heat treatment of the electric-resistance-welded portion includes heating the electric-resistance-welded portion to a temperature in the range of 830°C to 1150°C and cooling the electric-resistance-welded portion to a cooling stop temperature of 550°C or less at the center of plate thickness such that the average cooling rate in a temperature range of 800°C to 550°C at the center of plate thickness ranges from 10°C/s to 70°C/s.

[8] The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of [4] to [7], wherein a reduction ratio in the reducing rolling is in the range of 0.2% to 3.3%.

[9] The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of [4] to [8], wherein the composition further contains one or two or more selected from V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B: 0.0030% or less on a mass percent basis.

[10] The method for manufacturing a high-strength thick-

walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of [4] to [9], wherein the composition further contains one or two selected from Ca: 0.0050% or less and REM: 0.0050% or less on a mass percent basis.

[11] A high-strength thick-walled conductor casing for deep wells, comprising a screw member disposed on each end of the high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of [1] to [3].

[0016a]

According to an embodiment, there is provided a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing, the steel pipe having a thickness of 15 mm or more, a yield strength of 555 MPa or more, and a tensile strength of 625 MPa or more, and having a composition containing, on a mass percent basis:

C: 0.01% to 0.12%, Si: 0.05% to 0.50%,

Mn: 1.0% to 2.2%, P: 0.03% or less,

S: 0.005% or less, Al: 0.001% to 0.10%,

N: 0.006% or less, Nb: 0.010% to 0.100%, and

Ti: 0.001% to 0.050%,

the remainder being Fe and incidental impurities, the steel pipe having a structure composed of 90% or more by volume of a bainitic ferrite phase as a main phase and 0% or more and 10%

or less by volume of a second phase, the bainitic ferrite phase having an average grain size of 10 μm or less, the structure containing fine Nb precipitates having a particle size of less than 20 nm dispersed in a base material portion, a ratio (%) of the fine Nb precipitates to the total amount of Nb being 45% or more and 75% or less by total mass of only Nb element in the precipitates, and a circularity of an end portion of the steel pipe defined by the following formula (1) being 0.6% or less, Circularity (%) = {(maximum outer diameter $\text{mm}\phi$ of steel pipe) - (minimum outer diameter $\text{mm}\phi$ of steel pipe)}/(nominal outer diameter $\text{mm}\phi$) x 100 (1).

[0016b]

According to another embodiment, there is provided a method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing, the steel pipe having a thickness of 15 mm or more, a yield strength of 555 MPa or more, and a tensile strength of 625 MPa or more, the method comprising: continuously rolling a hot-rolled steel plate with a roll forming machine to form an open pipe having a U-shaped cross section; butting edges of the open pipe; electric-resistance-welding a portion where the edges being butted while pressing the butted edges to contact each other by squeeze rolls to form an electric-resistance-welded steel pipe; subjecting the electric-resistance-welded portion of the electric-resistance-welded steel pipe to in-line

heat treatment; and reducing a diameter of the electric-resistance-welded steel pipe by rolling, wherein the hot-rolled steel plate is manufactured by heating to soak a steel at a heating temperature in the range of 1150°C to 1250°C for 60 minutes or more, the steel having a composition containing, on a mass percent basis,

C: 0.01% to 0.12%, Si: 0.05% to 0.50%,

Mn: 1.0% to 2.2%, P: 0.03% or less,

S: 0.005% or less, Al: 0.001% to 0.10%,

N: 0.006% or less, Nb: 0.010% to 0.100%, and

Ti: 0.001% to 0.050%,

the remainder being Fe and incidental impurities, hot-rolling the steel with a finishing delivery temperature of 750°C or more, the hot-rolling having a rolling reduction adjusted to be 20% or more in a non-recrystallization temperature range in which a temperature at a center of plate thickness is 950°C or less, after completion of the hot rolling, subjecting the hot-rolled steel plate to accelerated cooling such that an average cooling rate in a temperature range of 750°C to 650°C at the center of plate thickness ranges from 16°C/s to 70°C/s, and coiling the hot-rolled steel plate at a coiling temperature in the range of 580°C to 400°C.

[0016c]

According to another embodiment, there is provided a high-strength thick-walled conductor casing for deep wells,

comprising a screw member disposed on each end of the high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing as described herein.

Advantageous Effects of Invention

[0017]

The present invention has industrially great advantageous effects in that a high-strength thick-walled electric-resistance-welded steel pipe having high resistance to post-weld heat treatment can be easily manufactured at low cost without particular additional treatment. The steel pipe is suitable for a deep-well conductor casing, has high strength and toughness, and can maintain desired high strength even after post-weld heat treatment performed at 600°C or more. The present invention can also reduce the occurrence of breakage of a conductor casing during placement and contributes to reduced placement costs. The present invention can also provide a conductor casing that can maintain the strength of at least the API X80 grade even

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after post-weld heat treatment performed at 600°C or more. An electric-resistance-welded steel pipe according to the present invention also has an effect that it is useful as a line pipe manufactured by joining pipes together by girth welding.

Brief Description of Drawings

[0018]

[Fig. 1] Fig. 1 is a schematic explanatory view of an example of a production line suitable for the manufacture of an electric-resistance-welded steel pipe according to the present invention.

[Fig. 2] Fig. 2 is a schematic explanatory view of an example of the shape of inner rolls.

[Fig. 3] Fig. 3 is a schematic explanatory view of an example of in-line heat treatment facilities.

Description of Embodiments

[0019]

A high-strength thick-walled electric-resistance-welded steel pipe according to the present invention is a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing. The term "high-strength thick-walled electric-resistance-welded steel pipe", as used herein, refers to a thick-walled electric-resistance-welded steel pipe having a thickness of 15 mm or more in which both a base material portion and an electric-resistance-welded

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portion have high strength of at least the API X80 grade. The base material portion has a yield strength YS of 555 MPa or more and a tensile strength TS of 625 MPa or more, and the electric-resistance-welded portion has a tensile strength TS of 625 MPa or more.

[0020]

A high-strength thick-walled electric-resistance-welded steel pipe according to the present invention has a composition containing, on a mass percent basis, C: 0.01% to 0.12%, Si: 0.05% to 0.50%, Mn: 1.0% to 2.2%, P: 0.03% or less, S: 0.005% or less, Al: 0.001% to 0.10%, N: 0.006% or less, Nb: 0.010% to 0.100%, and Ti: 0.001% to 0.050%, optionally further containing one or two or more selected from V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B: 0.0030% or less, and/or one or two selected from Ca: 0.0050% or less and REM: 0.0050% or less, the remainder being Fe and incidental impurities.

[0021]

First, the reasons for limiting the composition of a high-strength thick-walled electric-resistance-welded steel pipe according to the present invention will be described below. Unless otherwise specified, the mass percentage of a component is simply expressed in %.

[0022]

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C: 0.01% to 0.12%

C is an important element that contributes to increased strength of a steel pipe. A C content of 0.01% or more is required to achieve desired high strength. However, a high C content of more than 0.12% results in poor weldability. Furthermore, during cooling after hot rolling or during in-line heat treatment of an electric-resistance-welded portion, a high C content of more than 0.12% makes the formation of martensite easier in the case of rapid cooling or the formation of a large amount of pearlite easier in the case of slow cooling, thereby possibly reducing toughness or strength. Thus, the C content is limited to the range of 0.01% to 0.12%. The lower limit of the C content is preferably 0.03% or more. The upper limit is preferably 0.10% or less, more preferably 0.08% or less.

[0023]

Si: 0.05% to 0.50%

Si is an element that contributes to increased strength of a steel pipe by solid-solution strengthening. A Si content of 0.05% or more is required to achieve desired high strength by such an effect. Si has a higher affinity for O (oxygen) than Fe and, together with Mn oxide, forms a viscous eutectic oxide during electric resistance welding. Thus, an excessive Si content of more than 0.50% results in poor quality of an electric-resistance-welded portion. Thus,

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the Si content is limited to the range of 0.05% to 0.50%.

The Si content preferably ranges from 0.05% to 0.30%.

[0024]

Mn: 1.0% to 2.2%

Mn is an element that contributes to increased strength of a steel pipe. A Mn content of 1.0% or more is required to achieve desired high strength. However, in the same manner as in C, a high Mn content of more than 2.2% makes the formation of martensite easier and results in poor weldability. Thus, the Mn content is limited to the range of 1.0% to 2.2%. The lower limit of the Mn content is preferably 1.2% or more. The upper limit is preferably 2.0% or less.

[0025]

P: 0.03% or less

P exists as an impurity in steel, tends to segregate at grain boundaries, and adversely affects the steel pipe characteristics, such as toughness. Thus, the P content is preferably minimized. In the present invention, the allowable P content is up to 0.03%. Thus, the P content is limited to 0.03% or less. The P content is preferably 0.02% or less. However, an excessive reduction in P content increases refining costs. Thus, the P content is preferably 0.001% or more.

[0026]

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S: 0.005% or less

S exists in the form of coarse sulfide inclusions, such as MnS, in steel and reduces ductility and toughness. Thus, the S content is desirably minimized. In the present invention, the allowable S content is up to 0.005%. Thus, the S content is limited to 0.005% or less. The S content is preferably 0.004% or less. However, an excessive reduction in S content increases refining costs. Thus, the S content is preferably 0.001% or more.

[0027]

Al: 0.001% to 0.10%

Al is an element that acts usefully as a deoxidizing agent for steel. Such an effect requires an Al content of 0.001% or more. However, a high Al content of more than 0.10% results in the formation of an Al oxide and low cleanliness of steel. Thus, the Al content is limited to the range of 0.001% to 0.10%. The lower limit of the Al content is preferably 0.005% or more. The upper limit is preferably 0.08% or less.

[0028]

N: 0.006% or less

N exists as an incidental impurity in steel and forms a solid solution or nitride, thereby reducing toughness of a base material portion or an electric-resistance-welded portion of a steel pipe. Thus, the N content is desirably

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minimized. In the present invention, the allowable N content is up to 0.006%. Thus, the N content is limited to 0.006% or less.

[0029]

Nb: 0.010% to 0.100%

Nb is an important element in the present invention. While steel (a slab) is heated, Nb is present as Nb carbonitride in the steel, suppresses coarsening of austenite grains, and contributes to a finer structure. Nb forms fine precipitates during post-weld heat treatment performed at 600°C or more and contributes to a smaller decrease in the strength of a base material portion of a steel pipe after the post-weld heat treatment. Such an effect requires a Nb content of 0.010% or more. However, an excessive Nb content of more than 0.100% adversely affects the toughness of a steel pipe and possibly results in an inability to achieve the desired toughness of the steel pipe for a conductor casing. Thus, the Nb content is limited to the range of 0.010% to 0.100%. The lower limit of the Nb content is preferably 0.020% or more. The upper limit is preferably 0.080% or less.

[0030]

Ti: 0.001% to 0.050%

Ti forms a Ti nitride combining with N and fixes N that adversely affects the toughness of a steel pipe, and thereby

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has the action of improving the toughness of the steel pipe. Such an effect requires a Ti content of 0.001% or more. However, a Ti content of more than 0.050% results in a significant decrease in the toughness of a steel pipe. Thus, the Ti content is limited to the range of 0.001% to 0.050%. The lower limit of the Ti content is preferably 0.005% or more. The upper limit is preferably 0.030% or less.

[0031]

These components are base components. In addition to the base components, a steel pipe according to the present invention may contain one or two or more selected from V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B: 0.0030% or less, and/or one or two selected from Ca: 0.0050% or less and REM: 0.0050% or less.

[0032]

One or two or more selected from V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B: 0.0030% or less

V, Mo, Cr, Cu, Ni, and B are elements that improve hardenability and contribute to increased strength of a steel plate, and can be appropriately selected for use. These elements reduce the formation of pearlite and polygonal ferrite particularly in thick plates having a thickness of 15 mm or more and are effective in achieving

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desired strength and toughness. It is desirable to contain V: 0.005% or more, Mo: 0.05% or more, Cr: 0.05% or more, Cu: 0.05% or more, Ni: 0.05% or more, and/or B: 0.0005% or more to produce such an effect. However, the content exceeding V: 0.1%, Mo: 0.5%, Cr: 0.5%, Cu: 0.5%, Ni: 1.0%, or B: 0.0030% may result in reduced weldability and toughness and increased material costs. Thus, the amounts of these elements are preferably limited to V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B: 0.0030% or less, if any. V: 0.08% or less, Mo: 0.45% or less, Cr: 0.30% or less, Cu: 0.35% or less, Ni: 0.35% or less, and B: 0.0025% or less are more preferred.

[0033]

One or two selected from Ca: 0.0050% or less and REM: 0.0050% or less

Ca and REM are elements that contribute to morphology control of inclusions in which elongated sulfide inclusions, such as MnS, are transformed into spherical sulfide inclusions, and can be appropriately selected for use. It is desirable to contain at least 0.0005% Ca or at least 0.0005% REM to produce such an effect. However, more than 0.0050% Ca or REM may result in increased oxide inclusions and reduced toughness. Thus, if present, Ca and REM are preferably limited to Ca: 0.0050% or less and REM: 0.0050% or less, respectively.

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[0034]

The remainder other than the components described above is made up of Fe and incidental impurities.

[0035]

A high-strength thick-walled electric-resistance-welded steel pipe according to the present invention has the composition described above and has the structure in which a base material portion and an electric-resistance-welded portion of the high-strength thick-walled electric-resistance-welded steel pipe have a structure composed of 90% or more by volume of a bainitic ferrite phase as a main phase and 10% or less (including 0%) by volume of a second phase, the bainitic ferrite phase described above having an average grain size of 10 μm or less, fine Nb precipitates having a particle size of less than 20 nm being dispersed in the base material portion, the ratio (%) of the fine Nb precipitates to the total amount of Nb being 75% or less on a Nb equivalent basis, and the circularity of an end portion of the steel pipe is 0.6% or less.

[0036]

Main phase: 90% or more by volume of a bainitic ferrite phase

In order to achieve desired high strength and high toughness for a conductor casing, both a base material portion and an electric-resistance-welded portion of an

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electric-resistance-welded steel pipe according to the present invention have a structure composed mainly of 90% or more by volume of a bainitic ferrite phase. Less than 90% of a bainitic ferrite phase or 10% or more of a second phase other than the main phase results in an inability to achieve desired toughness. The second phase other than the main phase may be a hard phase, such as pearlite, degenerate pearlite, bainite, or martensite. Thus, the volume percentage of the bainitic ferrite phase serving as the main phase is limited to 90% or more. The volume percentage of the bainitic ferrite phase is preferably 95% or more.

[0037]

Average grain size of bainitic ferrite phase: 10 μm or less

In order to achieve desired high strength and high toughness for a conductor casing, in the present invention, a bainitic ferrite phase serving as the main phase has a fine structure having an average grain size of 10 μm or less. An average grain size of more than 10 μm results in an inability to achieve desired high toughness. Thus, the average grain size of the bainitic ferrite phase serving as the main phase is limited to 10 μm or less.

[0038]

Fine Nb precipitates having a particle size of less than 20 nm: the ratio (%) of the Nb precipitates to the

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total amount of Nb is 75% or less on a Nb equivalent basis

Fine Nb precipitates (mainly carbonitride) having a particle size of less than 20 nm effectively contribute to achieving desired high strength. Thus, the ratio (%) of the fine Nb precipitates to the total amount of Nb is preferably 20% or more on a Nb equivalent basis. However, precipitation of more than 75% of the total amount of Nb on a Nb equivalent basis results in Ostwald growth of precipitates during post-weld heat treatment performed at a temperature of 600°C or more and reduces yield strength after post-weld heat treatment. Thus, in the present invention, the ratio (%) of fine Nb precipitates having a particle size of less than 20 nm in a base material portion of a steel pipe to the total amount of Nb is 75% or less on a Nb equivalent basis. Thus, fine Nb precipitates remain even after post-weld heat treatment and can suppress the decrease in yield strength. Thus, the ratio (%) of the amount of fine Nb precipitates having a particle size of less than 20 nm to the total amount of Nb on a Nb equivalent basis is limited to 75% or less.

[0039]

The phrase "the amount of fine Nb precipitates having a particle size of less than 20 nm", as used herein, refers to a value determined by electrolyzing an electroextraction test piece taken from a base material portion of an

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electric-resistance-welded steel pipe in an electrolyte solution (10% by volume acetylacetone-1% by mass tetramethylammonium chloride-methanol solution), filtering the resulting electrolytic residue through a filter having a pore size of 0.02 μm , and analyzing the amount of Nb passing through the filter.

[0040]

A high-strength thick-walled electric-resistance-welded steel pipe according to the present invention has the composition and structure described above, and the circularity of an end portion of the steel pipe is 0.6% or less.

[0041]

Circularity: 0.6% or less

If the circularity of an end portion of an electric-resistance-welded steel pipe is 0.6% or less, without cutting and/or straightening before the end portion of the pipe is joined to a connector by girth welding, linear misalignment in the joint is allowable, and the occurrence of breakage by repeated bending deformation can be reduced. If the circularity of an electric-resistance-welded steel pipe is more than 0.6%, the linear misalignment of a joint between the steel pipe and a connector (screw member) increases, and the joint is likely to be broken by the weight of the pipe and bending deformation during placement.

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Thus, the circularity of an electric-resistance-welded steel pipe is limited to 0.6% or less. The circularity of a steel pipe is defined by the following formula (1).

$$\text{Circularity (\%)} = \{(\text{maximum outer diameter mm}\phi \text{ of steel pipe}) - (\text{minimum outer diameter mm}\phi \text{ of steel pipe})\} / (\text{nominal outer diameter mm}\phi) \times 100 \quad (1)$$

It is desirable to continuously measure the maximum outer diameter and minimum outer diameter of a steel pipe with a laser displacement meter. In the case of manual measurement from necessity, the maximum outer diameter and minimum outer diameter of a steel pipe should be determined from measurements of at least 32 points on the circumference of the steel pipe.

[0042]

In a deep-well conductor casing including a high-strength thick-walled electric-resistance-welded steel pipe according to the present invention, the high-strength thick-walled electric-resistance-welded steel pipe is provided with a screw member at each end thereof. The screw member may be attached by any method, for example, by MIG welding or TIG welding. The screw member may be made of, for example, carbon steel or stainless steel.

A method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe according to the present invention will be described below.

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[0043]

An electric-resistance-welded steel pipe according to the present invention is manufactured using a hot-rolled steel plate as a material.

[0044]

More specifically, an electric-resistance-welded steel pipe according to the present invention is manufactured by continuously cold-rolling a hot-rolled steel plate with a roll forming machine (preferably with a cage roll group composed of a plurality of rolls and a fin pass forming roll group composed of a plurality of rolls) to form an open pipe having a generally circular cross section, butting against edges of the open pipe each other, electric-resistance-welding a portion where the edges butted while pressing the butted edges to contact each other by squeeze rolls to form an electric-resistance-welded steel pipe, subjecting the electric-resistance-welded portion of the electric-resistance-welded steel pipe to in-line heat treatment, and reducing the diameter of the electric-resistance-welded steel pipe by rolling.

[0045]

The hot-rolled steel plate used as a material is a thick- hot-rolled steel plate having a thickness of 15 mm or more and preferably 51 mm or less manufactured by subjecting a steel having the composition described above to the

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following process.

[0046]

The steel may be manufactured by any method. Preferably, a molten steel having the composition described above is produced by a conventional melting method, such as with a converter, and is formed into a cast block (steel), such as a slab, by a conventional casting process, such as a continuous casting process. Instead of the continuous casting process, a steel (steel block) may be manufactured by an ingot casting and slabbing process without problems.

[0047]

A steel having the above composition is heated to a temperature in the range of 1150°C to 1250°C and is subjected to hot-rolling, which includes rough rolling and finish rolling, at a finishing delivery temperature of 750°C or more.

[0048]

Heating temperature: 1150°C to 1250°C

Although a low heating temperature at which finer crystal grains are expected to grow is preferred in order to improve the toughness of a hot-rolled steel plate, a heating temperature of less than 1150°C is too low to promote solid solution of undissolved carbide, failing to achieve the desired high strength of at least the API X80 grade in some cases. On the other hand, a high heating temperature of

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more than 1250°C may cause coarsening of austenite (γ) grains, reduced toughness, more scales and poor surface quality, and result in economic disadvantages due to increased energy loss. Thus, the heating temperature of steel ranges from 1150°C to 1250°C. The soaking time at the heating temperature is preferably 60 minutes or more, in order to make the temperature of steel which is heated uniform.

[0049]

The rough rolling is not particularly limited, provided that the resulting sheet bar has a predetermined size and shape. The finishing delivery temperature of the finish rolling is adjusted to be 750°C or more. Here, the temperature is expressed in terms of a surface temperature.

[0050]

Finishing delivery temperature: 750°C or more

A finishing delivery temperature of less than 750°C causes in induction of ferrite transformation, and processing of the resulting ferrite results in reduced toughness. Thus, the finishing delivery temperature is limited to 750°C or more. In the finish rolling, the rolling reduction in a non-recrystallization temperature range in which a temperature at the center of plate thickness is 950°C or less is preferably adjusted to be 20% or more. A rolling reduction of less than 20% in the non-recrystallization temperature range is an insufficient

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rolling reduction for the non-recrystallization temperature range and may therefore result in a small number of ferrite nucleation sites, thus failing to decrease the size of ferrite grains. Thus, the rolling reduction in the non-recrystallization temperature range is preferably adjusted to be 20% or more. From the viewpoint of the load to a rolling mill, the cumulative rolling reduction in hot rolling is preferably 95% or less.

[0051]

In the present invention, after the completion of the hot rolling, cooling is immediately started preferably within 5 s (s refers to second). The hot-rolled plate is subjected to accelerated cooling such that the average cooling rate in a temperature range of 750°C to 650°C at the center of plate thickness ranges from 8°C/s to 70°C/s, and is coiled at a coiling temperature in the range of 400°C to 580°C. The coiled plate is left to cool.

[0052]

Average cooling rate of accelerated cooling in the temperature range of 750°C to 650°C: 8°C/s to 70°C/s

An average cooling rate of less than 8°C/s in the temperature range of 750°C to 650°C is slow and results in a structure containing a coarse polygonal ferrite phase having an average grain size of more than 10 μm and pearlite, thus failing to achieve the toughness and strength required for

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casing. On the other hand, an average cooling rate of more than 70°C/s may result in the formation of a martensite phase and reduced toughness. Thus, the average cooling rate in the temperature range of 750°C to 650°C is limited to the range of 8°C/s to 70°C/s. The lower limit of the cooling rate is preferably 10°C/s or more. The upper limit is preferably 50°C/s or less. These temperatures are the temperatures at the center of plate thickness. The temperatures at the center of plate thickness are determined by calculating the temperature distribution in a cross section by heat transfer analysis and correcting the calculated data in accordance with the actual outer and inner surface temperatures.

[0053]

The cooling stop temperature of the accelerated cooling preferably ranges from 400°C to 630°C in terms of the surface temperature. When the cooling stop temperature of the accelerated cooling is outside the temperature range of 400°C to 630°C, the desired coiling temperature in the range of 400°C to 580°C may be impossible to consistently achieve.

[0054]

Coiling temperature: 400°C to 580°C

A high coiling temperature of more than 580°C causes promotion of precipitation of Nb carbonitride (precipitates), a Nb precipitation ratio of more than 75% after the coiling

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process, and results in reduced yield strength after post-weld heat treatment performed at a heating temperature of 600°C or more. On the other hand, a coiling temperature of less than 400°C causes insufficient precipitation of fine Nb carbonitride (precipitates) and results in an inability to achieve desired high strength (at least the API X80 grade). Thus, the coiling temperature is limited to a temperature in the range of 400°C to 580°C. The coiling temperature preferably ranges from 460°C to 550°C. When the coiling temperature is adjusted to be in this temperature range, the structure can contain fine Nb precipitates having a particle size of less than 20 nm dispersed in a base material portion, and the ratio (%) of the fine Nb precipitates to the total amount of Nb is 75% or less on a Nb equivalent basis. This can suppress the decrease in yield strength due to post-weld heat treatment performed at 600°C or more. These temperatures are expressed in terms of a plate surface temperature.

[0055]

A hot-rolled steel plate manufactured under the conditions described above has a structure composed of 90% or more by volume of a bainitic ferrite phase as a main phase and 10% or less (including 0%) by volume of a second phase as the remainder other than the bainitic ferrite phase, the main phase having an average grain size of 10 μm or less,

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fine Nb precipitates having a particle size of less than 20 nm being dispersed, the ratio (%) of the fine Nb precipitates to the total amount of Nb being 75% or less on a Nb equivalent basis. The hot-rolled steel plate has high strength of at least the API X80 grade, that is, a yield strength YS of 555 MPa or more, and high toughness represented by an absorbed energy vE_{-40} of 27 J or more in a Charpy impact test at a test temperature of -40°C .

[0056]

A hot-rolled steel plate (hot-rolled steel strip) 1 having the composition and structure described above is used as a steel pipe material and is continuously rolled with a roll forming machine 2 illustrated in Fig. 1 to form an open pipe having a generally circular cross section. After that, the edges of the open pipe are butted against each other while butted edges of the open pipe are pressed to contact each other by squeeze rolls 4, the portion where the edges being butted are heated to at least the melting point thereof and are electric-resistance-welded with a welding machine 3 by high-frequency resistance heating, high-frequency induction heating, or the like, thus forming an electric-resistance-welded steel pipe 5. The roll forming machine 2 preferably includes a cage roll group 2a composed of a plurality of rolls and a fin pass forming roll group 2b composed of a plurality of rolls.

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[0057]

The circularity is preferably improved by pressing two or more portions of an inner wall of a hot-rolled steel plate with at least one set of inner rolls 2a1 disposed downstream of the cage roll group 2a during a forming process. Preferably, the inner rolls disposed have shape as illustrated in Fig. 2 so as to press two or more positions from the viewpoint of improving circularity and reducing the load to facilities. Fig. 2 illustrates two sets of inner rolls 2a1 ((2a1)₁ and (2a1)₂).

[0058]

Methods of roll forming, pressing by squeeze rolls, and electric resistance welding are not particularly limited, provided that an electric-resistance-welded steel pipe having predetermined dimensions can be manufactured, and any conventional method may be employed.

[0059]

The electric-resistance-welded steel pipe thus formed is subjected to in-line heat treatment (seam annealing) of an electric-resistance-welded portion, as illustrated in Fig. 1.

[0060]

In-line heat treatment of an electric-resistance-welded portion is preferably performed with an induction heating apparatus 9 and a cooling apparatus 10 disposed downstream

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of the squeeze rolls 4 such that the electric-resistance-welded portion can be heated, for example, as illustrated in Fig. 1. As illustrated in Fig. 3, the induction heating apparatus 9 preferably includes one or a plurality of coils 9a so as to enable one or a plurality of heating steps. By using a plurality of coils 9a, uniform heating can be achieved.

[0061]

In the heat treatment of an electric-resistance-welded portion, preferably, the electric-resistance-welded portion is heated so as to the minimum temperature in the thickness direction being 830°C or more and the maximum heating temperature in the thickness direction being 1150°C or less and is cooled with water to a cooling stop temperature (at the center of plate thickness) of 550°C or less such that the average cooling rate in the temperature range of 800°C to 550°C at the center of plate thickness ranges from 10°C/s to 70°C/s. The cooling stop temperature may be lowered. When the minimum heating temperature in an electric-resistance-welded portion is less than 830°C, the heating temperature may be too low to provide the desired structure of the electric-resistance-welded portion. On the other hand, a maximum heating temperature of more than 1150°C may result in coarsening of crystal grains and reduced toughness. Thus, the heating temperature of an electric-resistance-

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welded portion in heat treatment preferably ranges from 830°C to 1150°C.

[0062]

When the average cooling rate is less than 10°C/s, this may promote the formation of polygonal ferrite and result in an inability to provide the desired structure of an electric-resistance-welded portion. On the other hand, rapid cooling with an average cooling rate of more than 70°C/s may result in the formation of a hard phase, such as martensite, an inability to provide the desired structure of an electric-resistance-welded portion, and reduced toughness. Thus, the average cooling rate of cooling after heating preferably ranges from 10°C/s to 70°C/s. The cooling stop temperature is preferably 550°C or less. A high cooling stop temperature of more than 550°C may cause incomplete ferrite transformation, and formation of a coarse pearlite structure when left standing after cooling, and reduced in reduced toughness, or reduced strength.

[0063]

The heat treatment (seam annealing) of an electric-resistance-welded portion can change the structure of the electric-resistance-welded portion into a structure similar to the structure of the base material portion, that is, a structure composed of 90% or more by volume of a bainitic ferrite phase as a main phase and 10% or less (including 0%)

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by volume of a second phase, the bainitic ferrite phase having an average grain size of 10 μm or less.

[0064]

Subsequently, the circularity is improved by reducing rolling.

[0065]

The reducing rolling is preferably cold rolling with a sizer 8 composed of two or three or more pairs of rolls. In the reducing rolling, a reduction ratio in the range of 0.2% to 3.3% is preferable. A reduction ratio of less than 0.2% may result in an inability to achieve the desired circularity (0.6% or less). On the other hand, a reduction ratio of more than 3.3% may cause excessive circumferential compression and considerable thickness variations in the circumferential direction, and result in reduced efficiency of girth welding. Thus, in the reducing rolling, a reduction ratio in the range of 0.2% to 3.3% is preferable. The reduction ratio is calculated using the following formula.

$$\text{Reduction ratio (\%)} = \{(\text{outer perimeter of pipe before reducing rolling mm}) - (\text{outer perimeter of pipe after reducing rolling mm})\} / (\text{outer perimeter of pipe before reducing rolling mm}) \times 100$$

The circularity of an end portion of a high-strength thick-walled electric-resistance-welded steel pipe can be

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adjusted to be 0.6% or less by the reducing rolling.

[0066]

The present invention will be more specifically described below with examples.

EXAMPLES

[0067]

A molten steel having the composition listed in Table 1 (the remainder was made up of Fe and incidental impurities) was produced in a converter and was cast into a slab (a cast block having a thickness of 250 mm) by a continuous casting process. The slab was used as steel that is a starting material.

[0068]

The steel obtained was reheated under the conditions (heating temperature (°C) x holding time (min)) listed in Table 2 and was hot-rolled into a hot-rolled steel plate. The hot rolling included rough rolling and finish rolling. The hot-rolling was performed under the conditions of the rolling reduction (%) in a non-recrystallization temperature range and the finishing delivery temperature (°C) listed in Table 2. After the finish rolling, cooling was immediately started and here, accelerated cooling, that is, cooling was performed under the conditions of temperatures at the center of plate thickness (the average cooling rate in the temperature range of 750°C to 650°C and the cooling stop

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temperature) listed in Table 2 was performed. The resultant hot-rolled steel plate was coiled at a coiling temperature listed in Table 2 to produce a steel pipe material.

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[0069]

[Table 1]

Steel No.	Chemical components (mass%)											Remarks
	C	Si	Mn	P	S	Al	N	Nb	Ti	V, Mo, Cr, Cu, Ni, B	Ca, REM	
A	0.090	0.15	1.90	0.006	0.0050	0.034	0.003	0.037	0.010	-	-	Working example
B	0.054	0.15	1.74	0.012	0.0009	0.026	0.0003	0.060	0.015	V:0.08	-	Working example
C	0.050	0.20	1.55	0.012	0.0005	0.032	0.004	0.060	0.015	Mo:0.28, Cu:0.22, Ni:0.20	-	Working example
D	0.066	0.23	1.82	0.010	0.0016	0.037	0.004	0.063	0.016	V:0.04, Cr:0.13	-	Working example
E	0.022	0.23	1.45	0.015	0.0022	0.026	0.002	0.055	0.014	V:0.07, Mo:0.15, Cu:0.32	Ca:0.0025	Working example
F	0.040	0.18	1.60	0.010	0.0010	0.033	0.002	0.025	0.045	Mo:0.10, Ni:0.25	Ca:0.0020	Working example
G	0.032	0.28	2.06	0.010	0.0019	0.040	0.003	0.053	0.012	Mo:0.37, Cr:0.40, B:0.0022	REM:0.003	Working example
H	<u>0.004</u>	0.22	1.85	0.010	0.0010	0.030	0.003	0.032	0.020	V:0.075, Cu:0.22, Ni:0.24	-	Comparative example
I	<u>0.146</u>	0.20	1.44	0.012	0.0025	0.023	0.004	0.024	0.008	V:0.043	Ca:0.0011	Comparative example
J	0.042	<u>0.56</u>	1.58	0.005	0.0015	0.038	0.004	0.052	0.016	Cr:0.23, Ni:0.15	Ca:0.0022	Comparative example
K	0.037	0.19	<u>0.65</u>	0.017	0.0008	0.021	0.003	0.080	0.017	-	-	Comparative example
L	0.036	0.35	<u>2.31</u>	0.012	0.0008	0.048	0.003	0.025	0.012	Cu:0.15, Ni:0.13	Ca:0.0025	Comparative example
M	0.050	0.27	1.36	0.006	0.0021	0.045	0.004	<u>0.002</u>	0.005	V:0.040	-	Comparative example
N	0.071	0.21	1.26	0.012	0.0006	0.031	0.003	<u>0.131</u>	0.015	Mo:0.18, Cr:0.32	-	Comparative example
O	0.061	0.23	1.05	0.008	0.0007	0.041	0.001	0.015	<u>0.065</u>	-	-	Comparative example

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[0070]

[Table 2]

Hot-rolled plate No.	Steel No.	Heating		Hot rolling		Cooling after hot rolling		Coiling	Plate thickness (mm)	Remarks
		Heating temperature (°C)	Holding time (min)	Rolling reduction in non-recrystallization temperature range* (%)	Finishing delivery temperature e** (°C)	Average cooling rate*** (°C/s)	Cooling stop temperature*** (°C)	Coiling temperature** (°C)		
1	A	1210	90	40	820	18	540	520	25.2	Working example
2	B	1210	75	40	810	20	540	530	20.4	Working example
3	C	1200	80	50	800	20	510	500	22.0	Working example
4	D	1220	90	20	820	16	560	540	25.2	Working example
5	E	1230	90	85	820	30	520	500	25.2	Working example
6	F	1180	65	55	780	22	520	500	20.4	Working example
7	G	1200	100	60	820	45	490	470	18.9	Working example
8	H	1200	100	20	820	25	480	460	18.9	Comparative example
9	I	1200	120	85	820	18	490	460	25.2	Comparative example
10	J	1190	75	40	780	28	500	480	15.7	Comparative example
11	K	1170	80	50	830	16	520	500	25.2	Comparative example
12	L	1200	80	20	820	20	560	540	22.0	Comparative example
13	M	1210	90	85	820	35	570	540	25.2	Comparative example
14	N	1210	90	40	820	20	515	500	20.4	Comparative example
15	O	1230	95	40	840	25	470	450	18.9	Comparative example
16	A	1100	100	50	820	18	440	420	25.2	Comparative example
17	A	1300	100	50	820	60	500	480	17.3	Comparative example
18	A	1230	105	20	820	5	540	520	22.0	Comparative example
19	A	1200	90	85	820	100	440	420	25.2	Comparative example
20	A	1200	95	40	780	18	680	650	25.2	Comparative example
21	A	1200	90	40	840	45	355	350	25.2	Comparative example
22	C	1280	100	50	820	25	520	500	18.9	Comparative example
23	C	1220	100	20	820	120	500	480	25.2	Comparative example
24	C	1210	110	85	820	20	730	700	20.4	Comparative example
25	E	1110	110	55	790	20	500	480	22.0	Comparative example
26	E	1180	100	60	820	3	520	500	25.2	Comparative example
27	E	1180	90	20	820	15	310	300	25.2	Comparative example
28	F	1100	90	20	800	15	515	500	25.2	Comparative example
29	F	1170	85	85	820	5	525	520	25.2	Comparative example
30	F	1190	75	40	820	25	650	630	18.9	Comparative example
31	G	1300	75	40	790	20	600	580	25.2	Comparative example
32	G	1200	80	50	820	110	565	550	15.7	Comparative example

*) Temperature range of 930°C or less

**) Surface temperature

***) Temperature at the center of plate thickness

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[0071]

The hot-rolled steel plate serving as a steel pipe material was continuously cold-rolled with a roll forming machine including a cage roll group composed of a plurality of rolls and a fin pass forming roll group composed of a plurality of rolls, thereby forming an open pipe having a generally circular cross section. Then, the edges of the open pipe, which were opposite each other, were butted together. While butted edges of the open pipe were pressed to contact each other by squeeze rolls, the portion where the edges were butted was electric-resistance-welded to form an electric-resistance-welded steel pipe. In some electric-resistance-welded steel pipes, at least two portions, which were separate each other in the width direction, of the inner wall of the semi-formed product were pressed with inner rolls disposed downstream of the cage roll group.

[0072]

The electric-resistance-welded portion of the electric-resistance-welded steel pipe was then subjected to in-line heat treatment under the conditions listed in Table 3. The in-line heat treatment was performed with an in-line heat treatment apparatus disposed downstream of the squeeze rolls. The in-line heat treatment apparatus included an induction heating apparatus and a water cooling apparatus. The average cooling rate and the cooling stop temperature were

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expressed in terms of a temperature at the center of plate thickness. The average cooling rate listed was an average cooling rate in the temperature range of 800°C to 550°C.

[0073]

The electric-resistance-welded steel pipe subjected to the in-line heat treatment was subjected to reducing-cold-rolling with a reducing rolling mill (sizer roll) at the reduction ratio listed in Table 3, thereby forming an electric-resistance-welded steel pipe having the dimensions listed in Table 3. The reducing rolling mill included 2 to 8 sets of rolls, as listed in Table 3. Some electric-resistance-welded steel pipes were not subjected to reducing rolling. The circularity of an end portion of a pipe was calculated using the formula (1). The outer diameters listed in Table 3 were nominal outer diameters.

[0074]

[Table 3]

Steel pipe No.	Hot-rolled plate No.	Steel No.	Heat treatment of electric-resistance-welded portion			Reducing rolling		Dimensions of steel pipe			Remarks
			Maximum heating temperature (°C)	Average cooling rate (°C/s)	Cooling stop temperature (°C)	Number of rolls in sizer mill	Reduction ratio (%)	Thickness (mm)	Outer diameter (mmφ)	Circularity of end portion of pipe (%)	
1	1	A	1120	15	450	2	0.4	25.4	558.8	0.45	Working example
2	2	B	1080	25	500	2	0.4	20.6	558.8	0.43	Working example
3*	3	C	1100	20	500	3	0.5	22.2	558.8	0.32	Working example
4*	4	D	1100	15	500	3	0.5	25.4	609.6	0.35	Working example
5	5	E	1090	15	480	4	0.4	25.4	558.8	0.27	Working example
6*	6	F	1060	20	400	4	0.4	20.6	558.8	0.26	Working example
7*	7	G	1050	25	450	8	0.3	19.1	660.4	0.15	Working example
8	8	H	1050	25	350	2	0.3	19.1	558.8	0.42	Comparative example
9	9	I	1080	15	350	2	0.5	25.4	558.8	0.45	Comparative example
10	10	J	1100	33	300	2	0.5	15.9	558.8	0.44	Comparative example
11	11	K	1120	15	480	4	0.5	25.4	558.8	0.33	Comparative example
12	12	L	1100	15	450	4	0.5	22.2	558.8	0.34	Comparative example
13	13	M	1020	15	500	4	0.5	25.4	558.8	0.29	Comparative example
14*	14	N	1000	20	300	4	0.5	20.6	558.8	0.28	Comparative example
15	15	O	1040	30	300	4	0.5	19.1	457.2	0.28	Comparative example
16*	16	A	1070	15	350	3	0.4	25.4	558.8	0.32	Comparative example
17	17	A	1075	30	400	2	0.4	17.5	609.6	0.42	Comparative example
18	18	A	1060	15	350	2	0.4	22.2	508.0	0.45	Comparative example
19	19	A	1050	15	350	2	0.4	25.4	609.6	0.42	Comparative example
20	20	A	1100	15	400	2	0.6	25.4	457.2	0.45	Comparative example
21	21	A	1100	15	300	2	0.6	25.4	558.8	0.44	Comparative example
22	22	C	1100	25	300	2	0.6	19.1	558.8	0.42	Comparative example
23	23	C	1120	15	350	2	0.6	25.4	558.8	0.40	Comparative example
24	24	C	1080	20	350	2	0.6	20.6	558.8	0.40	Comparative example
25	25	E	1070	20	400	2	0.6	22.2	508.0	0.44	Comparative example
26	26	E	1080	15	400	2	0.6	25.4	558.8	0.44	Comparative example
27	27	E	1060	15	380	2	0.5	25.4	558.8	0.44	Comparative example
28	28	F	1100	15	450	2	0.5	25.4	508.0	0.48	Comparative example
29	29	F	1100	20	440	2	0.5	25.4	558.8	0.38	Comparative example
30	30	F	1030	25	430	2	0.5	19.1	558.8	0.40	Comparative example
31	31	G	1100	20	470	2	0.5	25.4	558.8	0.41	Comparative example
32	32	G	990	55	450	2	0.4	15.9	558.8	0.40	Comparative example
33	17	A	1080	25	300	-	-	17.5	406.4	0.86	Comparative example

*) With use of inner rolls

[0075]

Test pieces were taken from the electric-resistance-welded steel pipe and were subjected to structure observation, a tensile test, an impact test, and a post-weld heat treatment
5 test. These test methods are described below.

(1) Structure Observation

A test piece for structure observation was taken from a base material portion (a position at an angle of 90 degrees with respect to the electric-resistance-welded portion in the
10 circumferential direction) and the electric-resistance-welded portion of the electric-resistance-welded steel pipe. The base material portion was polished and etched (etchant: nital) such that the observation surface was at a the central position of the plate thickness, that is, at a center of the thickness, in
15 a cross section in the longitudinal direction of the pipe (L cross section). The electric-resistance-welded portion was polished and etched (etchant: nital) such that the observation surface was a cross section in the circumferential direction of the pipe (C cross section). The structure was observed with a
20 scanning electron microscope (SEM) (magnification: 1000), and images were taken in at least 2 fields. The structure images were analyzed to identify the structure and to determine the fraction of each phase. The average of the area fractions thus determined was treated as the volume fraction.

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[0076]

Grain boundaries having an orientation difference of 15 degrees or more were determined by a SEM/electron back scattering diffraction (EBSD) method. The arithmetic mean of the equivalent circular diameters of the grains determine was defined to be the average grain size of the main phase. "Orientation Imaging Microscopy Data Analysis", which is a software available from AMETEK Co., Ltd., was used for the calculation of the grain size.

[0077]

Specimen for an electroextraction test piece was taken from the base material portion of the electric-resistance-welded steel pipe (a position at an angle of 90 degrees with respect to the electric-resistance-welded portion in the circumferential direction) and was electrolyzed at a current density of 20 mA/cm² in an electrolyte solution (10% by volume acetylacetone-1% by mass tetramethylammonium chloride-methanol solution). The resulting electrolytic residue was dissolved in a liquid and was collected with an aluminum filter (pore size: 0.02 μ m). The amount of Nb in the filtrate was measured by ICP spectroscopy and was considered to be the amount of precipitated Nb having a grain size of 20 nm or less. The ratio (%) of the amount of precipitated Nb to the total amount of Nb was calculated.

(2) Tensile Test

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A plate-like tensile test piece was taken from the base material portion (a position at an angle of 180 degrees with respect to the electric-resistance-welded portion in the circumferential direction) and the electric-resistance-welded portion of the electric-resistance-welded steel pipe according to ASTM A 370 such that the tensile direction was a direction perpendicular to the longitudinal direction of the pipe (C direction). The tensile properties (yield strength YS and tensile strength TS) of the tensile test piece were measured.

(3) Impact Test

A V-notched test piece was taken from the base material portion (a position at an angle of 90 degrees with respect to the electric-resistance-welded portion in the circumferential direction) and the electric-resistance-welded portion of the electric-resistance-welded steel pipe according to ASTM A 370 such that the longitudinal direction of the test piece was the circumferential direction (C direction). The absorbed energy vE_{-40} (J) each of three test pieces for a steel pipe was measured in a Charpy impact test at a test temperature of -40°C . The average value of the three measurements was considered to be the vE_{-40} of the steel pipe.

(4) Post-Weld Heat Treatment Test

A test material was taken from the base material

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portion of the electric-resistance-welded steel pipe. The test material was placed in a heat treatment furnace maintained at a heating temperature simulating post-weld heat treatment listed in Table 5. When a predetermined holding time listed in Table 5 elapsed since the temperature of the test material reached (heating temperature - 10°C), the test material was removed from the heat treatment furnace and was left to cool. A plate-like tensile test piece was taken from the heat-treated test material according to ASTM A 370 such that the tensile direction was a direction perpendicular to the longitudinal direction of the pipe (C direction). The tensile properties (yield strength YS and tensile strength TS) of the tensile test piece were measured. A difference ΔYS in yield strength between before and after the post-weld heat treatment was calculated. If the strength is decreased after the post-weld heat treatment, the ΔYS is negative. For reference, an electroextraction test piece was taken from the test material after the post-weld heat treatment, and the ratio of the amount of precipitated Nb was determined in the same manner as in (1).

[0078]

Tables 4 and 5 show the results.

84006312

[0079]

[Table 4]

Steel pipe No.	Hot- rolled plate No.	Steel No.	Base material portion					Electric-resistance-welded portion					Remarks		
			Structure			Strength		Toughness Absorbed energy vE ₄₀ (J)	Structure			Strength		Toughness Absorbed energy vE ₄₀ (J)	
			Type*	Fraction of main phase structure (vol%)	Average grain size of main phase (μm)	Precipitated Nb ratio** (%)	Yield strength YS (MPa)		Tensile strength TS (MPa)	Type*	Fraction of main phase structure (vol%)	Average grain size of main phase (μm)			Tensile strength TS (MPa)
1	1	A	BF+B	BF-98	4.5	62	582	664	234	BF	100	5.6	650	196	Working example
2	2	B	BF	BF-100	5.1	57	624	701	311	BF	100	5.3	660	225	Working example
3	3	C	BF	BF-100	6.6	48	574	650	341	BF	100	6.2	654	189	Working example
4	4	D	BF+B	BF-96	4.3	67	610	692	300	BF	100	6.3	680	199	Working example
5	5	E	BF	BF-100	4.9	45	596	676	340	BF	100	6.6	672	194	Working example
6	6	F	BF	BF-100	4.1	48	580	674	336	BF	100	6.8	666	223	Working example
7	7	G	BF	BF-100	4.2	45	722	849	215	BF	100	7.1	801	237	Working example
8	8	H	BF	BF-100	4.0	38	412	460	452	BF	100	7.0	650	169	Comparative example
9	9	I	F+BF+P	F-92	5.5	41	486	609	20	B	100	7.5	630	88	Comparative example
10	10	J	BF+F	BF-97	5.9	49	563	634	282	BF	100	5.4	651	16	Comparative example
11	11	K	BF+F	BF-85	8.3	54	529	608	360	BF	100	5.1	580	255	Comparative example
12	12	L	B+M	B-90	3.7	71	576	677	10	B	100	6.0	640	25	Comparative example
13	13	M	BF	BF-100	7.2	-	492	562	386	BF	100	6.1	627	221	Comparative example
14	14	N	BF	BF-100	4.3	53	605	685	11	BF	100	6.4	675	173	Comparative example
15	15	O	BF+F	BF-95	5.5	32	612	699	8	BF	100	6.6	633	162	Comparative example
16	16	A	BF+B	BF-96	4.4	15	541	637	356	BF	100	6.9	644	190	Comparative example
17	17	A	BF+B	BF-86	11.5	68	585	678	20	BF	100	6.8	643	189	Comparative example
18	18	A	F+P	F-92	12.8	66	499	640	14	BF	100	5.7	667	217	Comparative example
19	19	A	M+B	M-55	2.7	38	524	760	17	BF	100	5.4	651	215	Comparative example
20	20	A	BF+F+P	BF-80	8.6	85	624	711	22	BF	100	6.3	646	231	Comparative example
21	21	A	BF+B	BF-89	4.4	18	533	605	410	BF	100	6.4	659	166	Comparative example
22	22	C	BF+B	BF-88	7.8	55	642	682	9	BF	100	5.7	640	190	Comparative example
23	23	C	M+B	M-60	3.3	53	559	780	19	BF	100	5.4	642	192	Comparative example
24	24	C	BF+F+P	BF-95	8.5	95	571	680	30	BF	100	5.7	639	225	Comparative example
25	25	E	BF	BF-100	3.5	13	489	555	415	BF	100	5.4	671	202	Comparative example
26	26	E	F+B	F-94	10.5	65	470	553	287	BF	100	6.3	675	145	Comparative example
27	27	E	BF+B	BF-94	3.8	18	522	639	311	BF	100	6.4	664	166	Comparative example
28	28	F	BF	BF-100	4.5	12	538	674	352	BF	100	6.7	653	178	Comparative example
29	29	F	F+P	F-93	11.2	73	460	541	366	BF	100	6.9	658	227	Comparative example
30	30	F	BF+P	BF-96	7.7	88	593	706	333	BF	100	7.2	668	210	Comparative example
31	31	G	BF	BF-100	10.2	70	660	880	16	B	100	7.1	810	194	Comparative example
32	32	G	B+M	B-70	4.5	68	734	895	22	B	100	7.6	812	197	Comparative example
33	33	A	BF+B	BF-95	11.1	65	580	675	19	BF	100	6.7	650	176	Comparative example

*) BF: bainitic ferrite, B: bainite, P: pearlite, M: martensite, F: ferrite

**) Amount of precipitated Nb. Amount of precipitated Nb having a particle size less than 20 nm (Ratio (%)) relative to the total amount of Nb on a Nb equivalent basis)

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[0080]

[Table 5]

Steel pipe No.	Hot-rolled plate No.	Steel No.	Post-weld heat treatment conditions		Strength after post-weld heat treatment		Difference in strength between before and after post-weld heat treatment	Precipitated Nb ratio*	Remarks
			Heating temperature (°C)	Holding time (h)	Yield strength YS (MPa)	Tensile strength TS (MPa)	Δ YS (MPa)	(%)	
1	1	A	620	2	622	666	40	95	Working example
2	2	B	620	2	670	695	46	90	Working example
3	3	C	670	1	622	643	48	88	Working example
4	4	D	670	1	650	684	40	89	Working example
5	5	E	650	2	634	662	38	85	Working example
6	6	F	650	2	640	660	60	92	Working example
7	7	G	650	4	766	839	44	92	Working example
8	8	H	620	2	435	455	23	91	Comparative example
9	9	I	620	2	530	579	44	95	Comparative example
10	10	J	650	1	606	627	43	96	Comparative example
11	11	K	675	2	570	603	41	96	Comparative example
12	12	L	620	2	618	662	42	94	Comparative example
13	13	M	650	2	493	521	1	-	Comparative example
14	14	N	675	2	627	681	22	94	Comparative example
15	15	O	620	2	633	690	21	90	Comparative example
16	16	A	620	2	511	588	-30	10	Comparative example
17	17	A	620	2	623	663	38	92	Comparative example
18	18	A	650	2	538	625	39	90	Comparative example
19	19	A	620	2	568	745	44	92	Comparative example
20	20	A	675	2	604	696	-20	50	Comparative example
21	21	A	650	2	575	653	42	56	Comparative example
22	22	C	620	2	672	685	30	90	Comparative example
23	23	C	675	2	593	765	34	90	Comparative example
24	24	C	620	2	554	622	-17	63	Comparative example
25	25	E	620	2	495	540	6	17	Comparative example
26	26	E	675	2	503	538	33	90	Comparative example
27	27	E	650	2	560	624	38	68	Comparative example
28	28	F	620	2	540	659	2	20	Comparative example
29	29	F	650	2	500	526	40	89	Comparative example
30	30	F	675	2	550	691	-43	60	Comparative example
31	31	G	620	2	694	865	34	92	Comparative example
32	32	G	650	2	769	880	35	90	Comparative example
33	17	A	650	2	615	658	35	90	Comparative example

*) Amount of precipitated Nb after post-weld heat treatment (Ratio (%) relative to the total amount of Nb on a Nb equivalent basis)

[0081]

All the working examples of the present invention are electric-resistance-welded steel pipes that are suitable for a deep-well conductor casing, have high strength of the API X80
5 grade, that is, a yield strength YS of 555 MPa or more and a tensile strength TS of 625 MPa or more, have good low-temperature toughness, suffer a smaller decrease in strength even after post-weld heat treatment, and have high resistance to post-weld heat treatment. The comparative examples outside
10 the scope of the present invention are insufficient in strength, low-temperature toughness, or resistance to post-weld heat treatment.

Reference Signs List

[0082]

- | | | |
|----|----|---|
| 15 | 1 | Hot-rolled steel plate (hot-rolled steel strip) |
| | 2 | Roll forming machine |
| | 3 | Welding machine |
| | 4 | Squeeze roll |
| | 5 | Electric-resistance-welded steel pipe |
| 20 | 6 | Bead cutter |
| | 7 | Leveler |
| | 8 | Sizer |
| | 9 | Inline heat treatment apparatus (induction heating apparatus) |
| 25 | 10 | Cooling apparatus |

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11 Thermometer

CLAIMS:

1. A high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing,

the steel pipe having a thickness of 15 mm or more, a yield strength of 555 MPa or more, and a tensile strength of 625 MPa or more, and having a composition containing, on a mass percent basis:

C: 0.01% to 0.12%, Si: 0.05% to 0.50%,

Mn: 1.0% to 2.2%, P: 0.03% or less,

S: 0.005% or less, Al: 0.001% to 0.10%,

N: 0.006% or less, Nb: 0.010% to 0.100%, and

Ti: 0.001% to 0.050%,

the remainder being Fe and incidental impurities,

the steel pipe having a structure composed of 90% or more by volume of a bainitic ferrite phase as a main phase and 0% or more and 10% or less by volume of a second phase, the bainitic ferrite phase having an average grain size of 10 μm or less, the structure containing fine Nb precipitates having a particle size of less than 20 nm dispersed in a base material portion, a ratio (%) of the fine Nb precipitates to the total

amount of Nb being 45% or more and 75% or less by total mass of only Nb element in the precipitates, and

a circularity of an end portion of the steel pipe defined by the following formula (1) being 0.6% or less,

$$\text{Circularity (\%)} = \{(\text{maximum outer diameter mm}\phi \text{ of steel pipe}) - (\text{minimum outer diameter mm}\phi \text{ of steel pipe})\} / (\text{nominal outer diameter mm}\phi) \times 100 \quad (1).$$

2. The high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to Claim 1, wherein the composition further contains one or two or more selected from V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B: 0.0030% or less on a mass percent basis.

3. The high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to Claim 1 or 2, wherein the composition further contains one or two selected from Ca: 0.0050% or less and REM: 0.0050% or less on a mass percent basis.

4. A method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing, the steel pipe having a thickness of 15 mm or more, a yield strength of 555 MPa or more, and a tensile strength of 625 MPa or more, the method comprising: continuously rolling a

hot-rolled steel plate with a roll forming machine to form an open pipe having a U-shaped cross section; butting edges of the open pipe; electric-resistance-welding a portion where the edges being butted while pressing the butted edges to contact each other by squeeze rolls to form an electric-resistance-welded steel pipe; subjecting the electric-resistance-welded portion of the electric-resistance-welded steel pipe to in-line heat treatment; and reducing a diameter of the electric-resistance-welded steel pipe by rolling,

wherein the hot-rolled steel plate is manufactured by

heating to soak a steel at a heating temperature in the range of 1150°C to 1250°C for 60 minutes or more,

the steel having a composition containing, on a mass percent basis,

C: 0.01% to 0.12%, Si: 0.05% to 0.50%,

Mn: 1.0% to 2.2%, P: 0.03% or less,

S: 0.005% or less, Al: 0.001% to 0.10%,

N: 0.006% or less, Nb: 0.010% to 0.100%, and

Ti: 0.001% to 0.050%,

the remainder being Fe and incidental impurities,

hot-rolling the steel with a finishing delivery temperature of 750°C or more, the hot-rolling having a rolling reduction adjusted to be 20% or more in a non-recrystallization temperature range in which a temperature at a center of plate thickness is 950°C or less,

after completion of the hot rolling, subjecting the hot-rolled steel plate to accelerated cooling such that an average cooling rate in a temperature range of 750°C to 650°C at the center of plate thickness ranges from 16°C/s to 70°C/s, and

coiling the hot-rolled steel plate at a coiling temperature in the range of 580°C to 400°C.

5. The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to Claim 4, wherein the roll forming machine includes a cage roll group composed of a plurality of rolls and a fin pass forming roll group composed of a plurality of rolls.

6. The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to Claim 5, wherein two or more portions of an inner wall of the hot-rolled steel plate are pressed with an inner roll disposed downstream of the cage roll group during a forming process.

7. The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of Claims 4 to 6, wherein the in-line heat treatment of the electric-resistance-welded portion includes heating the electric-resistance-welded portion to a heating temperature in the range of 830°C to 1150°C and cooling the electric-resistance-welded portion to a cooling stop temperature 550°C or less at the center of plate thickness such that an average cooling rate in a temperature range of 800°C to 550°C at the center of plate thickness ranges from 10°C/s to 70°C/s.

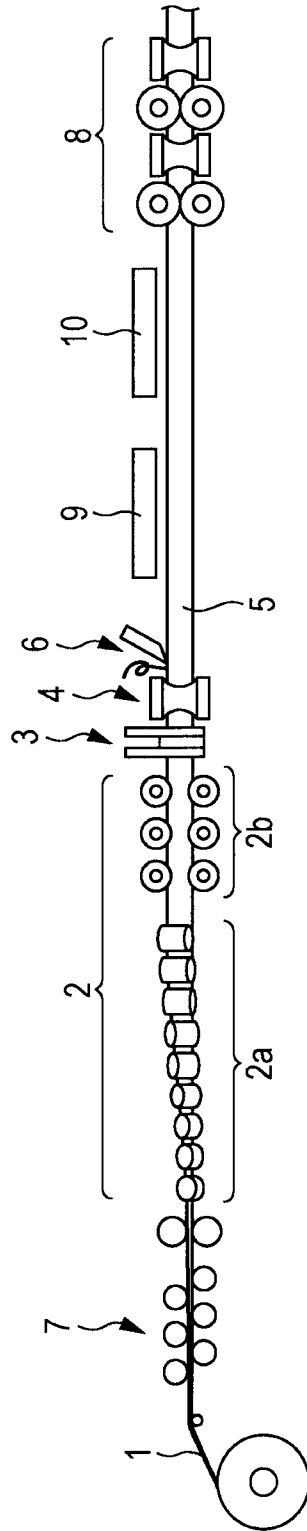
8. The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of Claims 4 to 7, wherein a reduction ratio in the outer diameter from the rolling is in the range of 0.2% to 3.3%.

9. The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of Claims 4 to 8, wherein the composition further contains one or two or more selected from V: 0.1% or less, Mo: 0.5% or less, Cr: 0.5% or less, Cu: 0.5% or less, Ni: 1.0% or less, and B: 0.0030% or less on a mass percent basis.

10. The method for manufacturing a high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of Claims 4 to 9, wherein the composition further contains one or two selected from Ca: 0.0050% or less and REM: 0.0050% or less on a mass percent basis.

11. A high-strength thick-walled conductor casing for deep wells, comprising a screw member disposed on each end of the high-strength thick-walled electric-resistance-welded steel pipe for a deep-well conductor casing according to any one of Claims 1 to 3.

FIG. 1



2/2

FIG. 2

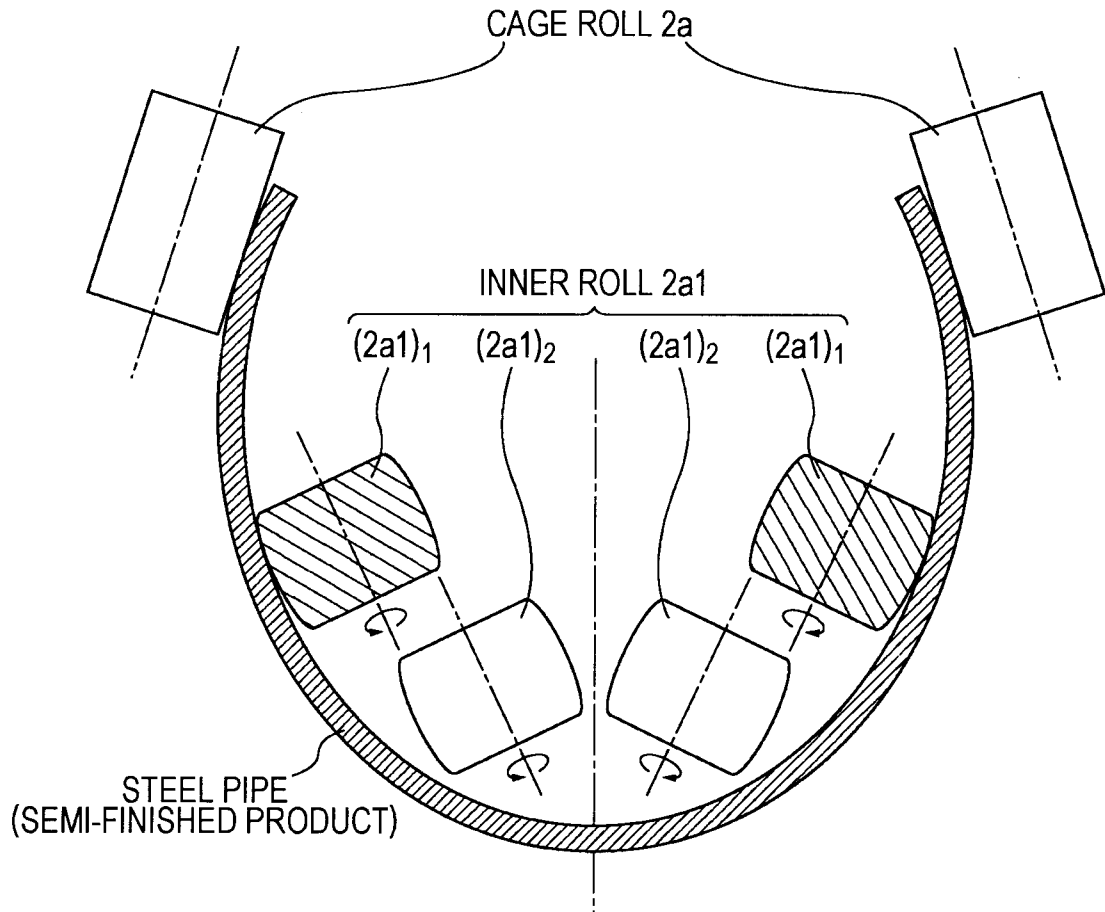


FIG. 3

