(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 206 338 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
05.07.2023 Bulletin 2023/27

(21) Application number: **20951521.2**

(22) Date of filing: **28.08.2020**

(51) International Patent Classification (IPC):
C21D 8/10 *(2006.01)* ***C21D 9/08*** *(2006.01)*
C21D 9/50 *(2006.01)* ***C22C 38/00*** *(2006.01)*
C22C 38/58 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
C22C 38/00; C22C 38/58; C21D 8/10; C21D 9/08; C21D 9/50

(86) International application number:
PCT/JP2020/032636

(87) International publication number:
WO 2022/044271 (03.03.2022 Gazette 2022/09)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **NIPPON STEEL CORPORATION**
Chiyoda-ku
Tokyo 100-8071 (JP)

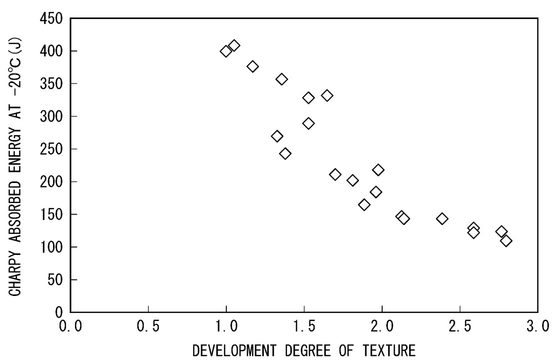
(72) Inventors:
- **NAGAI, Kensuke**
  Tokyo 100-8071 (JP)
- **YOKOI, Tatsuo**
  Tokyo 100-8071 (JP)
- **KAWANO, Hideto**
  Tokyo 100-8071 (JP)
- **KOBAYASHI, Shunichi**
  Tokyo 100-8071 (JP)
- **IWAMOTO, Shuji**
  Tokyo 100-8071 (JP)

(74) Representative: **Zimmermann & Partner Patentanwälte mbB**
Postfach 330 920
80069 München (DE)

(54) **ELECTRIC RESISTANCE WELDED STEEL PIPE**

(57) This electric resistance welded steel pipe includes a base material portion having a predetermined chemical composition and a weld, when a wall thickness of the base material portion is represented by tB and a wall thickness of the weld is represented by tS, a microstructure at a (1/4)tB position from an outer surface of the base material portion is composed of, by area%, 10% to 50% of bainite, 50% to 90% polygonal ferrite, and 1% or less of a remainder in microstructure, an average grain size is 20 μm or less, a microstructure at a (1/4)tS position from an outer surface of the weld is composed of, by area%, 70% to 90% of bainite, polygonal ferrite, and 1 % or less of a remainder in microstructure, an average grain size is 15 μm or less, a development degree of {001} on a butting surface of the weld is 1.5 or less, a hardness of the weld is 250 Hv or less, Charpy impact absorbed energies of the base material portion and the weld at -20°C are 150 J or more, a yield stress is 360 to 600 MPa, and a tensile strength is 465 to 760 MPa.

FIG. 1



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Description

[Technical Field of the Invention]

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

[Related Art]

[0002] In recent years, pipelines are becoming more and more important as a long-range transportation method for crude oil and natural gas. At present, trunk line pipes that are used in long-range transportation pipelines are designed according to the standards of the American Petroleum Institute (API).

[0003] Pipelines are laid in various environments, for example, in cold regions. Line pipes that are used in pipelines laid in cold regions are required to have not only strength but also excellent toughness. Conventionally, UOE steel pipes have generally been used for such applications. However, in recent years, the application of electric resistance welded steel pipes, which are less expensive than UOE steel pipes, is required for line pipes that are used in cold regions. Electric resistance welded steel pipes that are applied to such line pipes are required to have excellent toughness in the base material portion and the electric resistance welding portion (hereinafter, sometimes simply referred to as the weld).

[0004] For example, in Patent Documents 1 and 2, as a material for 5L-X56 or higher-grade high-strength electric resistance welding steel pipes in terms of API standard, high strength hot rolled steel sheets having excellent toughness in the base material portion and the weld and having a sheet thickness of 18 mm or more in consideration of improvement in the toughness of the circumferential welds of electric resistance welding steel pipes are disclosed.

[0005] However, in Patent Documents 1 and 2, the high-strength hot rolled steel sheets need to contain boron (B) as a chemical composition and have a problem in that the material properties of the steel pipe are likely to be uneven.

[0006] Patent Document 3 discloses a technique for improving the toughness of a base material portion and the electric resistance welding portion in an electric resistance welded steel pipe for a line pipe that does not contain B. However, in Patent Document 3, a tempering treatment performed after pipe making is premised, and there is a problem in that the number of manufacturing steps increases.

[Prior Art Document]

[Patent Document]

[0007]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2007-138289
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2007-138290
[Patent Document 3] Japanese Patent No. 6213703

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0008] The present invention has been made in view of the above-described problems. An object of the present invention is to provide an electric resistance welded steel pipe that does not contain B, does not require a tempering step after pipe making, has high strength, and has excellent toughness in a base material portion and a weld.

[Means for Solving the Problem]

[0009] The present invention has been made to solve the above-described problems and relates to the following electric resistance welded steel pipe.

(1) An electric resistance welded steel pipe according to an aspect of the present invention includes a base material portion and a weld, in which a chemical composition of the base material portion contains, by mass%, C: 0.040% to 0.120%, Si: 0.03% to 0.50%, Mn: 0.50% to 2.00%, P: 0.020% or less, S: 0.003% or less, Al: 0.060% or less, Ti: 0.005% to 0.030%, Nb: 0.005% to 0.050%, N: 0.0010% to 0.0080%, O: 0.005% or less, Cu: 0% to 0.500%, Ni: 0% to 0.500%, Cr: 0% to 0.500%, Mo: 0% to 0.500%, V: 0% to 0.100%, W: 0% to 0.500%, Ca: 0% to 0.0050%, REM: 0% to 0.0050%, and a remainder of Fe and an impurity, Ceq represented by the following formula (i) is 0.20 to 0.53, and Mn/Si is 2.0 to 16.0, when a wall thickness of the base material portion is represented by tB and a wall thickness

of the weld is represented by tS, a microstructure at a (1/4)tB position from an outer surface of the base material portion is composed of, by area%, 10% to 50% of bainite, 50% to 90% polygonal ferrite, and 1% or less of a remainder in microstructure, an average grain size at the (1/4)tB position from the outer surface of the base material portion is 20 μm or less, a microstructure at a (1/4)tS position from an outer surface of the weld is composed of, by area%, 70% to 90% of bainite, polygonal ferrite, and 1% or less of a remainder in microstructure, an average grain size at the (1/4)tS position from the outer surface of the weld is 15 μm or less, a development degree of {001} on a butting surface of the weld is 1.5 or less, a hardness of the weld is 250 Hv or less, a Charpy impact absorbed energy of the base material portion and a Charpy impact absorbed energy of the weld at -20°C are each 150 J or more, a yield stress is 360 to 600 MPa, and a tensile strength is 465 to 760 MPa.

$$Ceq = C + Mn/6 + (Ni + Cu)/15 + (Cr + Mo + V)/5 \cdots (i)$$

Here, each element symbol in the formula represents a content by mass% of each element contained in steel and is regarded as zero in a case where the corresponding element is not contained.

(2) In the electric resistance welded steel pipe according to (1), the chemical composition may contain, by mass%, one or more selected from the group consisting of Cu: 0.010% to 0.500%, Ni: 0.010% to 0.500%, Cr: 0.010% to 0.500%, Mo: 0.010% to 0.500%, V: 0.001% to 0.100%, W: 0.100% to 0.500%, Ca: 0.0010% to 0.0050%, and REM: 0.0010% to 0.0050%.

(3) In the electric resistance welded steel pipe according to (1) or (2), a pipe diameter may be 300 to 670 mm and a wall thickness may be 10.0 to 25.4 mm.

[Effects of the Invention]

[0010] According to the above-described aspect of the present invention, it becomes possible to obtain an electric resistance welded steel pipe that does not contain B, does not require a tempering step after pipe making, has high strength, and has excellent toughness in a base material portion and a weld.

[Brief Description of the Drawings]

[0011] FIG. 1 is a view showing a relationship between a development degree of a texture and a Charpy absorbed energy at -20°C of a weld.

[Embodiments of the Invention]

[0012] The present inventors have studied a method for obtaining an electric resistance welded steel pipe having high strength and having excellent toughness in both a base material portion and a weld and obtained the following findings.

(i) In the base material, it is important to control the microstructure not only by adjusting the chemical composition of the steel pipe but also by the hot rolling conditions.

(ii) In the electric resistance welded steel pipe, normally, compressive stress is applied in the circumferential direction in an austenite region during welding. When such compressive stress is applied in the circumferential direction, {001} planes accumulate on a butting surface (abutment surface) of the weld, and the toughness deteriorates. Therefore, in the weld, it is important to control the microstructure by adjusting the chemical composition of the steel pipe and the heat treatment conditions and also to control the texture by adjusting the welding conditions.

(iii) In order to control the microstructure of the weld, the heat treatment conditions are controlled such that the weld is reheated after welding and water-cooled from the outer surface side. Here, when the weld is reheated and then water-cooled from the outer surface, the outer surface side is rapidly cooled, and the hardness of the outer surface side increases. When the hardness of the outer surface side becomes too high, since the toughness deteriorates, it is important to suppress the hardness of the weld, particularly, the outer surface side.

[0013] That is, for the weld, it is required to moderate the development of the texture and suppress the increase in hardness by strictly controlling both the welding conditions and the subsequent heat treatment conditions.

[0014] Hereinafter, an electric resistance welded steel pipe according to an embodiment of the present invention (the electric resistance welded steel pipe according to the present embodiment) made based on the above-described findings will be described.

[0015] The electric resistance welded steel pipe according to the present embodiment has a base material portion and a weld, the base material portion has a predetermined chemical composition, when the wall thickness of the base material portion is represented by tB, the microstructure at a (1/4)tB position from the outer surface of the base material portion is composed of, by area%, 10% to 50% of bainite, 50% to 90% polygonal ferrite, and 1% or less of a remainder in microstructure, the average grain size at the (1/4)tB position is 20 μm or less, when the wall thickness of the weld is represented by tS, the microstructure at a (1/4)tS position from the outer surface of the weld is composed of, by area%, 70% to 90% of bainite, polygonal ferrite, and 1% or less of a remainder in microstructure, the average grain size at the (1/4)tS position from the outer surface of the weld is 15 μm or less, the development degree of { 001} on the butting surface of the weld is 1.5 or less, and the hardness of the weld is 250 Hv or less. In addition, in the electric resistance welded steel pipe according to the present embodiment, the Charpy impact absorbed energy of the base material portion and the Charpy impact absorbed energy of the weld at -20°C are each 150 J or more, the yield stress is 360 to 600 MPa, and the tensile strength is 465 to 760 MPa.

[0016] Hereinafter, each requirement of the electric resistance welded steel pipe according to the present embodiment will be described in detail.

1. Chemical composition of base material portion

[0017] The reasons for limiting each element are as described below. In the following description, "%" regarding contents refers to "mass%" unless otherwise described.

[0018] The electric resistance welded steel pipe according to the present embodiment has a steel sheet that serves as the base material portion and a weld (electric resistance welding portion) that is provided in a butting portion of the steel sheet and extends in the longitudinal direction of the steel sheet. In the electric resistance welded steel pipe according to the present embodiment, since no welding material is used at the time of performing electric resistance welding on the steel sheet to form the electric resistance welded steel pipe, the chemical composition becomes substantially the same in the base material portion and in the weld except for C. Regarding C, there are cases where the C content in the weld and the C content in the base material portion differ due to decarburization during electric resistance welding.

C: 0.040% to 0.120%

[0019] C is an effective element for increasing the strength of steel. In order to obtain the above-described effect, the C content is set to 0.040% or more. The C content is preferably 0.060% or more.

[0020] On the other hand, when the C content is too large, the hardness of the weld increases, and the toughness deteriorates. In the electric resistance welded steel pipe according to the present embodiment, in order to reduce the hardness of the weld, the C content is set to 0.120% or less. The C content is preferably 0.100% or less.

Si: 0.03% to 0.50%

[0021] In order to satisfy the parameter of Mn/Si, the Si content is set to 0.03% or more. The Si content is preferably 0.05% or more.

[0022] On the other hand, when the Si content exceeds 0.50%, a Si oxide is formed in the weld, and the toughness deteriorates. Therefore, the Si content is set to 0.50% or less. The Si content is preferably 0.45% or less.

Mn: 0.50% to 2.00%

[0023] Mn is an effective element for ensuring the strength and toughness of the base material portion. In order to obtain the above-described effect, the Mn content is set to 0.50% or more. The Mn content is preferably 0.70% or more.

[0024] On the other hand, when the Mn content exceeds 2.00%, a hardened phase is formed in the center segregation portion, and the toughness of the base material portion significantly deteriorates. Therefore, the Mn content is set to 2.00% or less. The Mn content is preferably 1.60% or less.

P: 0.020% or less

[0025] P is an element that is contained as an impurity and affects the toughness of steel. When the P content exceeds 0.020%, intergranular embrittlement is caused in the base material portion and the weld, and the toughness significantly deteriorates. Therefore, the P content is set to 0.020% or less. The P content is preferably as small as possible and may be 0%. However, the substantial lower limit in mass-produced steel is 0.002%.

S: 0.003% or less

[0026] S is an element that is contained as an impurity. When the S content exceeds 0.003%, a coarse sulfide is formed, and the toughness deteriorates. Therefore, the S content is set to 0.003% or less. The S content is preferably as small as possible and may be 0%. However, the substantial lower limit in mass-produced steel is 0.0003%.

Al: 0.060% or less

[0027] Al is an effective element as a deoxidizing material. However, when the Al content exceeds 0.060%, a large amount of anAl oxide is formed, and the toughness in the base material portion and the weld deteriorates. Therefore, the Al content is set to 0.060% or less. The Al content is preferably 0.050% or less. The Al content may be 0%, but the Al content is preferably 0.010% or more in order to obtain the deoxidizing effect.

Ti: 0.005% to 0.030%

[0028] Ti is a nitride-forming element and is an element that contributes to the refinement of crystal grains through forming a nitride. In order to obtain this effect, the Ti content is set to 0.005% or more. The Ti content is preferably set to 0.010% or more.

[0029] On the other hand, when the Ti content exceeds 0.030%, the toughness significantly deteriorates due to the formation of a coarse carbide. Therefore, the Ti content is set to 0.030% or less. The Ti content is preferably set to 0.025% or less.

Nb: 0.005% to 0.050%

[0030] Nb is an element that forms a carbide, a nitride, and/or a carbonitride and contributes to increase in the strength of steel. In addition, Nb is an element having an effect of improving the toughness of the base material portion of the steel pipe by expanding the non-recrystallization rolling temperature range. In order to obtain this effect, the Nb content is set to 0.005% or more. The Nb content is preferably set to 0.010% or more.

[0031] On the other hand, when the Nb content exceeds 0.050%, a large amount of a Nb-based carbonitride is formed, and the toughness of the base material and the weld deteriorates. Therefore, the Nb content is set to 0.050% or less. The Nb content is preferably set to 0.040% or less.

N: 0.0010% to 0.0080%

[0032] N is an element that forms a nitride, refines the crystal grain of steel, and improves toughness. In order to obtain these effects, the N content is set to 0.0010% or more.

[0033] On the other hand, when the N content exceeds 0.0080%, a large amount of a nitride is formed, which degrades the toughness of the base material portion and the weld. Therefore, the N content is set to 0.0080% or less.

O: 0.005% or less

[0034] O is an element that is contained as an impurity and affects the toughness of steel. When the O content exceeds 0.005%, a large amount of an oxide is formed, and the toughness of the base material portion and the weld significantly deteriorates. Therefore, the O content is set to 0.005% or less. The O content is preferably as small as possible and may be 0%. However, the substantial lower limit in mass-produced steel is 0.001%.

[0035] The basic chemical composition of the electric resistance welded steel pipe according to the present embodiment is that the above-described elements are contained and the remainder is Fe and an impurity. However, in order to improve strength, toughness, or other characteristics, Cu, Ni, Cr, Mo, V, W, Ca, and REM may be further contained within ranges to be described below. However, these elements are not essentially contained, and thus the lower limits thereof are all 0%.

[0036] In addition, "impurity" refers to a component that is incorporated from a raw material such as an ore or a scrap or from a variety of causes in manufacturing steps during the industrial manufacturing of steel and is allowed to be contained to an extent that the characteristics of the electric resistance welded steel pipe according to the present embodiment are not adversely affected.

Cu: 0% to 0.500%

[0037] Cu is an effective element for increasing strength without degrading toughness. Therefore, Cu may be contained as necessary. In the case of obtaining the above-described effect, the Cu content is preferably set to 0.010% or more.

[0038] On the other hand, when the Cu content exceeds 0.500%, cracking is likely to occur during the heating and the welding of steel pieces. Therefore, even in a case where Cu is contained, the Cu content is set to 0.500% or less.

Ni: 0% to 0.500%

[0039] Ni is an effective element for improving toughness and strength. Therefore, Ni may be contained as necessary. In the case of obtaining the above-described effect, the Ni content is preferably set to 0.010% or more.

[0040] On the other hand, when the Ni content exceeds 0.500%, weldability deteriorates. Therefore, even in a case where Ni is contained, the Ni content is set to 0.500% or less.

Cr: 0% to 0.500%

[0041] Cr is an element that improves the strength of steel through precipitation hardening. Therefore, Cr may be contained as necessary. In the case of obtaining this effect, the Cr content is preferably set to 0.010% or more.

[0042] On the other hand, when the Cr content exceeds 0.500%, hardenability improves, which makes the proportion of bainite in the structure increase excessively and degrades toughness. Therefore, even in a case where Cr is contained, the Cr content is set to 0.500% or less.

Mo: 0% to 0.500%

[0043] Mo is an element that improves hardenability, at the same time, forms a carbonitride, and contributes to increase in the strength of steel. Therefore, Mo may be contained as necessary. In the case of obtaining the above-described effect, the Mo content is preferably set to 0.010% or more.

[0044] On the other hand, when the Mo content exceeds 0.500%, the strength of steel becomes higher than necessary, and the toughness deteriorates. Therefore, even in a case where Mo is contained, the Mo content is set to 0.500% or less.

V: 0% to 0.100%

[0045] V is an element that forms a carbide and/or a nitride and contributes to increase in the strength of steel. Therefore, V may be contained as necessary. In the case of obtaining the above-described effect, the V content is preferably set to 0.001% or more.

[0046] On the other hand, when the V content exceeds 0.100%, a number of precipitates are formed, and toughness deteriorates. Therefore, even in a case where V is contained, the V content is set to 0.100% or less.

W: 0% to 0.500%

[0047] W is an element that forms a carbide and contributes to increase in the strength of steel. Therefore, W may be contained as necessary. In the case of obtaining the above-described effect, the W content is preferably set to 0.100% or more.

[0048] On the other hand, when the W content exceeds 0.500%, a number of carbides are formed, and toughness deteriorates. Therefore, even in a case where W is contained, the W content is set to 0.500% or less.

Ca: 0% to 0.0050%

[0049] Ca is an element that suppresses the formation of elongated MnS by forming a sulfide and contributes to improvement in toughness or lamella tear resistance. Therefore, Ca may be contained as necessary. In the case of obtaining the above-described effect, the Ca content is preferably set to 0.0010% or more.

[0050] On the other hand, when the Ca content exceeds 0.0050%, a large amount of CaO is formed in the weld, and the toughness of the weld deteriorates. Therefore, even in a case where Ca is contained, the Ca content is set to 0.0050% or less.

REM: 0% to 0.0050%

[0051] Similar to Ca, REM is an element that suppresses the formation of elongated MnS by forming a sulfide and contributes to improvement in toughness or lamella tear resistance. Therefore, REM may be contained as necessary. In the case of obtaining the above-described effect, the REM content is preferably set to 0.0010% or more.

[0052] On the other hand, when the REM content exceeds 0.0050%, the number of REM oxides increases, and toughness deteriorates. Therefore, even in a case where REM is contained, the REM content is set to 0.0050% or less.

[0053] Here, REM refers to a total of 15 lanthanoid elements, and the REM content refers to the total content of these elements.

[0054] As described above, the electric resistance welded steel pipe according to the present embodiment has a chemical composition in which the essential elements are contained, optional elements contained as necessary, and the remainder is Fe and an impurity in the base material portion and the weld.

[0055] In the electric resistance welded steel pipe according to the present embodiment, once the content of each element is controlled as described above, furthermore, there is a need to set Ceq and Mn/Si that are determined by the content of each element within predetermined ranges as described below.

Ceq: 0.20 to 0.53

[0056] Ceq is a value that serves as an index of hardenability and is represented by the following formula (i). When Ceq is less than 0.20, a required strength cannot be obtained. On the other hand, when Ceq exceeds 0.53, the strength becomes excessively high, and the toughness deteriorates. Therefore, Ceq is set to 0.20 to 0.53.

$$Ceq = C + Mn/6 + (Ni + Cu)/15 + (Cr + Mo + V)/5 \cdots (i)$$

[0057] Here, each element symbol in the formulae represents the content (mass%) of each element contained in steel and is regarded as zero in a case where the corresponding element is not contained.

$2.0 \leq Mn/Si \leq 16.0$

[0058] When Mn/Si is less than 2.0 or more than 16.0, the toughness of the weld (electric resistance welding portion) deteriorates. The reason therefor is considered that the melting point of a MnSi-based oxide that is formed during welding becomes high, the MnSi-based oxide is likely to remain in the weld and acts as a starting point of brittle fracture, which degrades the toughness.

[0059] Therefore, in the electric resistance welded steel pipe according to the present embodiment, Mn/Si (the ratio of mass% of Mn to mass% of Si) is set to 2.0 to 16.0.

2. Microstructure

[0060] As described above, in order to improve the strength and toughness of the steel pipe (electric resistance welded steel pipe), the control of the microstructure of the base material portion and the texture and microstructure of the weld becomes important. Each of the base material portion and the weld will be described in detail.

<Base material portion>

[Microstructure at 1/4 position of wall thickness from outer surface composed of, by area%, 10% to 50% of bainite, 50% to 90% of polygonal ferrite, and 1% or less of remainder in microstructure]

[0061] In order to ensure the strength and toughness of the steel pipe, the control of the microstructure of the base material portion becomes important. Specifically, the microstructure of the base material portion needs to contain, by area%, 10% to 50% of bainite and 50% to 90% of polygonal ferrite, and the structure other than bainite and polygonal ferrite (remainder in microstructure) needs to be 1% or less.

[0062] When the area ratio of bainite that is contained in the base material portion exceeds 50%, the strength becomes too high, and the toughness deteriorates. In addition, when the area ratio of bainite is less than 10%, a sufficient strength cannot be obtained. The concept of "bainite" in the electric resistance welded steel pipe according to the present embodiment includes granular bainite, upper bainite, and lower bainite.

[0063] The microstructure except bainite is mainly polygonal ferrite. Polygonal ferrite also includes quasi-polygonal ferrite. The total of bainite and polygonal ferrite is 99% or more and may be 100%. In addition, as the remainder in microstructure, one or more of pearlite, pseudo- pearlite, and residual austenite are contained in some cases. Even when these are present, the characteristics of the steel pipe are not affected as long as the total area ratio is 1% or less. The remainder in microstructure may be 0%.

[0064] In the electric resistance welded steel pipe according to the present embodiment, the microstructure at a 1/4 position of the wall thickness from the outer surface of the base material portion (a position of (1/4)tB in the thickness direction from the outer surface of the base material portion when the wall thickness of the base material portion is represented by tB) is the above-described range.

[0065] The reason for limiting the microstructure at the (1/4)tB position from the outer surface of the base material portion is that the structure at this position is a representative structure of the base material portion of the steel pipe. In the present embodiment, in the case of simply referring to, the surface of the electric resistance welded steel pipe refers to the outer surface, not the inner surface.

[0066] In the microstructure of the base material portion, the proportion (area%) of each structure can be measured by the following method.

[0067] A test piece for microstructure observation is collected from the base material such that a cross section parallel to the pipe axis direction and the thickness direction becomes an observed section. The collected test piece for microstructure observation is wet-polished to mirror-finish the observed section, and then the observed section is Nital-etched to expose the microstructure. Then, at the above-described portion of the base material portion, the structure is observed using an optical microscope at a magnification of 500 times, each structure is identified from a microstructure photograph, and the area ratio of each structure is measured. Each structure has the following characteristics, and each structure is identified based on these characteristics.

[0068] Polygonal ferrite that is formed by transformation accompanying atomic diffusion has no internal structure in the grains, and the grain boundaries are straight lines or arc-shaped. On the other hand, bainite has an internal structure, has grain boundaries with an acicular shape, and has a clearly different structure from polygonal ferrite. Therefore, polygonal ferrite and bainite are determined by the grain boundary shape and the presence or absence of an internal structure from a microstructure photograph obtained using an optical microscope after the etching with Nital. A microstructure in which no internal structure clearly appears and the grain boundary shape is acicular is referred to as quasi-polygonal ferrite, but counted as polygonal ferrite in the present embodiment. In addition, pearlite and pseudo-pearlite are etched black and thus can be clearly distinguished from polygonal ferrite.

[0069] In addition, the total area ratio of residual austenite and M-A constituent (martensite-austenite constituent) can be calculated by performing LePera etching on the same test piece for microstructure observation and performing image analysis on a structure photograph obtained with an optical microscope.

[0070] In addition, it is possible to obtain the area ratio of residual austenite based on the difference in crystal structure using EBSD. The area ratio of M-A constituent (martensite-austenite constituent) can be obtained by subtracting the area ratio of residual austenite from the total area ratio of residual austenite and M-A constituent (martensite-austenite constituent). In the measurement of residual austenite using EBSD, measurement is performed on a 300 × 300 μm (300 square micrometers) region with a measurement step size of 0.5 μm.

[Average grain size at 1/4 position of wall thickness from outer surface being 20 μm or less]

[0071] In the electric resistance welded steel pipe according to the present embodiment, in order to ensure favorable toughness of the base material portion, the average grain size at the (1/4)tB position from the outer surface of the base material portion needs to be set to 20 μm or less. When the average grain size exceeds 20 μm, sufficient toughness cannot be ensured. When the above-described structure is formed and then the average grain size is set to 20 μm or less, the Charpy impact absorbed energy at -20°C becomes 150 J or more.

[0072] The average grain size is measured by the following method.

[0073] Using the same test piece as the test piece on which the microstructure has been observed, the microstructure at the (1/4)tB position from the outer surface is observed using an SEM-EBSD device. The measurement is performed on a 500 μm × 500 μm region under a condition of a step size of 0.3 μm. From data obtained by the measurement, a region that is surrounded by high-angle grain boundaries with an inclination of 15° or more is defined as a crystal grain, the equivalent circle diameter of the crystal grain is defined as the crystal grain size, and the average grain size is calculated by the AREA FRACTION method. Here, regions with an equivalent circle diameter of 0.25 μm or less are excluded from the calculation of the average grain size.

<Weld>

[Microstructure at 1/4 position of wall thickness from outer surface being composed of, by area%, 70% to 90% of bainite, polygonal ferrite, and 1 % or less of remainder in microstructure]

[0074] The microstructure of the weld is controlled by reheating the weld and then cooling the weld with water from the outer surface side. In the weld, a precipitate that contributes to increase in strength is less likely to be formed. Therefore, in the electric resistance welded steel pipe according to the present embodiment, from the viewpoint of ensuring the strength of the weld, the microstructure at a 1/4 position of the wall thickness from the outer surface (a position of (1/4)tS in the thickness direction from the outer surface of the weld when the wall thickness of the weld is represented by tS) needs to be mainly bainite. Specifically, the area ratio of bainite needs to be 70% to 90%.

[0075] When the area ratio of bainite is less than 70%, the strength of the weld decreases. In addition, when the area ratio of bainite exceeds 90%, the hardness becomes too high, and the toughness of the weld deteriorates. In addition, when the area ratio of polygonal ferrite is excessive, it is difficult to obtain a required strength. Therefore, the area ratio of polygonal ferrite is set to 30% or less. The total area ratio of bainite and polygonal ferrite is 99% or more and may be 100%.
[0076] As structures other than bainite and polygonal ferrite (the remainder in microstructure), one or more of pearlite, pseudo- pearlite, and residual austenite are contained in some cases. Even when these are present, the characteristics of the steel pipe are not affected as long as the area ratio is 1 % or less. The remainder in microstructure may be 0%.
[0077] The area ratio of each structure in the microstructure of the weld is obtained as described below.
[0078] A test piece for microstructure observation is collected such that a cross section that includes the weld and is perpendicular to the pipe circumferential direction and parallel to the thickness direction becomes an observed section. The test piece for microstructure observation is wet-polished to mirror-finish the observed section, and the area ratio of each structure is measured in the same manner as for the base material portion using an optical microscope and EBSD at, as an observation position, a position 200 to 300 μm away in a direction perpendicular to the thickness direction from the butting surface. Since the butting surface is decarburized, etching makes it possible to specify the butting surface.

[Average grain size at 1/4 position of wall thickness from outer surface being 15 μm or less]

[0079] In order to ensure favorable toughness in the weld, the refinement of the microstructure is important together with the above-described control. In the electric resistance welded steel pipe according to the present embodiment, in order to ensure the toughness of the weld, the average grain size at the 1/4 position of the wall thickness from the outer surface ((1/4)tS position from the outer surface) of the weld is controlled to 15 μm or less. When the average grain size exceeds 15 μm, the toughness deteriorates.
[0080] The average grain size is obtained by the following method.
[0081] Using the same test piece as the test piece by which the microstructure has been observed, the microstructure at the (1/4)tS position from the outer surface is observed using an SEM-EBSD device. The measurement is performed on a 500 μm × 500 μm region under a condition of a step size of 0.3 μm. From data obtained by the measurement, a region that is surrounded by high-angle grain boundaries with an inclination of 15° or more is defined as a crystal grain, the equivalent circle diameter of the crystal grain is defined as the crystal grain size, and the average grain size is calculated by the AREA FRACTION method. Here, regions with an equivalent circle diameter of 0.25 μm or less are excluded from the calculation of the average grain size.

[Development degree of {001 } on butting surface of weld being 1.5 of less]

[0082] In order to ensure toughness in the weld, there is a need to control the texture in addition to the above-described control of the microstructure. Specifically, it is necessary to control the texture so that {001}, which is a cleavage plane of an iron and steel material, ({001} planes) does not accumulate on the butting surface during welding.
[0083] An electric resistance welded steel pipe is obtained by forming a steel sheet into a tubular shape and joining both end portions by contact bonding while heating the end surfaces of the steel sheet by high-frequency induction heating or electric resistance heating. At this time, compressive stress is applied in the circumferential direction. That is, high-temperature hot working is performed on heated portions. This high-temperature hot working develops the texture. This texture remains even when the weld is heated after welding.
[0084] According to the present inventors' studies, it has been clarified that such high-temperature hot working makes it easy for {001 } to accumulate on the butting surface of welding. Since this {001} is a cleavage plane of an iron and steel material, when {001} accumulates on the butting surface, the toughness deteriorates. The present inventors further progressed the studies and found that, as shown in FIG. 1, when the development degree of {001} (development degree of texture) exceeds 1.5, the Charpy absorbed energy at -20°C becomes less than 150 J.
[0085] Therefore, the development degree of {001} on the butting surface is set to 1.5 or less. While there is no need to limit the lower limit of the development degree, the development degree becomes 1.0 in structures where the crystal orientations are random, and thus the lower limit may be set to 1.0.
[0086] The texture is measured as described below.
[0087] First, a test piece is collected from the weld, a surface perpendicular to the pipe axis direction is polished and Nital-etched to expose the butting surface, and the test piece is cut and polished such that the butting surface becomes a measurement surface, thereby producing a test piece for texture measurement. Crystal orientations are measured using an SEM-EBSD device on this test piece. The measurement position is the wall thickness center ((1/2)tS) position of the cross section. In the present embodiment, a range where decarburization occurs is determined as the butting surface.
[0088] OIM Data Collection from TSL is used for the measurement. As the measurement conditions, the measurement

range is set to a 1 mm × 1 mm or more region, and the step size is set to 3.0 μm.

[0089] The development degree of {001} parallel to the measurement surface is calculated from the obtained data using OIM Data Analysis, which is analysis software. The calculated development degree becomes 1.0 in a case where the crystal orientations are random, and this value becomes larger as texture develops more.

3. Mechanical properties

[0090] In the weld, when the hardness is high, the toughness deteriorates. Therefore, the hardness of the weld is set to 250 HV10 or less. "HV10" refers to "hardness symbol" in a case where a Vickers hardness test is performed with a test force set to 98 N (10 kgf) (JIS Z 2244: 2009).

[0091] In the base material portion as well, there is a concern that, when the hardness is high, the toughness may deteriorate. Therefore, the average hardness of the base material portion is preferably 250 HV10 or less.

[0092] Regarding the measurement of the hardness of the weld, a test piece is collected from the weld such that the butting surface becomes a measurement surface, and measurement is performed at 5 points in a (1/4)tS portion from the outer surface of the measurement surface using a Vickers hardness meter with a load of 10 kgf. Out of 3 points excluding the maximum value and the minimum value from the 5 points, the highest value is regarded as the maximum hardness of the weld, and, if this maximum hardness is 250 Hv or less, the hardness of the weld is determined to be 250 Hv or less.

[0093] The average hardness of the base material portion is obtained as described below. A test piece is collected such that a surface (C cross section) including two axes of the wall thickness direction axis and the circumferential direction axis becomes a measurement surface, and measurement is performed at 5 points in a (1/4)tB portion from the outer surface of the measurement surface and at 5 points in a (3/4)tB portion from the outer surface using the Vickers hardness meter with a load of 10 kgf. A value obtained by averaging the obtained values is defined as the average hardness of the base material portion.

[0094] With an assumption that the electric resistance welded steel pipe according to the present embodiment is used as a line pipe, the yield stress that is measured from the base material portion is set to 360 to 600 MPa, and the tensile strength is set to 465 to 760 MPa.

[0095] In addition, the electric resistance welded steel pipe according to the present embodiment has a Charpy impact absorbed energy of 150 J or more at -20°C in both the base material portion and the weld. In this case, sufficient toughness can be ensured even when the electric resistance welded steel pipe is used in cold regions.

[0096] The above-described mechanical properties can be evaluated by a tensile test and a Charpy test. The tensile test and the Charpy test are performed according to API 5CT of the American Petroleum Institute. The test piece is collected such that the butting surface (abutment surface) is specified in a C cross section by etching and a notch is formed in the wall thickness direction in the butting surface.

4. Wall thickness

[0097] There is no particular limitation provided regarding the wall thickness of the base material portion of the electric resistance welded steel pipe according to the present embodiment. However, in a case where the electric resistance welded steel pipe is used as a line pipe, the wall thickness is preferably 10.0 mm or more in order to increase the internal pressure from the viewpoint of improving the transportation efficiency of fluids passing through the pipe. On the other hand, the upper limit of the wall thickness of the electric resistance welded steel pipe is generally 25.4 mm.

[0098] In addition, the pipe diameter is preferably 300 to 670 mm with an assumption of a line pipe.

5. Manufacturing method

[0099] The electric resistance welded steel pipe according to the present embodiment can obtain the effects as long as the electric resistance welded steel pipe has the above-described characteristics regardless of the manufacturing method. The electric resistance welded steel pipe according to the present embodiment can be manufactured by, for example, a manufacturing method including the following steps.

(I) A casting step of manufacturing a slab having a predetermined chemical composition
(II) A hot rolling step of heating and hot rolling the slab to produce a steel sheet
(III) A coiling step of cooling and coiling a hot rolled steel sheet after the hot rolling step
(IV) An electric resistance welding step of uncoiling the hot rolled steel sheet after the coiling step, then, roll-forming the hot rolled steel sheet into a tubular shape, and performing electric resistance welding to produce an electric resistance welded steel pipe
(V) A heat treatment step of performing a heat treatment on a weld of the electric resistance welded steel pipe

[0100] Hereinafter, preferable conditions for each step will be described.

<Casting step>

[0101] In the casting step, steel having the above-described chemical composition is melted in a furnace, and then a slab is produced by casting. The casting method is not particularly limited and may be a method such as normal continuous casting, casting by an ingot method, or, additionally, thin slab casting.

<Hot rolling step>

[0102] In the hot rolling step, the slab is heated up to a temperature range of Ac3 point or higher and hot-rolled. The heating temperature before the hot rolling is preferably 1000°C or higher. The heating temperature is more preferably 1100°C or higher. On the other hand, when the heating temperature exceeds 1250°C, there is a concern that coarsening of austenite grains may occur and a fine structure cannot be obtained. Therefore, the heating temperature is preferably set to 1250°C or lower.
[0103] In addition, during the hot rolling, it is preferable that the reduction ratio in the recrystallization region is set to 2.0 or more and the reduction ratio in the non-recrystallization region is set to 2.0 or more. In particular, when the reduction ratio in the non-recrystallization region is set to 2.0 or more, it becomes possible to set the average grain size of the base material portion to 20 μm or less. The boundary between the recrystallization region and the non-recrystallization region is approximately 900°C to 950°C although depending on the composition of the steel.
[0104] In addition, the hot rolling finishing temperature (finish rolling finishing temperature) is preferably set to 770°C or higher. When the hot rolling finishing temperature is lower than 770°C, the hot rolling becomes dual phase rolling, and the toughness of the base material portion deteriorates.
[0105] The finish rolling start temperature is preferably 900°C to 950°C in order to ensure toughness by rolling in the non-recrystallization region.

<Coiling step>

[0106] In the coiling step, the steel sheet after the hot rolling step is cooled to a temperature range of 500°C to 650°C in terms of the surface temperature such that the average cooling rate at the sheet thickness center portion falls into a range of 10 to 80 °C/sec and coiled in the temperature range. The average cooling rate at the sheet thickness center portion can be calculated by heat transfer calculation from the temperature history of the outer surface.
[0107] In order to control the microstructure of the base material portion of the electric resistance welded steel pipe according to the present embodiment to have a predetermined structure, particularly, the control of the cooling rate is important. In a case where the average cooling rate is slower than 10 °C/sec, ferritic transformation proceeds, and the bainite fraction becomes less than 10%. On the other hand, in a case where the average cooling rate exceeds 80 °C/sec, since the cooling rate is too fast, ferritic transformation does not occur, and the bainite fraction exceeds 50%.
[0108] In addition, when the cooling stop temperature exceeds 650°C, since ferritic transformation occurs after coiling, the bainite fraction (area%) becomes less than 10%. When the cooling stop temperature (coiling temperature) becomes lower than 500°C, the temperature unevenness during cooling becomes significant, the strength becomes uneven, and the stable production of the electric resistance welded steel pipe according to the present embodiment is not possible.

<Electric resistance welding step>

[0109] The obtained hot rolled steel sheet is roll-formed, and an electric resistance welded steel pipe is manufactured by electric resistance welding (electric resistance welding or high frequency welding).
[0110] In the electric resistance welding, the end portions of the steel sheet are melted by high-frequency induction heating or electric resistance heating, and both are butted together to be welded. At this time, when the molten portions are exposed to the atmosphere, an oxide or the like is formed, and, if the oxide or the like remains as it is, the toughness of the weld is degraded. In order to remove the oxide, compressive stress is applied (upset) in the circumferential direction to the weld with a squeeze roll, thereby discharging and removing the oxide. The upset amount can be organized with the absolute value of a change in the circumferential length before and after the welding.
[0111] However, in the electric resistance welded steel pipe manufacturing method according to the present embodiment, it is important to set the upset amount to 22.0 mm or less (including 0) in order to control the texture.
[0112] Conventionally, it was considered that, when the upset amount is decreased, the oxide remains, and the toughness of the weld deteriorates. Therefore, normally, the upset is increased as much as possible in order to completely discharge the oxide. In addition, there has been little study about a decrease in the upset amount in consideration of condition fluctuation during pipe making.

[0113] In contrast, the present inventors found that a decrease in the upset amount makes it possible to control the texture and consequently makes it possible to improve the toughness of the weld. Furthermore, it was found that, in steel pipes having a low S content, when the fluctuation in the upset is minimized by performing measures, such as the tightening of the sheet width and the appropriate adjustment of forming conditions in accordance with facilities for preventing fluctuation of the welding point in a complex manner, the oxide can be stably discharged even when the upset amount is decreased.

<Heat treatment step>

[0114] In the heat treatment step, the weld formed in the electric resistance welding step is heated and then water-cooled from the outer surface side. The weld can be heated by, for example, high-frequency heating.

[0115] Specifically, the weld is heated up to a temperature range of 900°C to 1050°C and cooled to a temperature range of 500°C to 680°C by water cooling. This heat treatment (heating and cooling) makes it possible to control the microstructure (the fraction of each structure and the average grain size) and hardness (maximum hardness) of the weld within the above-described ranges. However, in this heat treatment step, the development degree of {001} on the butting surface does not change.

[0116] When the heating temperature is lower than 900°C, a region where austenite transformation does not occur during the heat treatment remains, whereby the microstructure coarsens, and the toughness deteriorates. In addition, when the heating temperature exceeds 1050°C, coarse austenite is formed during the heat treatment, whereby the microstructure after the cooling coarsens, and the toughness deteriorates.

[0117] In addition, when the cooling stop temperature is lower than 500°C, the bainite fraction becomes excessive, the maximum hardness of the weld is surpassed, and the toughness deteriorates. When the cooling stop temperature exceeds 680°C, coarse pearlite is formed, and the toughness deteriorates.

[0118] When water cooling is performed, in a case where the steel pipe has a wall thickness of approximately 10.0 mm to 25.4 mm, the average cooling rate on the outer surface side becomes 10 °C/sec to 100 °C/sec.

[0119] After the water cooling is stopped, the weld may be cooled to room temperature by air cooling (air cooling).

[Examples]

[0120] Hereinafter, the present invention will be described more specifically with examples, but the present invention is not limited to these examples.

[0121] Kinds of steel A to AA and a to t each having a chemical composition shown in Table 1-1 and Table 1-2 (the remainder being Fe and an impurity) were melted. These kinds of steel A to AA and a to t were hot-rolled (heated to be hot-rolled) under conditions shown in Table 2-1 and Table 2-2, cooled, and coiled to produce hot rolled steel sheets.

[0122] In addition, on these hot rolled steel sheets, roll forming and electric resistance welding with a predetermined upset amount as shown in Table 2-2 were performed, and the welds were heat-treated (heated and water-cooled) under predetermined conditions to manufacture electric resistance welded steel pipes.

[Table 1-1]

Kind of steel	C	Si	Mn	P	S	Al	Ti	Nb	N	O
A	0.083	0.42	1.38	0.013	0.003	0.049	0.024	0.025	0.0050	0.003
B	0.054	0.33	1.52	0.020	0.003	0.006	0.010	0.006	0.0040	0.001
C	0.051	0.28	0.93	0.014	0.003	0.022	0.017	0.005	0.0060	0.001
D	0.092	0.34	1.59	0.011	0.003	0.010	0.005	0.020	0.0080	0.003
E	0.085	0.11	1.15	0.018	0.001	0.047	0.019	0.049	0.0020	0.001
F	0.088	0.41	1.31	0.007	0.003	0.048	0.028	0.023	0.0070	0.002
G	0.078	0.24	1.92	0.012	0.002	0.018	0.006	0.035	0.0030	0.004
H	0.098	0.48	0.97	0.009	0.002	0.040	0.016	0.009	0.0020	0.002
I	0.053	0.09	0.73	0.013	0.002	0.023	0.014	0.050	0.0060	0.004
J	0.102	0.15	1.47	0.009	0.001	0.002	0.016	0.014	0.0030	0.002
K	0.092	0.25	0.77	0.018	0.001	0.014	0.016	0.025	0.0030	0.003
L	0.076	0.48	1.85	0.010	0.001	0.009	0.030	0.045	0.0070	0.003

(continued)

Kind of steel	C	Si	Mn	P	S	Al	Ti	Nb	N	O
M	0.093	0.08	0.83	0.007	0.002	0.044	0.016	0.047	0.0070	0.003
N	0.096	0.28	1.41	0.011	0.001	0.037	0.016	0.005	0.0050	0.004
O	0.061	0.42	1.20	0.017	0.001	0.039	0.007	0.034	0.0040	0.004
P	0.076	0.45	0.94	0.001	0.001	0.009	0.023	0.021	0.0050	0.004
Q	0.115	0.08	0.57	0.002	0.001	0.018	0.018	0.037	0.0040	0.001
R	0.060	0.12	0.88	0.011	0.002	0.020	0.019	0.019	0.0020	0.002
S	0.077	0.46	0.92	0.016	0.002	0.007	0.030	0.044	0.0020	0.004
T	0.090	0.22	1.88	0.012	0.002	0.033	0.005	0.029	0.0020	0.005
a	0.035	0.22	1.80	0.009	0.002	0.005	0.029	0.031	0.0010	0.004
b	0.130	0.10	1.42	0.018	0.001	0.005	0.021	0.024	0.0010	0.005
d	0.076	0.60	1.90	0.018	0.002	0.002	0.020	0.029	0.0070	0.004
e	0.057	0.03	0.40	0.012	0.000	0.021	0.017	0.010	0.0040	0.005
f	0.084	0.36	2.10	0.016	0.002	0.003	0.022	0.038	0.0060	0.003
g	0.098	0.30	1.26	0.028	0.002	0.005	0.012	0.045	0.0070	0.004
h	0.110	0.33	0.70	0.002	0.004	0.009	0.030	0.023	0.0040	0.005
i	0.111	0.18	0.75	0.020	0.002	0.070	0.019	0.009	0.0060	0.002
j	0.108	0.17	1.23	0.000	0.003	0.045	0.003	0.026	0.0010	0.001
k	0.059	0.20	0.85	0.014	0.003	0.033	0.040	0.045	0.0060	0.005
l	0.065	0.15	1.21	0.016	0.001	0.014	0.024	0.003	0.0020	0.003
m	0.055	0.33	0.92	0.009	0.001	0.039	0.014	0.060	0.0060	0.004
n	0.104	0.30	1.01	0.003	0.003	0.025	0.023	0.006	0.0008	0.003
o	0.063	0.25	1.15	0.019	0.001	0.004	0.027	0.034	0.0090	0.003
p	0.092	0.14	0.86	0.008	0.000	0.033	0.006	0.046	0.0050	0.008
q	0.102	0.44	0.66	0.014	0.000	0.035	0.010	0.043	0.0050	0.001
r	0.040	0.02	0.50	0.003	0.002	0.029	0.022	0.015	0.0050	0.002
s	0.055	0.10	0.54	0.001	0.001	0.039	0.025	0.023	0.0030	0.002
t	0.118	0.17	1.90	0.014	0.002	0.045	0.030	0.016	0.0060	0.003
D	0.092	0.34	1.59	0.011	0.003	0.010	0.005	0.020	0.0080	0.003
D	0.092	0.34	1.59	0.011	0.003	0.010	0.005	0.020	0.0080	0.003
U	0.065	0.29	0.97	0.012	0.003	0.019	0.007	0.018	0.0070	0.005
V	0.052	0.27	1.20	0.018	0.001	0.041	0.005	0.026	0.0080	0.004
W	0.079	0.30	1.31	0.018	0.002	0.015	0.020	0.016	0.0060	0.002
X	0.111	0.46	1.52	0.004	0.002	0.045	0.025	0.029	0.0050	0.003
Y	0.058	0.21	0.89	0.020	0.003	0.007	0.010	0.012	0.0030	0.003
Z	0.100	0.22	0.73	0.009	0.000	0.009	0.025	0.011	0.0010	0.003
AA	0.102	0.34	0.87	0.017	0.001	0.015	0.007	0.006	0.0010	0.004

[Table 1-2]

Kind of steel	Cu	Ni	Cr	Mo	V	W	Ca	REM	Mn/Si	Ceq
A									3.3	0.31
B									4.7	0.31
C									3.4	0.21
D									4.7	0.36
E									10.8	0.28
F	0.098								3.2	0.31
G		0.017							8.0	0.40
H			0.427						2.0	0.34
I				0.291					8.6	0.23
J					0.091				9.8	0.36
K									3.1	0.22
L						0.246			3.9	0.38
M							0.0030		11.0	0.23
N								0.0010	5.0	0.33
O									2.9	0.26
P									2.1	0.23
Q									7.0	0.21
R					0.002				7.2	0.21
S		0.282							2.0	0.25
T		0.461			0.047				8.6	0.44
a									8.3	0.34
b									14.2	0.37
d									3.2	0.39
e	0.300	0.300	0.300		0.029				13.3	0.23
f		0.226							5.8	0.45
g				0.039					4.2	0.31
h									2.1	0.23
i									4.1	0.24
j									7.2	0.31
k									4.3	0.20
1							0.0050		8.0	0.27
m							0.0030		2.8	0.21
n							0.0050		3.4	0.27
o									4.6	0.25
p									6.3	0.24
q									<u>1.5</u>	0.21
r	0.300	0.300		0.250					<u>25.0</u>	0.21

(continued)

Kind of steel	Cu	Ni	Cr	Mo	V	W	Ca	REM	Mn/Si	Ceq
s									5.4	0.14
t	0.133	0.204	0.219	0.214					11.1	0.54
D									4.7	0.36
D									4.7	0.36
U									3.4	0.23
V									4.5	0.25
W									4.3	0.30
X									3.3	0.36
Y									4.2	0.21
Z									3.3	0.22
AA									2.5	0.25

[Table 2-1]

No.	Kind of steel	Hot rolling				
		Heating temperature (°C)	Reduction ratio in recrystallization region	i Reduction ratio in non-recrystallization region	Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)
1	A	1250	5.2	3.7	938	804
2	B	1180	7.9	2.1	928	819
3	C	1140	4.8	3.6	927	798
4	D	1190	6.4	2.0	923	793
5	E	1240	7.5	2.8	903	844
6	F	1120	8.0	2.1	925	806
7	G	1160	4.6	3.1	943	829
8	H	1230	4.7	2.7	922	825
9	I	1220	5.7	2.6	906	810
10	J	1160	6.7	3.0	926	797
11	K	1200	7.1	2.4	945	840
12	L	1230	4.6	2.3	904	794
13	M	1190	7.8	2.3	924	787
14	N	1150	6.1	2.1	924	802
15	O	1200	6.1	2.8	908	784
16	P	1110	6.9	2.8	941	844
17	Q	1100	4.6	2.3	941	848
18	R	1140	5.2	2.8	942	830
19	S	1130	4.9	4.4	919	825
20	T	1160	4.8	3.3	920	840

(continued)

No.	Kind of steel	Hot rolling				
		Heating temperature (°C)	Reduction ratio in recrystallization region	i Reduction ratio in non-recrystallization region	Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)
21 22	a b	1110 1240	6.6 4.7	2.9 3.7	904 930	790 798
24	d	1210	6.9	2.1	930	810
25	e	1250	4.9	2.9	932	792
26	f	1170	5.4	4.0	914	842
27	g	1180	4.7	2.8	918	804
28	h	1240	5.1	2.3	935	837
29	i	1100	5.5	2.9	907	812
30	i	1250	4.7	3.1	916	790
31	k	1100	8.0	2.7	928	789
32	l	1250	4.6	3.9	920	798
33	m	1160	6.5	2.0	918	843
34	n	1170	6.3	2.5	921	812
35	o	1250	6.7	3.2	933	803
36	p	1240	5.6	2.9	948	837
37	q	1210	6.8	3.2	930	789
38	r	1250	4.6	3.2	935	820
39	s	1210	5.7	2.8	932	832
40	t	1100	6.2	2.3	903	808
41	D	1190	6.4	2.0	923	793
42	D	1190	6.4	2.0	923	793
43	U	1130	6.2	1.5	902	812
44	V	1230	6.2	2.6	930	805
45	W	1150	6.2	4.9	909	808
46	X	1240	6.2	2.5	910	807
47	Y	1140	6.2	2.4	929	782
48	Z	1190	6.2	3.0	913	819
49	AA	1180	6.2	2.5	928	790

[Table 2-2]

No.	Coiling		Outer diameter (mm)	Sheet thickness (mm)	Welding and heat treatment conditions			
	Cooling rate (°C/s)	Coiling temperature (°C)			Upset (mm)	Heating temperature of weld (°C)	Cooling rate of weld °C/sec	Cooling stop temperature of weld (°C)
1	14	600	304	15.7	9.4	950	38	600

(continued)

No.	Coiling		Outer diameter (mm)	Sheet thickness (mm)	Welding and heat treatment conditions			
	Cooling rate (°C/s)	Coiling temperature (°C)			Upset (mm)	Heating temperature of weld (°C)	Cooling rate of weld °C/sec	Cooling stop temperature of weld (°C)
2	26	530	304	14.3	12.9	1050	30	540
3	79	650	609	19.1	13.4	940	15	570
4	16	510	457	20.3	20.3	980	19	680
5	39	530	457	20.6	12.4	1010	16	600
6	50	640	304	12.7	11.4	1040	32	610
7	42	590	304	14.3	12.9	980	28	510
8	14	550	406	14.3	8.6	960	29	640
9	63	610	457	19.1	21.0	980	17	520
10	49	540	304	12.7	10.2	950	17	670
11	10	530	304	14.3	7.2	1030	43	550
12	44	590	559	20.6	10.3	1040	20	600
13	28	560	304	12.7	6.4	930	24	580
14	58	600	304	14.3	14.3	1020	27	540
15	55	590	457	20.3	21.0	930	39	580
16	11	530	406	20.3	21.0	930	43	680
17	44	590	406	20.6	16.5	900	20	610
18	26	510	304	12.7	8.9	910	25	600
19	13	600	406	14.3	8.6	1030	40	580
20	47	570	406	19.1	19.1	910	19	620
21	53	600	304	12.7	15.2	1000	44	600
22	57	650	304	14.3	10.0	940	25	660
24	21	620	609	20.6	14.4	990	30	630
25	17	650	457	19.1	9.6	980	18	600
26	77	570	304	12.7	12.7	940	21	590
27	31	540	304	14.3	14.3	990	34	580
28	19	530	508	20.6	10.3	1050	17	600
29	63	640	304	12.7	12.7	1010	16	600
30	58	620	304	14.3	8.6	990	27	570
31	28	630	457	20.3	21.5	1000	32	600
32	62	600	304	14.3	11.4	990	27	510
33	20	640	406	14.3	12.9	1050	19	610
34	74	650	559	19.1	21.0	900	37	570
35	24	500	304	12.7	8.9	1050	35	620
36	32	550	609	20.6	18.5	1030	20	640
37	12	610	304	12.7	11.4	970	34	520

(continued)

No.	Coiling		Outer diameter (mm)	Sheet thickness (mm)	Welding and heat treatment conditions			
	Cooling rate (°C/s)	Coiling temperature (°C)			Upset (mm)	Heating temperature of weld (°C)	Cooling rate of weld °C/sec	Cooling stop temperature of weld (°C)
38	74	500	406	14.3	11.4	1050	17	510
39	63	560	559	19.1	21.0	1030	37	610
40	22	620	304	12.7	6.4	1010	37	650
41	16	510	457	20.3	23.0	980	19	680
42	16	510	457	20.3	25.0	980	19	680
43	30	630	508	19.1	21.0	930	45	540
44	100	650	304	12.7	15.2	940	43	570
45	5	590	304	14.3	15.7	1050	28	510
46	68	530	406	14.3	17.2	1100	35	610
47	33	650	304	14.3	7.2	850	27	630
48	75	650	457	19.1	9.6	970	38	700
49	73	620	304	12.7	11.4	940	37	300

[0123] For the obtained electric resistance welded steel pipes, the microstructures at the (1/4)tB positions from the outer surfaces of the base material portions, the average grain sizes at the (1/4)tB positions from the outer surfaces of the base material portions, the microstructures at the (1/4)tS positions from the outer surfaces of the welds, the average grain sizes at the (1/4)tS positions from the outer surfaces of the weld, the development degrees of {001} at the (1/2)tS positions from the outer surfaces of the butting surfaces of the welds, and the maximum hardness at the (1/4)tS positions of the welds were evaluated by the above-described methods.

[0124] In addition, tensile tests and Charpy tests were performed to evaluate the strengths (yield stress and tensile strength) and toughness (absorbed energies). The tensile tests and the Charpy tests were performed in the above-described manner in accordance with API 5CT of the American Petroleum Institute. The test temperature of the Charpy test was set to -20°C.

[0125] The results are shown in Table 3-1 and Table 3-2.

[Table 3-1]

No.	Base material portion					
	Polygonal ferrite fraction (area%)	Bainite fraction (area%)	Grain size (μm)	Yield stress (MPa)	Tensile strength (MPa)	Charpy absorbed energy at -20°C (J)
1	60	39	12	527	573	270
2	69	31	20	505	601	222
3	78	22	9	492	559	257
4	75	25	12	566	622	269
5	75	25	16	491	558	278
6	56	44	17	517	556	288
7	58	42	12	559	621	265
8	61	39	15	562	661	287
9	56	43	15	494	568	222

(continued)

No.	Base material portion					
	Polygonal ferrite fraction (area%)	Bainite fraction (area%)	Grain size (μm)	Yield stress (MPa)	Tensile strength (MPa)	Charpy absorbed energy at -20°C (J)
10	53	47	18	545	627	272
11	57	43	17	433	509	271
12	61	39	19	559	601	260
13	70	30	16	443	497	228
14	53	47	15	504	592	248
15	56	43	12	455	523	227
16	51	49	18	471	542	213
17	71	29	13	468	532	236
18	68	31	13	424	481	285
19	55	46	17	473	569	205
20	74	25	11	593	645	216
21	76	24	18	355	567	212
22	73	27	9	500	595	209
24	80	20	16	550	578	214
25	77	23	18	533	592	90
26	55	45	17	463	515	80
27	59	41	13	524	624	78
28	59	41	18	402	533	105
29	53	47	12	463	538	250
30	57	43	28	473	563	80
31	64	36	9	447	496	58
32	66	34	24	523	594	48
33	64	36	12	390	536	26
34	65	35	25	502	564	36
35	52	48	15	487	560	48
36	55	45	13	490	532	4
37	54	46	13	380	491	290
38	66	34	15	430	480	180
39	72	28	12	380	453	260
40	50	50	20	645	560	50
41	75	25	12	566	622	269
42	75	25	12	566	622	269
43	75	25	25	414	469	140
44	<u>20</u>	<u>80</u>	18	615	661	<u>100</u>
45	32	<u>8</u>	12	345	383	204

(continued)

No.	Base material portion					
	Polygonal ferrite fraction (area%)	Bainite fraction (area%)	Grain size (μm)	Yield stress (MPa)	Tensile strength (MPa)	Charpy absorbed energy at -20°C (J)
46	72	28	19	537	685	294
47	57	43	19	390	634	276
48	73	27	9	412	667	231
49	73	27	11	590	505	204

[Table 3-2]

No.	Weld: Bainite fraction (area%)	Weld: Main structures other than bainite (area%)	Weld: Grain size (μm)	Weld: Development degree of {001}	Weld: Maximum hardness (Hv10)	Weld: Charpy absorbed energy at -20°C (J)	Note
1	81	Polygonal ferrite	14	1.1	233	157	Invention Steel
2	89	Polygonal ferrite	10	1.4	237	234	
3	81	Polygonal ferrite	9	1.3	232	240	
4	72	Polygonal ferrite	8	1.4	203	275	
5	80	Polygonal ferrite	14	1.3	203	250	
6	74	Polygonal ferrite	13	1.4	226	215	
7	71	Polygonal ferrite	11	1.3	208	276	
8	90	Polygonal ferrite	11	1.4	229	174	
9	74	Polygonal ferrite	13	1.2	217	278	
10	89	Polygonal ferrite	14	1.2	223	224	
11	70	Polygonal ferrite	12	1.1	238	167	
12	83	Polygonal ferrite	13	1.2	237	292	
13	83	Polygonal ferrite	14	1.4	207	209	
14	85	Polygonal ferrite	11	1.1	237	288	
15	79	Polygonal ferrite	10	1.3	205	291	
16	77	Polygonal ferrite	11	1.2	203	174	
17	82	Polygonal ferrite	12	1.5	219	282	
18	81	Polygonal ferrite	15	1.2	241	203	
19	70	Polygonal ferrite	14	1.4	247	285	
20	89	Polygonal ferrite	10	1.2	201	276	
21	83	Polygonal ferrite	9	1.2	239	277	Comparative Steel
22	88	Polygonal ferrite	12	1.2	260	130	
24	75	Polygonal ferrite	14	1.2	207	120	
25	88	Polygonal ferrite	18	1.4	249	100	
26	86	Polygonal ferrite	20	1.1	216	140	
27	80	Polygonal ferrite	14	1.4	245	114	
28	82	Polygonal ferrite	14	1.2	250	80	
29	80	Polygonal ferrite	12	1.2	218	12	
30	73	Polygonal ferrite	9	1.4	231	213	
31	80	Polygonal ferrite	10	1.2	242	48	
32	78	Polygonal ferrite	10	1.1	211	295	
33	81	Polygonal ferrite	10	1.3	226	14	
34	70	Polygonal ferrite	15	1.4	215	220	
35	74	Polygonal ferrite	8	1.2	232	58	
36	82	Polygonal ferrite	9	1.3	239	52	
37	84	Polygonal ferrite	18	1.1	240	10	
38	74	Polygonal ferrite	8	1.4	226	15	
39	72	Polygonal ferrite	11	1.3	217	200	
40	83	Polygonal ferrite	16	1.5	221	20	
41	72	Polygonal ferrite	8	1.8	203	130	
42	72	Polygonal ferrite	8	2.1	203	120	
43	89	Polygonal ferrite	13	1.2	231	247	
44	77	Polygonal ferrite	14	1.2	241	209	
45	73	Polygonal ferrite	11	1.2	228	287	
46	77	Polygonal ferrite	25	1.2	248	85	
47	71	Polygonal ferrite	30	1.3	208	25	
48	25	Ferrite-pearlite	19	1.1	200	89	
49	95	Martensite	10	1.4	280	47	

[0126] As shown in Tables 1-1 to 3-2, in No. 1 to No. 20, the chemical compositions and microstructures of the base material portions were within the scope of the present invention, and the microstructures, textures, and maximum hardness of the welds were within the scope of the present invention. As a result, the strengths were high, and the toughness of the base material portion and the weld was excellent.

[0127] In Nos. 1 to 20, structures other than polygonal ferrite and bainite were 1% or less of the remainders in microstructure in the microstructures of the base material portions. In addition, in No. 10 and No. 17, the microstructures of the welds contained 1% or less of residual austenite as the remainder in microstructure in addition to bainite and polygonal ferrite. In addition, in No. 3, No. 11, and No. 18, in addition to bainite and polygonal ferrite, 1% or less of pearlite was contained as the remainder in microstructure.

[0128] On the other hand, No. 21 to No. 49, which were the comparative examples, did not satisfy the characteristics for reasons to be described below.

[0129] In No. 21, the C content was below the lower limit of the scope of the present invention. As a result, sufficient yield stress could not be obtained.

[0130] In No. 22, the C content exceeded the upper limit of the scope of the present invention, and the maximum hardness of the weld exceeded 250 Hv10. As a result, the toughness of the weld deteriorated.

[0131] In No. 24, the Si content exceeded the upper limit of the scope of the present invention. As a result, a large amount of a Si oxide was formed in the weld, and the toughness of the weld deteriorated.

[0132] In No. 25, the Mn content was below the lower limit of the scope of the present invention. As a result, embrittlement attributed to S occurred, and the toughness of the base material portion and the weld deteriorated.

[0133] In No. 26, the Mn content was above the upper limit of the scope of the present invention. As a result, embrittlement attributed to MnS occurred, and the base material portion and the toughness deteriorated.

[0134] In No. 27, the P content was above the upper limit of the scope of the present invention. As a result, intergranular embrittlement occurred, and the toughness of the base material portion and the weld deteriorated.

[0135] In No. 28, the S content was above the upper limit of the scope of the present invention. As a result, a coarse inclusion was formed, and the toughness of the base material portion and the weld deteriorated.

[0136] In No. 29, the Al content exceeded the upper limit of the scope of the present invention. As a result, a large amount of an Al oxide was formed in the weld, and the toughness of the weld deteriorated.

[0137] In No. 30, the Ti content was below the lower limit of the scope of the present invention, and the crystal grain size became large. As a result, the toughness of the base material deteriorated.

[0138] In No. 31, the Ti content exceeded the upper limit of the scope of the present invention. As a result, a large amount of a Ti-based carbide was formed, and the toughness of the base material and the weld deteriorated.

[0139] In No. 32, the Nb content was below the lower limit of the scope of the present invention, and the crystal grain size became large. As a result, the toughness of the base material portion deteriorated.

[0140] In No. 33, the Nb content exceeded the upper limit of the scope of the present invention. As a result, a large amount of a Nb-based carbonitride was formed, and the toughness of the base material and the weld deteriorated.

[0141] In No. 34, since the N content was below the lower limit of the scope of the present invention, a carbonitride was not formed, and the crystal grain size became coarse. As a result, the toughness of the base material portion deteriorated.

[0142] In No. 35, the N content exceeded the upper limit of the scope of the present invention. As a result, the formation of an alloy carbonitride increased, and the toughness of the base material portion and the weld deteriorated.

[0143] In No. 36, the O content exceeded the upper limit of the scope of the present invention. As a result, a large amount of an oxide was formed, and the toughness of the base material and the weld deteriorated.

[0144] In No. 37, the Mn/Si ratio was below the lower limit of the scope of the present invention. As a result, a MnSi-based oxide having a high melting point remained in the weld, and the toughness of the weld deteriorated.

[0145] In No. 38, the Mn/Si ratio exceeded the present invention. As a result, a MnSi-based oxide having a high melting point remained in the weld, and the toughness of the weld deteriorated.

[0146] In No. 39, Ceq was below the lower limit of the scope of the present invention. As a result, sufficient tensile strength could not be obtained.

[0147] In No. 40, Ceq was above the upper limit of the scope of the present invention. As a result, the yield stress became too high, and the toughness of the base material portion and the weld deteriorated.

[0148] In No. 41 and No. 42, since the upset amount during the electric resistance welding became large, the texture developed. As a result, the toughness of the weld deteriorated.

[0149] In No. 43, since the reduction ratio in the non-recrystallization region was below the lower limit, the average grain size of the base material portion became large. As a result, the toughness of the base material portion deteriorated.

[0150] In No. 44, the cooling rate after the hot rolling was fast, and the area ratio of bainite in the base material portion became excessive. As a result, the yield stress became too high, and the toughness of the base material portion deteriorated.

[0151] In No. 45, the cooling rate after the hot rolling was slow, and the area ratio of bainite in the base material portion became low. As a result, a sufficient strength could not be obtained.

[0152] In No. 46, the heating temperature of the weld was high, and the crystal grain size of the weld coarsened. As a result, the toughness of the weld deteriorated.

[0153] In No. 47, the heating temperature of the weld was low, and the microstructure of the weld coarsened. As a result, the toughness of the weld deteriorated.

[0154] In No. 48, the cooling stop temperature of the weld was high, and the microstructure became mainly ferrite and pearlite. As a result, the toughness of the weld deteriorated.

[0155] In No. 49, the cooling stop temperature of the weld was low, the area ratio of bainite in the weld became excessive, and the maximum hardness increased. As a result, the toughness of the weld deteriorated.

[Industrial Applicability]

[0156] According to the present invention, it becomes possible to obtain an electric resistance welded steel pipe having a high strength and excellent toughness in the base material portion and in the weld. Therefore, the present disclosure is highly industrially applicable.

Claims

1. An electric resistance welded steel pipe comprising:

   a base material portion; and
   a weld,
   wherein a chemical composition of the base material portion contains, by mass%,
   C: 0.040% to 0.120%,
   Si: 0.03% to 0.50%,
   Mn: 0.50% to 2.00%,
   P: 0.020% or less,
   S: 0.003% or less,
   Al: 0.060% or less,
   Ti: 0.005% to 0.030%,
   Nb: 0.005% to 0.050%,
   N: 0.0010% to 0.0080%,
   O: 0.005% or less,
   Cu: 0% to 0.500%,
   Ni: 0% to 0.500%,
   Cr: 0% to 0.500%,
   Mo: 0% to 0.500%,
   V: 0% to 0.100%,
   W: 0% to 0.500%,
   Ca: 0% to 0.0050%,
   REM: 0% to 0.0050%, and
   a remainder of Fe and an impurity,
   Ceq represented by the following formula (i) is 0.20 to 0.53, and Mn/Si is 2.0 to 16.0,
   when a wall thickness of the base material portion is represented by tB and a wall thickness of the weld is represented by tS,
   a microstructure at a (1/4)tB position from an outer surface of the base material portion is composed of, by area%, 10% to 50% of bainite, 50% to 90% polygonal ferrite, and 1% or less of a remainder in microstructure,
   an average grain size at the (1/4)tB position from the outer surface of the base material portion is 20 μm or less,
   a microstructure at a (1/4)tS position from an outer surface of the weld is composed of, by area%, 70% to 90% of bainite, polygonal ferrite, and 1% or less of a remainder in microstructure,
   an average grain size at the (1/4)tS position from the outer surface of the weld is 15 μm or less,
   a development degree of {001} on a butting surface of the weld is 1.5 or less,
   a hardness of the weld is 250 Hv or less,
   a Charpy impact absorbed energy of the base material portion and a Charpy impact absorbed energy of the weld at -20°C are each 150 J or more,
   a yield stress is 360 to 600 MPa, and
   a tensile strength is 465 to 760 MPa,

   $$Ceq = C + Mn/6 + (Ni + Cu)/15 + (Cr + Mo + V)/5 \cdots (i)$$

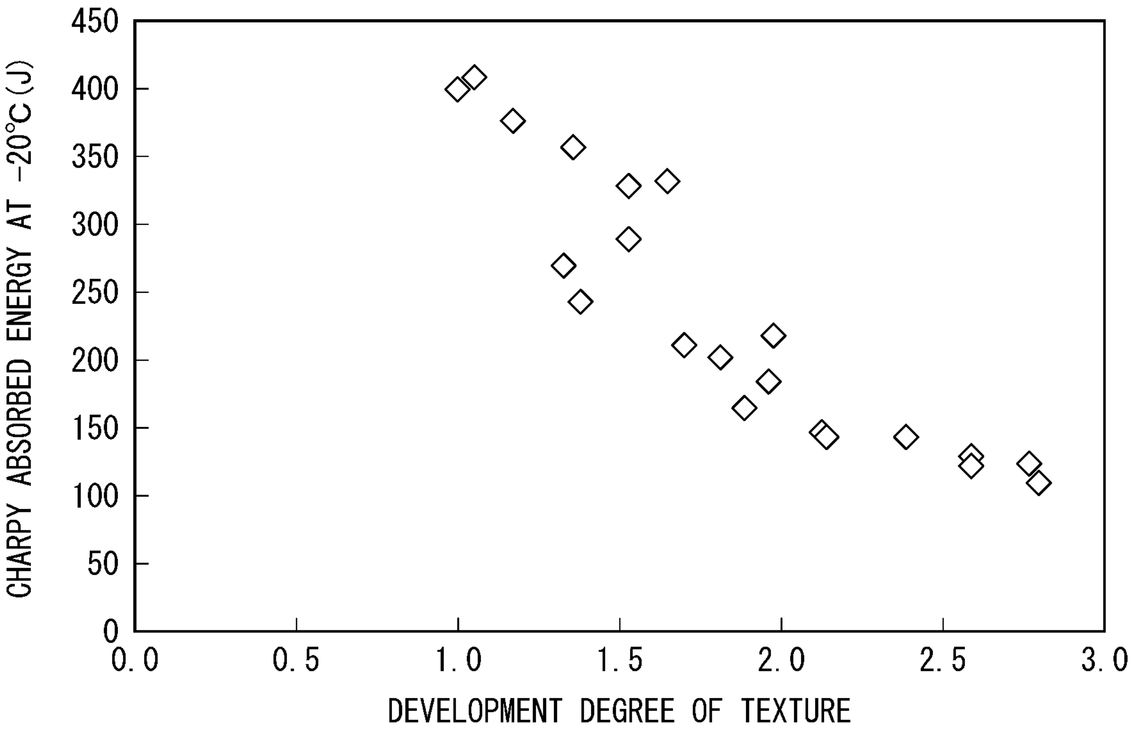
   here, each element symbol in the formula represents a content by mass% of each element contained in steel and is regarded as zero in a case where the corresponding element is not contained.

2. The electric resistance welded steel pipe according to claim 1,
   wherein the chemical composition contains, by mass%, one or more selected from the group consisting of

Cu: 0.010% to 0.500%,
Ni: 0.010% to 0.500%,
Cr: 0.010% to 0.500%,
Mo: 0.010% to 0.500%,
V: 0.001% to 0.100%,
W: 0.100% to 0.500%,
Ca: 0.0010% to 0.0050%, and
REM: 0.0010% to 0.0050%.

3. The electric resistance welded steel pipe according to claim 1 or 2,
wherein a pipe diameter is 300 to 670 mm, and a wall thickness is 10.0 to 25.4 mm.

FIG. 1


CHARPY ABSORBED ENERGY AT −20°C (J)
450
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
DEVELOPMENT DEGREE OF TEXTURE

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2020/032636

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C21D8/10(2006.01)n, C21D9/08(2006.01)n, C21D9/50(2006.01)n, C22C38/00(2006.01)i, C22C38/58(2006.01)i
FI: C22C38/00301Z, C22C38/58, C21D8/10B, C21D9/08F, C21D9/50101A
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. C21D8/10, C21D9/08, C21D9/50, C22C38/00-C22C38/60

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	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013/027779 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 28 February 2013 (2013-02-28), entire text, all drawings	1-3
A	JP 6693610 B1 (NIPPON STEEL CORP.) 13 May 2020 (2020-05-13), entire text	1-3
A	JP 2020-66747 A (NIPPON STEEL CORP.) 30 April 2020 (2020-04-30), entire text, all drawings	1-3
A	JP 6587041 B1 (NIPPON STEEL CORP.) 09 October 2019 (2019-10-09), entire text, all drawings	1-3
A	JP 2013-139051 A (JFE STEEL CORPORATION) 18 July 2013 (2013-07-18), entire text, all drawings	1-3
A	WO 2018/008194 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 11 January 2018 (2018-01-11), entire text, all drawings	1-3

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
04 November 2020	17 November 2020

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

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/032636

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