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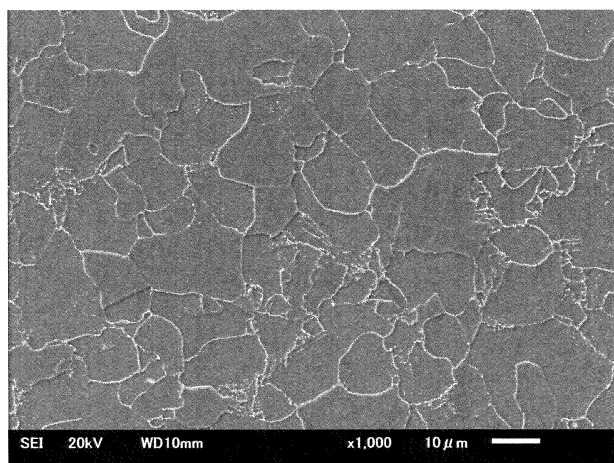
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(54) **OIL WELL PIPE FOR EXPANDABLE TUBULAR**

(57) An oil well pipe for expandable tubular, containing, in terms of % by mass: 0.020 to 0.080% of C, 0.50% or less of Si, 0.30 to 1.60% of Mn, 0.030% or less of P, 0.010% or less of S, 0.005 to 0.050% of Ti, and 0.010 to 0.500% of Al, and the balance being Fe and impurities, wherein, in a metallographic microstructure, an area frac-

tion of a first phase composed of ferrite is from 90.0% to 98.0% and an area fraction of a second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite is from 2.0% to 10.0%.

FIG.1



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Description

Technical Field

5 **[0001]** The present invention relates to an oil well pipe for expandable tubular.

Background Art

10 **[0002]** Expandable tubular is a technique (construction method) of expanding a steel pipe, which is inserted in an oil well or gas well, in the oil well or gas well. The steel pipe used in this technique is called "oil well pipe for expandable tubular".

[0003] For example, Patent Document 1 discloses an oil well pipe for expandable tubular having a specific chemical composition and having a ferrite fraction of a metallographic microstructure of a base metal of from 50 to 95%.

15 **[0004]** Patent Document 2 discloses an oil well pipe for expandable tubular having a specific chemical composition, wherein the microstructure is a two-phase structure composed of a martensite-austenite constituent having an area ratio of from 2 to 10% and a soft phase, and the soft phase is composed of one or more of ferrite, high-temperature tempered martensite, and high-temperature tempered bainite.

[0005] Patent Document 3 discloses an oil well pipe for expandable tubular manufactured by quenching and tempering an electric resistance welded steel pipe having a specific chemical composition.

20 **[0006]** Patent Document 4 discloses an oil well pipe for expandable tubular manufactured by quenching and tempering a seamless steel pipe having a specific chemical composition.

Patent Document 1: Japanese Patent Publication (JP-B) No. 5014831

Patent Document 2: JP-B No. 4575995

Patent Document 3: JP-B No. 4943325

25 Patent Document 4: Japanese Patent Application Laid-Open (JP-A) No. 2002-129283

SUMMARY OF INVENTION

Technical Problem

30 **[0007]** In recent years, not only properties of being able to be expanded without a flaw on the outer surface (hereinafter, also referred to as "flawless pipe expandability") but also properties of being able to be expanded with a flaw on the outer surface (hereinafter, also referred to as "flawed pipe expandability") have become needed for oil well pipes for expandable tubular.

35 **[0008]** However, it has been found by the inventors' investigation that there are cases in which it is difficult to achieve both flawless pipe expandability and flawed pipe expandability.

[0009] For example, Patent Documents 1 and 2 disclose an oil well pipe for expandable tubular including a DP steel (Dual Phase steel; for example, a steel containing a soft ferrite phase and a hard martensite phase).

40 **[0010]** It has been found by the inventors' investigation that there are cases in which an oil well pipe for expandable tubular made of a DP steel is excellent in flawless pipe expandability, but flawed pipe expandability is impaired (for example, see Comparative Example 17 described below).

[0011] Patent Document 3 discloses an oil well pipe for expandable tubular whose metallographic microstructure is composed of tempered martensite as an oil well pipe for expandable tubular having excellent toughness after expansion.

45 **[0012]** However, an oil well pipe for expandable tubular described in Patent Document 3 may be demanded to further improve flawless pipe expandability and flawed pipe expandability.

[0013] Patent Document 4 discloses an oil well pipe for expandable tubular having a chemical composition with a small content of Al and manufactured by quenching and tempering a steel pipe.

50 **[0014]** It has been found by the inventors' investigation that in the case of quenching and tempering a steel pipe having a small Al content (for example, an Al content of 0.1% by mass or less) to produce an oil well pipe for expandable tubular, during quenching, when time from quenching heating completion to rapid cooling start is short, the fraction of ferrite contributing to flawless pipe expandability and flawed pipe expandability becomes too low, and flawless pipe expandability and flawed pipe expandability tend to be impaired (for example, see Comparative Example 15 to be described below).

[0015] An object of one aspect of the invention is to provide an oil well pipe for expandable tubular which achieves both flawless pipe expandability and flawed pipe expandability.

Solution to Problem

[0016] Means for solving the problem described above includes the following aspects.

<1> An oil well pipe for expandable tubular, comprising, in terms of % by mass:

0.020 to 0.080% of C,
0.50% or less of Si,
0.30 to 1.60% of Mn,
0.030% or less of P,
0.010% or less of S,
0.005 to 0.050% of Ti, and
0.010 to 0.500% of Al,

the balance being Fe and impurities,

wherein, in a metallographic microstructure, an area fraction of a first phase composed of ferrite is from 90.0% to 98.0% and an area fraction of a second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite and pearlite is from 2.0% to 10.0%.

<2> The oil well pipe for expandable tubular according to <1>, comprising, in terms of % by mass, one or more of:

0.100% or less of Nb,
1.00% or less of Ni,
1.00% or less of Cu,
0.50% or less of Mo,
1.00% or less of Cr,
0.100% or less of V, or
0.0060% or less of Ca.

<3> The oil well pipe for expandable tubular according to <1> or <2>, wherein a content of Al is, in term of % by mass, 0.060 to 0.500%.

<4> The oil well pipe for expandable tubular according to any one of <1> to <3>, which is an electric resistance welded steel pipe and satisfies the following Formula (1):

$$\text{Mn/Si} > 2.0 \quad \text{Formula (1)}$$

wherein, in Formula (1), Mn and Si each represent % by mass of each element.

Advantageous Effects of Invention

[0017] According to one aspect of the invention, there is provided an oil well pipe for expandable tubular which achieves both flawless pipe expandability and flawed pipe expandability.

BRIEF DESCRIPTION OF DRAWINGS

[0018]

Fig. 1 is an SEM micrograph (magnification: 1,000 times) showing a metallographic microstructure of a section of an oil well pipe for expandable tubular of Example 1.

Fig. 2 is an SEM micrograph (magnification: 1,000 times) showing a metallographic microstructure of a section of an oil well pipe for expandable tubular of Comparative Example 17 (DP steel).

Fig. 3A is an SEM micrograph (magnification: 1,000 times) showing a metallographic microstructure of a section of an oil well pipe for expandable tubular of Comparative Example 14.

Fig. 3B is an SEM micrograph (magnification 3,000 times) in which a part of the SEM micrograph of Fig. 3A is enlarged.

DESCRIPTION OF EMBODIMENTS

[0019] Herein, a numerical range expressed by "x to y" includes the values of x and y in the range as the minimum and maximum values, respectively.

[0020] Herein, "%" indicating the content of a component (element) means "% by mass". Herein, the content of C (carbon) may be referred to as "C content" in some cases. The content of other elements may also be referred to similarly.

[0021] Herein, the concept of "oil well pipe" includes both steel pipes used for oil wells and steel pipes used for gas wells.

[0022] Herein, the term "martensite" not modified means martensite not tempered, and the term "bainite" not modified means bainite not tempered.

[0023] The oil well pipe for expandable tubular (hereinafter, also referred to as "oil well pipe according to the disclosure") is an oil well pipe for expandable tubular, containing, in terms of % by mass: 0.020 to 0.080% of C, 0.50% or less of Si, 0.30 to 1.60% of Mn, 0.030% or less of P, 0.010% or less of S, 0.005 to 0.050% of Ti, and 0.010 to 0.500% of Al, and the balance being Fe and impurities, wherein, in a metallographic microstructure, an area fraction (hereinafter, also referred to as "first phase fraction") of a first phase composed of ferrite is from 90.0% to 98.0% and an area fraction (hereinafter, also referred to as "second phase fraction") of a second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite is from 2.0% to 10.0%.

[0024] Herein, "area fraction of the first phase including ferrite" means an area fraction (%) of the first phase with respect to the entire metallographic microstructure in a metallographic micrograph showing the metallographic microstructure of an oil well pipe.

[0025] Herein, "area fraction a second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite" means an area fraction (%) of the second phase with respect to the entire metallographic microstructure in a metallographic micrograph showing the metallographic microstructure of an oil well pipe.

[0026] The sum of the area fraction (%) of the first phase and the area fraction of the second phase is 100%.

[0027] In the oil well pipe of the disclosure, both flawless pipe expandability (i.e., properties of being able to be expanded in a state in which there is no flaw on the outer surface) and flawed pipe expandability (i.e., properties of being able to be expanded in a state in which there is a flaw on the outer surface) are achieved.

[0028] The oil well pipe of the disclosure has a chemical composition, containing, in terms of % by mass, 0.020 to 0.080% of C, 0.50% or less of Si, 0.30 to 1.60% of Mn, 0.030% or less of P, 0.010% or less of S, 0.005 to 0.050% of Ti, and 0.010 to 0.500% of Al, and the balance being Fe and impurities.

[0029] In the oil well pipe of the disclosure, the above chemical composition contributes to both improvement of flawless pipe expandability and improvement of flawed pipe expandability.

[0030] The chemical composition and preferred embodiments thereof will be described below.

[0031] In the metallographic microstructure of the oil well pipe of the disclosure, the area fraction of the first phase composed of ferrite (i.e., the first phase fraction) is from 90.0% to 98.0%, and the area fraction of the second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite (i.e., the second phase fraction) is from 2.0% to 10.0%.

[0032] In the oil well pipe of the disclosure, the above-described metallographic microstructure contributes to both improvement of flawless pipe expandability and improvement of flawed pipe expandability. This point will be explained in more detail below.

[0033] In the oil well pipe of the disclosure, the first phase fraction of 90.0% or more and the second phase fraction of 10.0% or less contribute to improvement of flawed pipe expandability.

[0034] The reason for this is considered to be that the occurrence of voids (cracks) initiating from flaws on the outer surface, propagation of the voids, and coalescence of the voids are suppressed by the first phase fraction is 90.0% or more, and the second phase fraction is 10.0% or less (i.e., by a structure mainly composed of soft ferrite).

[0035] In the oil well pipe of the disclosure, the fact that the second phase is composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite contributes to both improvement of flawed pipe expandability and improvement of flawed pipe expandability.

[0036] Specifically, in the oil well pipe of the disclosure, the second phase is composed of one or more selected from the above group, whereby the flawed pipe expandability is improved as compared with cases in which the second phase is composed of one or more selected from the group consisting of martensite and bainite (i.e., DP steel) (see, for example, Comparative Example 17).

[0037] More specifically, when the second phase is one or more selected from the group consisting of martensite and bainite, since the difference in hardness between the soft first phase and the hard second phase is too large, strain concentration tends to occur in the metallographic microstructure, due to this strain concentration, generation of voids and coalescence of voids are likely to occur, and as a result, the flawed pipe expandability is considered to deteriorate.

[0038] Regarding this point, the second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite in the disclosure is not too hard. Therefore, in the oil well pipe of the disclosure, occurrence of strain concentration, generation of voids, and coalescence of voids are suppressed, and as a result, flawed pipe expandability is considered to be improved.

[0039] The second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite in the disclosure can be distinguished from the second phase composed of one or more selected from the group consisting of martensite and bainite in a DP steel by observation with a metallographic micrograph.

[0040] Furthermore, the second phase in the disclosure is also distinguishable from the second phase in a DP steel also in that the phase contains a carbide (i.e., cementite; the same applies hereinafter).

[0041] Specifically, tempered martensite is distinguishable from martensite in that tempered martensite contains granular carbide.

[0042] Likewise, tempered bainite is distinguishable from bainite in that tempered bainite contains granular carbide.

[0043] Pearlite, of course, contains a carbide.

5 **[0044]** The second phase in the disclosure also has an effect of improving the work hardening property of an oil well pipe to some extent. Therefore, the second phase is considered to contribute to flawless pipe expandability.

[0045] In the oil well pipe of the disclosure, the first phase fraction of 98.0% or less and the second phase fraction of 2.0% or more contribute to improvement of flawless pipe expandability.

10 **[0046]** The reason for this is considered to be that the work hardening property is secured because the first phase fraction is 98.0% or less and the second phase fraction is 2.0% or more.

[0047] Preferably, the oil well pipe of the disclosure is an electric resistance welded steel pipe.

[0048] When the oil well pipe of the disclosure is an electric resistance welded steel pipe, variations in wall thickness (i.e., eccentricity) are more suppressed (for example, in comparison with a seamless steel pipe), and therefore, the flawless pipe expandability and flawed pipe expandability are more excellent.

15 **[0049]** Next, the chemical composition of oil well pipe of the disclosure and preferred aspects thereof will be described.

C: 0.020 to 0.080%

[0050] C is an element that improves flawless pipe expandability by improving the work hardening property of steel.

20 **[0051]** However, when the C content is less than 0.020%, the second phase is difficult to be formed, which causes deterioration of flawless pipe expandability.

[0052] On the other hand, when the C content exceeds 0.080%, flawless pipe expandability and flawed pipe expandability are deteriorated.

[0053] Therefore, the C content is 0.020 to 0.080%.

25 **[0054]** From the viewpoint of further improving flawless pipe expandability, the C content is preferably 0.030% or more.

[0055] From the viewpoint of further improving flawed pipe expandability, the C content is preferably 0.070% or less.

Si: 0.50% or less

30 **[0056]** Si is an element that functions as a deoxidizer for steel.

[0057] However, when the Si content exceeds 0.50%, the flawless pipe expandability may deteriorate. When the oil well pipe of the disclosure is an electric resistance welded steel pipe, there is a possibility that an inclusion may be generated in the electric resistance welded portion.

[0058] Therefore, the content of Si is 0.50% or less.

35 **[0059]** From the viewpoint of more effectively exhibiting the function of the steel as a deoxidizer, the Si content is preferably 0.03% or more, and more preferably 0.05% or more.

[0060] The content of Si is preferably less than 0.50%, and more preferably 0.45% or less from the viewpoint of further improving flawless pipe expandability.

40 Mn: 0.30 to 1.60%

[0061] Mn is an element having an effect of improving hardenability of steel. Mn is an element effective for rendering S harmless. Accordingly, Mn is an element that improves both flawless pipe expandability and flawed pipe expandability.

[0062] Therefore, the Mn content is 0.30% or more.

45 **[0063]** The Mn content is preferably 0.33% or more.

[0064] On the other hand, excessive content of Mn promotes segregation of P and the like, which may deteriorate flawless pipe expandability. There is also the possibility of causing pipe expansion cracking. Therefore, the upper limit of the content of Mn is 1.60%.

[0065] The Mn content is preferably 1.50% or less.

50

P: 0.030% or less

[0066] P is an element that may exist as impurities in the steel.

55 **[0067]** However, excessive content of P will cause segregation at the grain boundary, which impairs the pipe expandability (especially the flawed pipe expandability). Therefore, the P content is 0.030% or less.

[0068] The P content may be 0%. From the viewpoint of further reducing the cost for dephosphorization, the P content may be 0.001% or more.

S: 0.010% or less

[0069] S is an element that can exist as an impurity in a steel.

[0070] However, excessive content of S deteriorates toughness or pipe expandability of a steel (in particular, flawed pipe expandability). Therefore, the S content is 0.010% or less.

[0071] The S content may be 0%. From the viewpoint of further reducing the cost for desulfurization, the S content may be 0.001% or more.

Ti: 0.005 to 0.050%

[0072] Ti is an element that forms a carbonitride and contributes to crystal grain size refining.

[0073] From the viewpoint of exerting its effect and improving flawless pipe expandability and flawed pipe expandability, the content of Ti is 0.005% or more. The Ti content is preferably 0.010% or more.

[0074] However, when the Ti content exceeds 0.050%, coarse TiN is generated, which leads to deterioration of flawed pipe expandability. Therefore, the Ti content is 0.050% or less. The Ti content is preferably 0.045% or less.

Al: 0.010 to 0.500%

[0075] Like Si, Al is an element that functions as a deoxidizer for steel. Al is also an element having a function of promoting ferrite formation.

[0076] Since Al has such functions, Al is an element that improves flawless pipe expandability and flawed pipe expandability.

[0077] In order to exhibit such effects, the Al content is 0.010% or more.

[0078] On the other hand, when the Al content exceeds 0.500%, the flawless pipe expandability deteriorates due to the decrease in the second phase fraction and the flawed pipe expandability also deteriorates due to the formation of an Al based inclusion. Therefore, the Al content is 0.500% or less. The Al content is preferably 0.490% or less.

[0079] The Al content is more preferably 0.060% to 0.500%, further preferably 0.100% to 0.500%, and particularly preferably more than 0.100% to 0.500%.

[0080] When the Al content is 0.060% to 0.500%, the function of promoting the formation of ferrite of Al is more effectively exhibited, and as a result, the metallographic microstructure according to the disclosure (i.e., a metallographic microstructure having a first phase fraction of from 90.0% to 98.0% and a second phase fraction of from 2.0% to 10.0%) is more easily formed.

[0081] In general, in the case of quenching and tempering a steel pipe having an Al content of 0.100% or less, when rapid cooling is performed immediately after quenching heating during quenching, the duration of time that the temperature of the steel pipe passes through the temperature region in which the ferrite is formed is short, and therefore the area fraction of the first phase composed of ferrite becomes too low, and as a result, the flawless pipe expandability and the flawed pipe expandability may be deteriorated (see Comparative Example 15 to be described below).

[0082] However, in the oil well pipe of the disclosure, even when the Al content is 0.100% or less, the area fraction of the first phase composed of ferrite is 90.0% or more.

[0083] Therefore, in the oil well pipe of the disclosure, flawless pipe expandability and flawed pipe expandability are secured even when the Al content is 0.100% or less.

[0084] In order to make the area fraction of the first phase composed of ferrite 90.0% or more when the Al content is 0.100% or less, it is effective to lengthen the time in a temperature region in which the ferrite is formed to some extent by slow cooling once after quenching heating, and subsequently performing rapid cooling (see, for example, Production Method A and Examples below).

[0085] In the chemical composition of the oil well pipe of the disclosure, the balance excluded from the above-described elements is Fe and impurities.

[0086] Herein, the impurity means a component contained in a raw material or a component mixed in a manufacturing process and not intentionally contained in a steel.

[0087] Examples of the impurities include O (oxygen), N (nitrogen), Sb, Sn, W, Co, As, Mg, Pb, Bi, H (hydrogen), and REM. Here, "REM" refers to a rare earth element, i.e., at least one element selected from the group consisting of Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

[0088] Among the elements described above, O is preferably controlled to have a content of 0.006% or less.

[0089] N is preferably controlled to have a content of 0.010% or less.

[0090] For the other elements, typically, Sb, Sn, W, Co, or As may be included in a content of 0.1% or less, Mg, Pb or Bi may be included in a content of 0.005% or less, H may be included in a content of 0.0004% or less, and the contents of the other elements need not particularly be controlled as long as being in a usual range.

[0091] The oil well pipe of the disclosure may contain one or more of: 0.100% or less of Nb, 1.00% or less of Ni, 1.00%

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or less of Cu, 0.50% or less of Mo, 1.00% or less of Cr, 0.100% or less of V, or 0.0060% or less of Ca.

[0092] Besides being intentionally contained in the oil well pipe, these elements may be mixed as impurities. Therefore, the lower limit of the content of these elements is not particularly limited, and may be 0%.

[0093] Hereinafter, preferred contents in the case where these elements are contained will be described.

5

Nb: 0.100% or less

[0094] Nb is an element contributing to improvement of strength and toughness.

10

[0095] However, excessive content of Nb may degrade the flawless pipe expandability or the flawed pipe expandability due to an Nb precipitate. Therefore, the Nb content is preferably 0.100% or less.

[0096] The Nb content may be 0%, or may be more than 0%.

[0097] From the viewpoint of the effect of Nb, the Nb content is preferably 0.001 % or more, more preferably 0.005% or more, and particularly preferably 0.010% or more.

15

Ni: 1.00% or less

[0098] Ni is an element contributing to improvement of strength and toughness.

[0099] However, when the Ni content is excessive, the strength becomes too high, and the flawless pipe expandability or the flawed pipe expandability may deteriorate. Therefore, the Ni content is preferably 1.00% or less.

20

[0100] The Ni content may be 0%, or may be more than 0%.

[0101] From the viewpoint of the effect of Ni, the Ni content is preferably 0.01 % or more, and more preferably 0.05% or more.

Cu: 1.00% or less

25

[0102] Cu is an element effective for improving the strength of a base metal.

[0103] However, when the Cu content is excessive, the strength becomes too high, and the flawless pipe expandability or the flawed pipe expandability may deteriorate. Therefore, the Cu content is preferably 1.00% or less.

[0104] The Cu content may be 0%, or may be more than 0%.

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[0105] From the viewpoint of the effect of Cu, the Cu content is preferably 0.01% or more, and more preferably 0.05% or more.

Mo: 0.50% or less

35

[0106] Mo is an element effective for improving the hardenability of steel and obtaining high strength.

[0107] However, when the Mo content is excessive, the strength becomes too high, and Mo carbonitride may be formed, and therefore the flawless pipe expandability or the flawed pipe expandability may deteriorate. Therefore, the Mo content is preferably 0.50% or less.

[0108] The Mo content may be 0%, or may be more than 0%.

40

[0109] From the viewpoint of the effect of Mo, the Mo content is preferably 0.01% or more, and more preferably 0.05% or more.

Cr: 1.00% or less

45

[0110] Cr is an element for improving hardenability.

[0111] However, when the Cr content is excessive, the strength becomes too high, and due to the formation of a Cr-based inclusion, the flawless pipe expandability or the flawed pipe expandability may deteriorate. Therefore, the Cr content is preferably 1.00% or less.

[0112] The Cr content may be 0%, or may be more than 0%.

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[0113] From the viewpoint of the effect of Cr, the Cr content is preferably 0.01% or more, and more preferably 0.05% or more.

V: 0.100% or less

55

[0114] V is an element having effects similar to those of Nb.

[0115] However, when the V content is excessive, the strength becomes too high, and due to the production of a V carbonitride, the flawless pipe expandability or the flawed pipe expandability may deteriorate. Therefore, the V content is preferably 0.100% or less.

[0116] The V content may be 0%, or may be more than 0%.

[0117] From the viewpoint of the effect of V above, the V content is preferably 0.005% or more, and more preferably 0.010% or more.

5 Ca: 0.0060% or less

[0118] Ca is an element that controls the form of a sulfide inclusion and improves low temperature toughness.

[0119] However, when the Ca content is excessive, a large cluster or inclusion composed of CaO, CaS, or the like is formed, and the flawless pipe expandability or flawed pipe expandability may deteriorate. Therefore, the Ca content is preferably 0.0060% or less.

[0120] The Ca content may be 0%, or may be more than 0%.

[0121] From the viewpoint of the effect of Ca, the Ca content is preferably 0.0005% or more, and more preferably 0.0010% or more.

15 **[0122]** When the oil well pipe of the disclosure is an electric resistance welded steel pipe, the oil well pipe of the disclosure preferably satisfies the following Formula (1) from the viewpoint of electric resistance weldability:

$$\text{Mn/Si} > 2.0 \quad \text{Formula (1)}$$

20 wherein, in Formula (1), Mn and Si each represent % by mass of each element.

[0123] The upper limit of Mn/Si is not particularly limited, and Mn/Si is preferably 40.0 or less.

[0124] Next, preferred aspects of the metallographic microstructure of the oil well pipe of the disclosure will be described.

[0125] As described above, in the metallographic microstructure of the oil well pipe of the disclosure, the first phase fraction (i.e., the first phase fraction (i.e., the area fraction of the first phase composed of ferrite) is from 90.0% to 98.0%.

25 **[0126]** From the viewpoint of further improving flawed pipe expandability, the first phase fraction is preferably 91.0% or more.

[0127] From the viewpoint of further improving flawless pipe expandability, the first phase fraction is preferably 97.0% or less.

30 **[0128]** In the metallographic microstructure of the oil well pipe of the disclosure, the area fraction of the second phase fraction (i.e., the area fraction of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite) is from 2.0% to 10.0%.

[0129] From the viewpoint of further improving the flawless pipe expandability, the second phase fraction is preferably 3.0% or more.

35 **[0130]** From the viewpoint of further improving the flawed pipe expandability, the second phase fraction is preferably 9.0% or less.

[0131] The outer diameter of the oil well pipe of the disclosure is preferably from 150 mm to 300 mm, and more preferably from 200 mm to 300 mm.

[0132] The wall thickness of the oil well pipe of the disclosure is preferably from 5.00 mm to 20.00 mm, and more preferably from 7.00 mm to 17.00 mm.

40 **[0133]** As a production method of the oil well pipe of the disclosure, any method can be used as long as the method can produce an oil well pipe having the above-described chemical composition and metallographic microstructure, and there is no particular limitation.

[0134] The oil well pipe of the disclosure can be produced, for example, by quenching an as-rolled steel pipe (preferably an electric resistance welded steel pipe) having the above-described chemical composition, followed by tempering.

45 **[0135]** In the disclosure, "quenching" means a process including a heating process in which a steel pipe is heated to an austenite region and a cooling process in which a steel pipe is cooled from an austenite region in this order, the cooling process including a step of rapid cooling (for example, secondary cooling described below). In other words, "quenching" in the disclosure does not mean a process of forming a structure consisting only of martensite.

[0136] The above "as-rolled steel pipe" means a steel pipe which has not yet been heat treated after pipe-making.

50 **[0137]** An as-rolled steel pipe (preferably an electric resistance welded steel pipe) can be prepared by a known method. For example, the electric resistance welded steel pipe can be prepared by bending a hot-rolled steel sheet having the above-described chemical composition into a pipe shape to form an open pipe and welding an abutting portion of the obtained open pipe.

55 **[0138]** Hereinafter, a preferred production method of producing the oil well pipe of the disclosure (hereinafter, also referred to as "Production Method A") will be described, but the method of producing the oil well pipe of the disclosure is not limited to Production Method A.

[0139] Production Method A includes quenching and then tempering an as-rolled steel pipe (preferably an electric resistance welded steel pipe) having the chemical composition described above.

[0140] In Production Method A, quenching includes a heating process and a cooling process in this order.

[0141] The heating temperature in the heating process of quenching (hereinafter, also referred to as "quenching heating temperature T_1 ") is preferably a temperature within the range of from 900°C to 1,100°C.

[0142] The heating time in the heating process of quenching is preferably from 180 s (seconds) to 3,600 s (seconds), and more preferably 300 s to 1,800 s.

[0143] In Production Method A, the cooling process of quenching preferably includes:

primary cooling for cooling the steel pipe after the heating process at a cooling rate of 10°C/s or less from the quenching heating temperature T_1 to the primary cooling stop temperature T_2 where the difference ($T_1 - T_2$) is from 20°C to 230°C; and

secondary cooling for cooling the primarily cooled electric resistance welded steel pipe at a cooling rate of 30°C/s or more from 300°C to room temperature (hereinafter, also referred to as "secondary cooling stop temperature").

[0144] In the quenching of the Production Method A, when the cooling process including the primary cooling and the secondary cooling is applied, the above-described metallographic microstructure (i.e., a metallographic microstructure having a first phase fraction of from 90.0% to 98.0% and a second phase fraction of from 2.0% to 10.0%) can be more easily formed.

[0145] In particular, when the chemical composition of the oil well pipe is a chemical composition having a small content of Al which is an element promoting ferrite formation (for example, in the case of a chemical composition having an Al content of 0.100% or less), it is preferable to apply a cooling process including primary cooling and secondary cooling.

[0146] The reason why the metallographic microstructure described above (i.e., a metallographic microstructure having a first phase fraction of from 90.0% to 98.0% and a second phase fraction of from 2.0% to 10.0%) is easy to form when a cooling process including primary cooling and secondary cooling is applied is presumed as follows.

[0147] In the primary cooling, a steel pipe after the heating process is cooled (i.e., slowly cooled) at a cooling rate of 10°C/s or less to the primary cooling stop temperature T_2 where the difference ($T_1 - T_2$) from the quenching heating temperature T_1 is from 20°C to 230°C.

[0148] In the primary cooling, since the difference ($T_1 - T_2$) between the quenching heating temperature T_1 and the primary cooling stop temperature T_2 is 20°C or more and the cooling rate is 10°C/s or less, it is considered that the time during which the temperature of the steel pipe passes through the temperature range where ferrite is formed (hereinafter, also referred to as "ferrite forming zone passing time") can be increased to some extent. This promotes the formation of ferrite, and therefore it is considered that the first phase fraction of 90.0% or more and the second phase fraction of 10.0% or less are finally easily achieved.

[0149] On the other hand, it is considered that excessive elongation of the ferrite forming zone passing time can be suppressed by the difference ($T_1 - T_2$) between the quenching heating temperature T_1 and the primary cooling stop temperature T_2 of 230°C or less in the primary cooling. This suppresses excessive production of ferrite, and therefore, it is considered that the first phase fraction of 98.0% or less and the second phase fraction of 2.0% or more are finally easily achieved.

[0150] In the secondary cooling, the primary-cooled electric resistance welded steel pipe is cooled (i.e., "rapidly cooled") at a cooling rate of 30°C/s or more.

[0151] Here, the cooling start temperature of the secondary cooling coincides with the cooling stop temperature T_2 of the primary cooling.

[0152] By this secondary cooling, it is considered that one or more selected from the group consisting of martensite, bainite, and pearlite are generated from a remaining structure excluding ferrite (i.e., the remaining structure having a fraction of from 2.0% to 10.0%).

[0153] It is considered that, in the steel having the above chemical composition, transformation is completed when the steel is cooled to 300°C. Therefore, the secondary cooling stop temperature is a temperature of from 300°C to room temperature.

[0154] By tempering a steel pipe after finishing the secondary cooling, it is considered that the metallographic microstructure of the disclosure in which the area fraction of a first phase composed of ferrite is from 90.0% to 98.0% and the area fraction of a second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite is from 2.0% to 10.0% can be easily formed.

[0155] Tempering in Production Method A includes a heating process and a cooling process in this order.

[0156] The heating temperature (hereinafter, also referred to as "tempering heating temperature") in the heating process of tempering is, for example, from 200°C to 670°C.

[0157] The heating time in the heating process of tempering is preferably from 180 s (seconds) to 1,800 s (seconds), and more preferably from 300 s to 900 s.

[0158] There is no particular restriction on the cooling process of tempering, and the process may be slow cooling or rapid cooling.

EXAMPLES

[0159] Hereinafter, one aspect of the invention will be described more specifically with reference to Examples, but the invention is not limited to the following Examples.

[Examples 1 to 70, Comparative Examples 1 to 16]

[0160] In Tables 1 and 2, as-rolled electric resistance welded steel pipes having chemical compositions of Steels 1 to 85, having an outer diameter of 244.5 mm, a wall thickness of 11.05 mm, and a length of 12,000 mm, were produced. Steels 71 to 81 have chemical compositions outside the scope of the disclosure.

[0161] The above-described as-rolled electric resistance welded steel pipes were quenched and then tempered to obtain oil well pipes of Examples 1 to 70 and Comparative Examples 1 to 16.

[0162] Here, quenching was carried out as follows.

[0163] First, the as-rolled electric resistance welded steel pipe was heated for 600 s at the quenching heating temperature T_1 shown in Tables 3 and 4.

[0164] Next, the pipe was primary cooled (slowly cooled) at the cooling rate of the primary cooling shown in Tables 3 and 4 until a temperature of the pipe reached the primary cooling stop temperature T_2 (i.e., secondary cooling start temperature) shown in Tables 3 and 4.

[0165] From the time when a temperature of the pipe reached the primary cooling stop temperature T_2 , secondary cooling (rapid cooling) of the pipe was started at the cooling rate of the secondary cooling shown in Tables 3 and 4, and the pipe was secondary cooled to room temperature as it was.

[0166] Tempering was carried out by heating the electric resistance welded steel pipe which was secondary cooled to room temperature at a heating temperature (i.e., a tempering heating temperature) shown in Tables 3 and 4 for 600 s and then cooling the pipe to room temperature with water.

[Comparative Example 17]

[0167] An oil well pipe of Comparative Example 17 was obtained in the same manner as in Example 1 except that the chemical composition was changed from Steel 1 to Steel 83 and the tempering was not carried out.

< Measure of First Phase Fraction and Second Phase Fraction >

[0168] For each oil well pipe, first phase fraction and second phase fraction were measured at a position to which the distance from the outer surface of the oil well pipe was 1/4 of the wall thickness (hereinafter, also referred to as "wall thickness 1/4 position") in a cross-section (specifically, a cross-section parallel to the pipe axis direction) at a position deviating at 90° in the circumferential direction of the pipe from the electric resistance welded portion of the oil well pipe.

[0169] Specifically, the cross-section was polished, and then was etched with Nital reagent. A metallographic micrograph of the wall thickness 1/4 position in the etched cross-section was taken by a scanning electron microscope (SEM) at a magnification of 1,000 times for 10 fields of view (as an actual area of the cross section of 0.15 mm²).

[0170] By image processing the metallographic micrograph (0.15 mm² as the actual area of the cross section) that was taken, the area fraction of a first phase composed of ferrite and the area fraction of a second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite were obtained, respectively.

[0171] Image processing was carried out using a small general purpose image analyzer LUZEX AP manufactured by NIRECO CORPORATION.

[0172] The results are shown in Tables 5 and 6.

[0173] Tables 5 and 6 also show the type of the second phase (second phase type).

< Evaluation of Flawless Pipe Expandability (25%) >

[0174] A sample pipe having a length of 3,000 mm cut out from each oil well pipe was expanded at a pipe expansion ratio of 25% using a pipe expanding plug.

[0175] In the pipe expansion with the pipe expansion ratio of 25%, a case where pipe expansion was possible without through wall cracking throughout the sample pipe was regarded as successful pipe expansion ("A" in Tables 5 and 6).

[0176] In the pipe expansion with the pipe expansion ratio of 25%, a case where through wall cracking occurred was regarded as failure pipe expansion ("B" in Tables 5 and 6).

[0177] The results are shown in Tables 5 and 6.

[0178] Here, "pipe expansion with a pipe expansion ratio of 25%" means expanding the pipe until a circumferential

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length of the outer surface was increased by 25%.

< Evaluation of Flawed Pipe Expandability (16.5%) >

- 5 **[0179]** In a sample pipe having a length of 3,000 mm cut out from each oil well pipe, a notch parallel to the longitudinal direction of the pipe was provided, the notch having a depth corresponding to 10% of the wall thickness. By this, a notched sample was obtained.
- [0180]** The notched sample was expanded at a pipe expansion ratio of 16.5% using a pipe expanding plug.
- 10 **[0181]** In the pipe expansion with the pipe expansion ratio of 16.5%, a case where pipe expansion was possible without through wall cracking throughout the sample was regarded as successful pipe expansion ("A" in Tables 5 and 6).
- [0182]** In the pipe expansion with the pipe expansion ratio of 16.5%, a case where a through wall cracking occurred was regarded as failure pipe expansion ("B" in Tables 5 and 6).
- [0183]** The results are shown in Tables 5 and 6.
- 15 **[0184]** Here, "pipe expansion with a pipe expansion ratio of 16.5%" means expanding the pipe until a circumferential length of the outer surface was increased by 16.5%.

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[Table 1]

Steel	C	Si	Mn	P	S	Ti	Al	Nb	Ni	Cu	Mo	Cr	V	Ca	Mn/Si
1	0.039	0.15	0.33	0.028	0.004	0.044	0.056								2.2
2	0.043	0.37	1.20	0.026	0.008	0.006	0.062								3.2
3	0.024	0.43	1.09	0.013	0.010	0.036	0.022								2.6
4	0.033	0.36	1.40	0.017	0.007	0.033	0.092								3.8
5	0.029	0.38	1.13	0.002	0.006	0.021	0.077			0.53					3.0
6	0.023	0.11	0.36	0.010	0.004	0.043	0.087		0.43						3.2
7	0.052	0.45	1.21	0.013	0.001	0.034	0.027					0.24			2.7
8	0.023	0.24	1.01	0.004	0.001	0.011	0.086				0.36				4.2
9	0.039	0.36	1.51	0.017	0.005	0.040	0.072	0.061							4.1
10	0.053	0.10	0.36	0.007	0.003	0.036	0.011						0.048		3.6
11	0.056	0.15	0.48	0.024	0.009	0.029	0.026							0.0021	3.2
12	0.022	0.11	1.26	0.021	0.007	0.044	0.072								11.6
13	0.045	0.20	0.62	0.003	0.001	0.050	0.076								3.1
14	0.042	0.20	0.61	0.009	0.010	0.016	0.017								3.1
15	0.052	0.27	0.87	0.009	0.007	0.011	0.048								3.3
16	0.060	0.10	0.41	0.009	0.005	0.027	0.027								4.1
17	0.048	0.39	1.42	0.003	0.001	0.019	0.028								3.7
18	0.043	0.12	0.30	0.004	0.004	0.011	0.025								2.5
19	0.057	0.40	0.92	0.025	0.004	0.013	0.038								2.3
20	0.060	0.50	1.60	0.030	0.010	0.050	0.100			1.00					3.2
21	0.024	0.21	0.49	0.015	0.007	0.022	0.092			0.77					2.3
22	0.028	0.10	0.30	0.025	0.002	0.034	0.056		0.29						3.0
23	0.028	0.15	0.53	0.015	0.005	0.021	0.077		0.89						3.5
24	0.029	0.45	1.45	0.004	0.007	0.023	0.063					0.23			3.3
25	0.038	0.28	1.00	0.010	0.004	0.025	0.059					0.74			3.6

(continued)

Steel	C	Si	Mn	P	S	Ti	Al	Nb	Ni	Cu	Mo	Cr	V	Ca	Mn/Si
26	0.033	0.46	1.34	0.021	0.000	0.020	0.016				0.19				2.9
27	0.041	0.41	1.20	0.016	0.004	0.013	0.080				0.43				2.9
28	0.054	0.10	0.36	0.011	0.001	0.020	0.065	0.071							3.5
29	0.033	0.19	0.45	0.028	0.009	0.012	0.091	0.084							2.4
30	0.053	0.46	1.51	0.028	0.007	0.029	0.059						0.043		3.3
31	0.058	0.37	1.05	0.011	0.002	0.023	0.053						0.030		2.8
32	0.054	0.44	0.93	0.003	0.007	0.031	0.040							0.0042	2.1
33	0.022	0.20	0.55	0.014	0.007	0.017	0.025							0.0012	2.8
34	0.058	0.42	1.52	0.029	0.007	0.038	0.013		0.53	0.39					3.6
35	0.037	0.36	1.12	0.010	0.004	0.020	0.071			0.92		0.11			3.1
36	0.056	0.22	0.46	0.017	0.002	0.014	0.044				0.16	0.72			2.1
37	0.040	0.11	0.37	0.027	0.003	0.022	0.078		0.24		0.39	0.85			3.4
38	0.045	0.28	1.49	0.021	0.006	0.013	0.040	0.076	0.89		0.41	0.35			5.4
39	0.053	0.30	0.76	0.012	0.009	0.007	0.040		0.21		0.40	0.28	0.062		2.5
40	0.059	0.05	0.96	0.009	0.008	0.027	0.470								20.1
41	0.022	0.38	1.34	0.001	0.009	0.016	0.393								3.5
42	0.033	0.07	0.87	0.012	0.008	0.018	0.392								13.0
43	0.029	0.15	1.20	0.026	0.002	0.026	0.228								7.8
44	0.023	0.12	0.92	0.002	0.007	0.015	0.053								7.7
45	0.049	0.24	1.08	0.021	0.009	0.011	0.262								4.5
46	0.065	0.30	1.42	0.006	0.008	0.028	0.284								4.8
47	0.047	0.04	1.27	0.002	0.004	0.007	0.201								35.3
48	0.058	0.41	1.49	0.013	0.002	0.013	0.085								3.7
49	0.076	0.12	0.94	0.010	0.003	0.014	0.358								8.1
50	0.078	0.16	1.19	0.025	0.004	0.010	0.158			0.96					7.7

[Table 2]

Steel	C	Si	Mn	P	S	Ti	Al	Nb	Ni	Cu	Mo	Cr	V	Ca	Mn/Si
51	0.041	0.34	1.17	0.005	0.003	0.028	0.104			0.39					3.4
52	0.048	0.20	1.55	0.028	0.004	0.009	0.374		0.46						7.8
53	0.042	0.26	1.28	0.003	0.000	0.006	0.140		0.95						4.8
54	0.054	0.41	1.11	0.018	0.007	0.018	0.238				0.13				2.7
55	0.024	0.38	1.00	0.005	0.008	0.025	0.245				0.37				2.6
56	0.046	0.35	0.78	0.018	0.008	0.030	0.062					0.84			2.2
57	0.066	0.32	1.30	0.025	0.001	0.027	0.257					0.31			4.1
58	0.050	0.07	0.37	0.029	0.001	0.023	0.420					0.43			5.2
59	0.061	0.21	1.48	0.014	0.009	0.026	0.485						0.098		7.1
60	0.068	0.44	1.47	0.002	0.007	0.021	0.267						0.043		3.3
61	0.021	0.34	1.00	0.023	0.004	0.027	0.141							0.0015	2.9
62	0.040	0.12	0.39	0.016	0.009	0.009	0.255							0.0052	3.3
63	0.034	0.30	1.30	0.011	0.002	0.019	0.265	0.064							4.3
64	0.053	0.50	1.19	0.018	0.007	0.025	0.335	0.046							2.4
65	0.071	0.28	1.10	0.016	0.004	0.024	0.321	0.091		0.92					3.9
66	0.062	0.43	1.00	0.014	0.001	0.015	0.343					0.91	0.026		2.3
67	0.027	0.31	1.46	0.026	0.002	0.016	0.289	0.093				0.35			4.7
68	0.031	0.28	1.11	0.009	0.002	0.005	0.499	0.008	0.80						4.0
69	0.071	0.03	0.49	0.028	0.007	0.028	0.433	0.067	0.65			0.96	0.073		15.3
70	0.025	0.41	1.59	0.025	0.002	0.009	0.213		0.43	0.35			0.011		3.8
71	<u>0.100</u>	0.31	1.36	0.023	0.007	0.013	0.052								4.4
72	<u>0.010</u>	0.31	0.93	0.008	0.004	0.024	0.066								3.0
73	0.026	<u>0.60</u>	1.30	0.016	0.002	0.049	0.055								2.2
74	0.054	0.22	<u>1.90</u>	0.026	0.004	0.034	0.099								8.5
75	0.036	0.10	<u>0.20</u>	0.022	0.004	0.018	0.089								2.0

(continued)

Steel	C	Si	Mn	P	S	Ti	Al	Nb	Ni	Cu	Mo	Cr	V	Ca	Mn /Si
<u>76</u>	0.037	0.14	0.51	<u>0.040</u>	0.010	0.032	0.031								3.6
<u>77</u>	0.038	0.40	0.94	<u>0.004</u>	<u>0.020</u>	0.039	0.036								2.3
<u>78</u>	0.040	0.27	1.47	0.030	0.004	<u>0.070</u>	0.086								5.4
<u>79</u>	0.028	0.32	1.06	0.009	0.004	<u>0.001</u>	0.032								3.3
<u>80</u>	0.053	0.28	1.29	0.006	0.001	0.031	<u>0.600</u>								4.7
<u>81</u>	0.024	0.35	1.35	0.021	0.005	0.032	<u>0.005</u>								3.9
82	0.052	0.43	0.93	0.010	0.009	0.045	0.063								2.2
83	0.059	0.17	1.35	0.028	0.002	0.033	0.083								7.8
84	0.030	0.30	1.20	0.002	0.008	0.028	0.091								3.9
85	0.023	0.41	1.41	0.029	0.002	0.033	0.066								3.4

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- Explanation of Tables 1 and 2 -

[0185]

- Numeric values in the column of each element indicate the content (% by mass) of each element.
- Mn/Si represents the ratio of Mn content (% by mass) to Si content (% by mass).
- In each steel, the balance except the elements shown in Table 1 is Fe and impurities.
- Numeric values underlined are values outside the scope of the disclosure.
- Steel numbers underlined are chemical compositions outside the scope of the disclosure.

[Table 3]

	Steel	Quenching					Tempering
		Quenching heating temp. (T ₁) (°C)	Cooling rate (°C/s) of primary cooling	Primary cooling stop temp. (T ₂) (°C)	T ₁ -T ₂ (°C)	Cooling rate (°C/s) of secondary cooling	Tempering heating temp. (°C)
Example 1	1	998	7	888	110	69	464
Example 2	2	940	3	793	147	95	563
Example 3	3	1035	5	913	122	82	207
Example 4	4	966	9	848	118	52	286
Example 5	5	952	6	920	32	76	366
Example 6	6	1022	2	840	182	37	286
Example 7	7	995	5	788	207	49	496
Example 8	8	1051	5	894	157	68	256
Example 9	9	986	2	889	97	35	405
Example 10	10	988	7	836	152	70	563
Example 11	11	991	5	860	131	41	286
Example 12	12	965	3	791	174	59	201
Example 13	13	976	2	894	82	89	464
Example 14	14	953	8	823	130	76	290

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(continued)

5		Steel	Quenching					Tempering
			Quenching heating temp. (T ₁) (°C)	Cooling rate (°C/s) of primary cooling	Primary cooling stop temp. (T ₂) (°C)	T ₁ -T ₂ (°C)	Cooling rate (°C/s) of secondary cooling	Tempering heating temp. (°C)
10	Example 15	15	1017	9	851	166	57	562
	Example 16	16	955	2	818	137	34	227
	Example 17	17	985	4	878	107	49	315
15	Example 18	18	951	5	870	81	70	624
	Example 19	19	968	7	787	181	91	218
	Example 20	20	994	4	791	203	100	670
25	Example 21	21	984	7	841	143	47	648
	Example 22	22	1008	4	858	150	96	496
	Example 23	23	967	5	887	80	94	405
30	Example 24	24	1027	2	817	210	65	492
	Example 25	25	960	2	826	134	62	550
	Example 26	26	1024	9	851	173	48	563
40	Example 27	27	968	8	839	129	91	641
	Example 28	28	964	2	872	92	55	207
	Example 29	29	965	9	925	40	57	570
45	Example 30	30	943	3	887	56	37	366
	Example 31	31	942	3	820	122	89	621
	Example 32	32	964	9	915	49	37	449
50	Example 33	33	982	5	861	121	60	286
	Example 34	34	959	8	791	168	91	261

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(continued)

	Steel	Quenching					Tempering
		Quenching heating temp. (T ₁) (°C)	Cooling rate (°C/s) of primary cooling	Primary cooling stop temp. (T ₂) (°C)	T ₁ -T ₂ (°C)	Cooling rate (°C/s) of secondary cooling	Tempering heating temp. (°C)
Example 35	35	999	3	858	141	31	322
Example 36	36	967	7	869	98	97	554
Example 37	37	1040	4	820	220	46	256
Example 38	38	970	7	780	190	71	379
Example 39	39	1016	7	934	82	76	280
Example 40	40	1022	9	901	121	72	564
Example 41	41	1095	7	1049	46	72	626
Example 42	42	1007	8	909	98	63	500
Example 43	43	981	9	852	129	81	545
Example 44	44	1004	8	938	66	60	482
Example 45	45	1055	3	990	65	56	231
Example 46	46	1053	8	941	112	51	377
Example 47	47	955	9	886	69	74	363
Example 48	48	954	4	914	40	84	289
Example 49	49	1000	7	979	21	79	245
Example 50	50	981	3	856	125	92	313

[Table 4]

	Steel	Quenching					Tempering
		Quenching heating temp. (T ₁) (°C)	Cooling rate (°C/s) of primary cooling	Primary cooling stop temp. (T ₂) (°C)	T ₁ -T ₂ (°C)	Cooling rate (°C/s) of secondary cooling	Heating temp. (°C)
Example 51	51	978	6	893	85	75	213

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(continued)

5		Steel	Quenching					Tempering
			Quenching heating temp. (T ₁) (°C)	Cooling rate (°C/s) of primary cooling	Primary cooling stop temp. (T ₂) (°C)	T ₁ -T ₂ (°C)	Cooling rate (°C/s) of secondary cooling	Heating temp. (°C)
10	Example 52	52	1018	6	896	122	57	591
	Example 53	53	1001	7	979	22	60	363
	Example 54	54	1014	6	898	116	55	490
	Example 55	55	1018	6	900	118	61	263
15	Example 56	56	1022	3	949	73	59	545
	Example 57	57	1034	9	1007	27	65	398
	Example 58	58	1090	6	1065	25	89	588
	Example 59	59	1033	5	944	89	64	226
20	Example 60	60	993	6	915	78	38	458
	Example 61	61	1041	9	954	87	99	503
	Example 62	62	1037	9	963	74	83	282
	Example 63	63	1037	3	1017	20	37	348
25	Example 64	64	1023	8	1003	20	38	337
	Example 65	65	996	8	896	100	94	474
	Example 66	66	1053	4	934	119	90	430
	Example 67	67	981	7	851	130	44	525
30	Example 68	68	1019	4	928	91	87	451
	Example 69	69	1013	3	900	113	90	282
	Example 70	70	1004	3	889	115	62	311
	Comparative Example 1	<u>71</u>	934	9	765	169	73	288
40	Comparative Example 2	<u>72</u>	1037	3	809	228	47	387
	Comparative Example 3	<u>73</u>	1009	7	841	168	89	477
	Comparative Example 4	<u>74</u>	998	7	818	180	62	429
	Comparative Example 5	<u>75</u>	981	7	923	58	79	528
45	Comparative Example 6	<u>76</u>	994	8	793	201	85	384
	Comparative Example 7	<u>77</u>	949	7	805	144	80	242
	Comparative Example 8	<u>78</u>	988	3	818	170	61	661
	Comparative Example 9	<u>79</u>	992	5	885	107	79	273

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(continued)

	Steel	Quenching					Tempering
		Quenching heating temp. (T_1) (°C)	Cooling rate (°C/s) of primary cooling	Primary cooling stop temp. (T_2) (°C)	T_1-T_2 (°C)	Cooling rate (°C/s) of secondary cooling	Heating temp. (°C)
Comparative Example 10	80	977	8	844	133	74	435
Comparative Example 11	81	973	6	788	185	31	346
Comparative Example 12	82	1013	20	802	211	68	426
Comparative Example 13	82	800	5	740	60	50	350
Comparative Example 14	83	995	5	839	156	33	643
Comparative Example 15	84	1008	6	1003	5	40	647
Comparative Example 16	85	1021	6	780	241	39	388
Comparative Example 17	83	998	7	888	110	69	-

- Explanation of Tables 3 and 4 -

[0186]

- The primary cooling stop temperature T_2 coincides with the secondary cooling start temperature.
- In Comparative Example 17, "-" in the heating temperature column for tempering means that tempering was not performed.

[Table 5]

	Steel	First phase fraction (%)	Second phase fraction (%)	Second phase type	Evaluation results	
					Flawless pipe expandability (25%)	Flawed pipe expandability (16.5%)
Example 1	1	92.3	7.7	Tempered bainite + tempered martensite	A	A
Example 2	2	90.2	9.8	Tempered martensite	A	A
Example 3	3	96.5	3.5	Tempered martensite	A	A
Example 4	4	92.5	7.5	Tempered martensite	A	A
Example 5	5	96.8	3.2	Tempered martensite	A	A
Example 6	6	91.0	9.0	Pearlite + tempered bainite	A	A

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(continued)

5		Steel	First phase fraction (%)	Second phase fraction (%)	Second phase type	Evaluation results	
						Flawless pipe expandability (25%)	Flawed pipe expandability (16.5%)
10	Example 7	7	90.1	9.9	Tempered martensite	A	A
	Example 8	8	92.9	7.1	Tempered bainite	A	A
	Example 9	9	94.5	5.5	Tempered martensite	A	A
15	Example 10	10	91.6	8.4	Pearlite + tempered bainite	A	A
	Example 11	11	92.9	7.1	Tempered bainite	A	A
20	Example 12	12	90.8	9.2	Pearlite	A	A
	Example 13	13	94.9	5.1	Pearlite	A	A
25	Example 14	14	90.8	9.2	Tempered bainite	A	A
	Example 15	15	93.5	6.5	Pearlite + tempered bainite + Tempered martensite	A	A
30	Example 16	16	90.4	9.6	Pearlite	A	A
	Example 17	17	94.7	5.3	Tempered martensite	A	A
35	Example 18	18	92.6	7.4	Pearlite	A	A
	Example 19	19	90.5	9.5	Tempered martensite	A	A
40	Example 20	20	90.7	9.3	Tempered martensite	A	A
	Example 21	21	91.9	8.1	Pearlite + tempered bainite	A	A
45	Example 22	22	93.7	6.3	Pearlite	A	A
	Example 23	23	94.0	6.0	Tempered bainite	A	A
50	Example 24	24	90.4	9.6	Tempered martensite	A	A
	Example 25	25	92.0	8.0	Tempered martensite	A	A
55	Example 26	26	91.2	8.8	Tempered martensite	A	A

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(continued)

5		Steel	First phase fraction (%)	Second phase fraction (%)	Second phase type	Evaluation results	
						Flawless pipe expandability (25%)	Flawed pipe expandability (16.5%)
10	Example 27	27	90.2	9.8	Tempered martensite	A	A
	Example 28	28	93.4	6.6	Pearlite	A	A
	Example 29	29	95.2	4.8	Pearlite	A	A
15	Example 30	30	94.8	5.2	Tempered martensite	A	A
	Example 31	31	91.3	8.7	Tempered martensite	A	A
20	Example 32	32	96.3	3.7	Tempered martensite	A	A
	Example 33	33	91.8	8.2	Pearlite + tempered bainite	A	A
25	Example 34	34	91.6	8.4	Tempered martensite	A	A
	Example 35	35	94.3	5.7	Tempered martensite	A	A
30	Example 36	36	93.0	7.0	Tempered bainite	A	A
	Example 37	37	90.8	9.2	Tempered bainite	A	A
35	Example 38	38	90.4	9.6	Tempered martensite	A	A
	Example 39	39	95.6	4.4	Tempered martensite	A	A
40	Example 40	40	96.8	3.2	Pearlite	A	A
	Example 41	41	92.4	7.6	Tempered bainite	A	A
45	Example 42	42	93.9	6.1	Pearlite	A	A
	Example 43	43	92.0	8.0	Pearlite + tempered bainite	A	A
50	Example 44	44	93.4	6.6	Pearlite	A	A
	Example 45	45	94.1	5.9	Pearlite + tempered bainite + tempered martensite	A	A
55	Example 46	46	94.9	5.1	Tempered bainite	A	A

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(continued)

	Steel	First phase fraction (%)	Second phase fraction (%)	Second phase type	Evaluation results	
					Flawless pipe expandability (25%)	Flawed pipe expandability (16.5%)
Example 47	47	93.8	6.2	Pearlite	A	A
Example 48	48	92.4	7.6	Tempered bainite	A	A
Example 49	49	92.4	7.8	Pearlite	A	A
Example 50	50	92.6	7.4	Pearlite + tempered bainite + tempered martensite	A	A

[Table 6]

	Steel	First phase fraction (%)	Second phase fraction (%)	Second phase type	Evaluation results	
					Flawless pipe expandability (25%)	Flawed pipe expandability (16.5%)
Example 51	51	91.5	8.5	Tempered bainite	A	A
Example 52	52	94.0	6.0	Tempered bainite	A	A
Example 53	53	93.5	6.5	Tempered bainite	A	A
Example 54	54	95.9	4.1	Tempered bainite	A	A
Example 55	55	94.9	5.1	Tempered bainite	A	A
Example 56	56	93.4	6.6	Tempered bainite	A	A
Example 57	57	95.8	4.2	Tempered bainite	A	A
Example 58	58	96.8	3.2	Pearlite	A	A
Example 59	59	94.3	5.7	Tempered bainite	A	A
Example 60	60	92.8	7.2	Tempered bainite	A	A
Example 61	61	91.8	8.2	Pearlite + tempered bainite + tempered martensite	A	A
Example 62	62	94.0	6.0	Pearlite	A	A
Example 63	63	94.0	6.0	Tempered bainite	A	A
Example 64	64	94.2	5.8	Tempered bainite	A	A
Example 65	65	96.0	4.0	Tempered bainite	A	A
Example 66	66	91.8	8.2	Tempered bainite	A	A
Example 67	67	92.9	7.1	Tempered bainite	A	A
Example 68	68	93.6	6.4	Tempered bainite	A	A
Example 69	69	93.0	7.0	Pearlite + tempered bainite	A	A
Example 70	70	95.7	4.3	Tempered bainite	A	A

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(continued)

	Steel	First phase fraction (%)	Second phase fraction (%)	Second phase type	Evaluation results	
					Flawless pipe expandability (25%)	Flawed pipe expandability (16.5%)
Comparative Example 1	<u>71</u>	91.1	8.9	Tempered martensite	B	B
Comparative Example 2	<u>72</u>	90.6	9.4	Tempered bainite	B	A
Comparative Example 3	<u>73</u>	91.7	8.3	Pearlite	B	A
Comparative Example 4	<u>74</u>	92.4	7.6	Tempered martensite	B	A
Comparative Example 5	<u>75</u>	96.6	3.4	Pearlite	B	B
Comparative Example 6	<u>76</u>	90.8	9.2	Pearlite + tempered bainite	A	B
Comparative Example 7	<u>77</u>	90.7	9.3	Tempered martensite	A	B
Comparative Example 8	<u>78</u>	90.6	9.4	Tempered martensite	A	B
Comparative Example 9	<u>79</u>	94.7	5.3	Tempered bainite + tempered martensite	B	B
Comparative Example 10	<u>80</u>	92.9	7.1	Tempered martensite	B	B
Comparative Example 11	<u>81</u>	90.5	9.5	Tempered martensite	B	B
Comparative Example 12	82	70.0	30.0	Tempered martensite	A	B
Comparative Example 13	82	72.0	28.0	Tempered martensite	A	B
Comparative Example 14	83	85.0	15.0	Tempered martensite	A	B
Comparative Example 15	84	10.0	90.0	Tempered bainite	B	B
Comparative Example 16	85	98.7	1.3	Tempered martensite	B	A
Comparative Example 17	83	92.3	7.7	Martensite	A	B

[0187] As shown in Tables 1 to 6, the oil well pipes of Examples 1 to 70 having the chemical composition of the disclosure, wherein the first phase fraction was from 90.0% to 98.0%, the second phase fraction was from 2.0% to 10.0%, and the second phase type was one or more selected from the group consisting of tempered martensite, tempered bainite, and pearlite achieved both flawless pipe expandability and flawed pipe expandability.

[0188] In contrast to each Example, in the oil well pipes of Comparative Examples 1 to 11 having no chemical composition of the disclosure, at least one of the flawless pipe expandability and the flawed pipe expandability was deteriorated.

[0189] In the oil well pipe of Comparative Examples 12 to 15, in which the first phase fraction was less than 90.0%

and the second phase fraction was more than 10.0%, the flawed pipe expandability was deteriorated. Among the oil well pipes of Comparative Examples 12 to 15, in the oil well pipe of Comparative Example 15 in which the first phase fraction was 10.0% and the second phase fraction was 90.0%, the flawless pipe expandability was also deteriorated.

[0190] In the oil well pipe of Comparative Example 16 in which the first phase fraction exceeded 98.0% and the second phase fraction was less than 2.0%, the flawless pipe expandability was deteriorated.

[0191] In Comparative Example 17 in which the first phase fraction was from 90.0% to 98.0% and the second phase fraction was from 2.0% to 10.0%, and the second phase was composed of martensite (i.e., a DP steel), the flawed pipe expandability was deteriorated. The reason for this is considered to be that, when the second phase was composed of martensite, the strength was too high and strain concentration tended to occur in the metallographic microstructure, whereby generation and coalescence of voids tended to occur.

[0192] Fig. 1 is a scanning electron micrograph (SEM micrograph; magnification: 1,000 times) showing the metallographic microstructure of the oil well pipe of Example 1.

[0193] The micrographing position of the SEM micrograph in Fig. 1 is the same as the micrographing position of the SEM micrograph in the measurement of the first phase fraction and the second phase fraction (i.e., a position deviating at 90° in the circumferential direction of the pipe from the electric resistance welded portion, and the position to which the distance from the outer surface is 1/4 of the wall thickness) (this also applies to Fig. 2, Fig. 3A, and Fig. 3B to be described below). As in the SEM micrograph used for the measurement of the first phase fraction and the second phase fraction, the SEM micrograph of Fig. 1 was micrographed after polishing a cross-section of the oil well pipe and then etched with a Nital reagent (this also applies to Fig. 2, Fig. 3A, and Fig. 3B to be described below).

[0194] As shown in Fig. 1, the first phase composed of ferrite can be confirmed as a smooth region surrounded by grains, and the second phase composed of tempered bainite and tempered martensite can be confirmed as the other region. A carbide (i.e., cementite) can be confirmed as a white dot.

[0195] Fig. 2 is an SEM micrograph (magnification: 1,000 times) showing the metallographic microstructure of the oil well pipe of Comparative Example 17 (DP steel).

[0196] As shown in Fig. 2, the first phase composed of ferrite can be confirmed, and the second phase composed of martensite, which looks relatively white and featherlike as the other region, can be confirmed. A carbide (i.e., cementite) is not confirmed.

[0197] Fig. 3A is an SEM micrograph (magnification: 1,000 times) showing the metallographic microstructure of the oil well pipe of Comparative Example 14, and Fig. 3B is an SEM micrograph (magnification: 3,000 times) in which a part of Fig. 3A is enlarged.

[0198] In Fig. 3A and Fig. 3B, unlike Fig. 2, a carbide (i.e., cementite) can be confirmed as a white dot. As a result, it can be seen that the second phase was tempered martensite.

Claims

1. An oil well pipe for expandable tubular, comprising, in terms of % by mass:

0.020 to 0.080% of C,
0.50% or less of Si,
0.30 to 1.60% of Mn,
0.030% or less of P,
0.010% or less of S,
0.005 to 0.050% of Ti, and
0.010 to 0.500% of Al,

the balance being Fe and impurities,

wherein, in a metallographic microstructure, an area fraction of a first phase composed of ferrite is from 90.0% to 98.0% and an area fraction of a second phase composed of one or more selected from the group consisting of tempered martensite, tempered bainite and pearlite is from 2.0% to 10.0%.

2. The oil well pipe for expandable tubular according to claim 1, comprising, in terms of % by mass, one or more of:

0.100% or less of Nb,
1.00% or less of Ni,
1.00% or less of Cu,
0.50% or less of Mo,
1.00% or less of Cr,

0.100% or less of V, or
0.0060% or less of Ca.

3. The oil well pipe for expandable tubular according to claim 1 or 2, wherein a content of Al is, in term of % by mass, 0.060 to 0.500%.
4. The oil well pipe for expandable tubular according to any one of claims 1 to 3, which is an electric resistance welded steel pipe and satisfies the following Formula (1):

$$\text{Mn/Si} > 2.0 \quad \text{Formula (1)}$$

wherein, in Formula (1), Mn and Si each represent % by mass of each element.

FIG.1

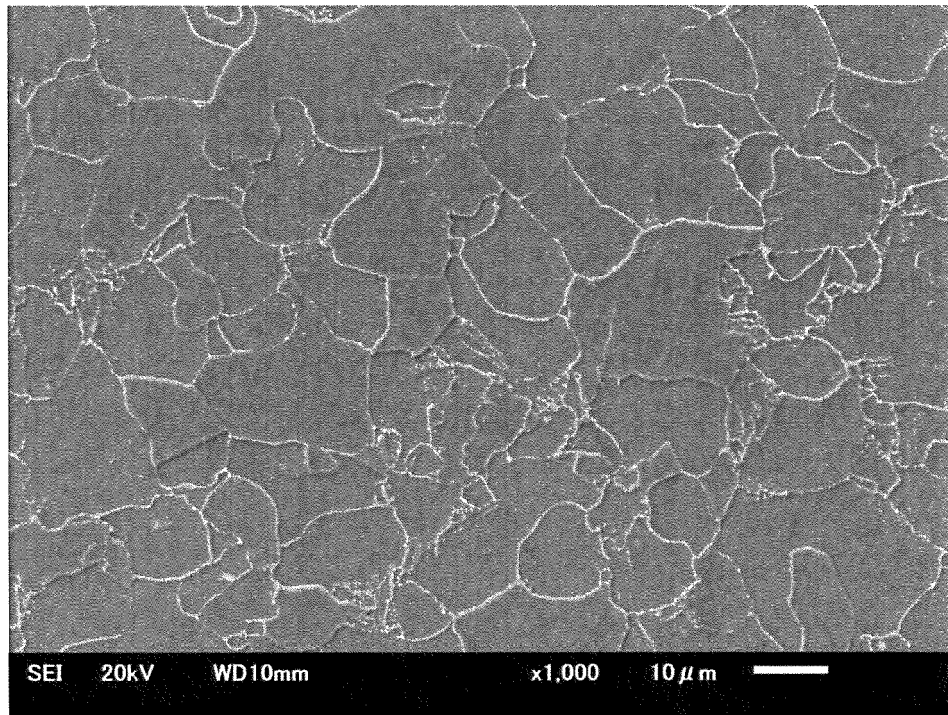


FIG.2

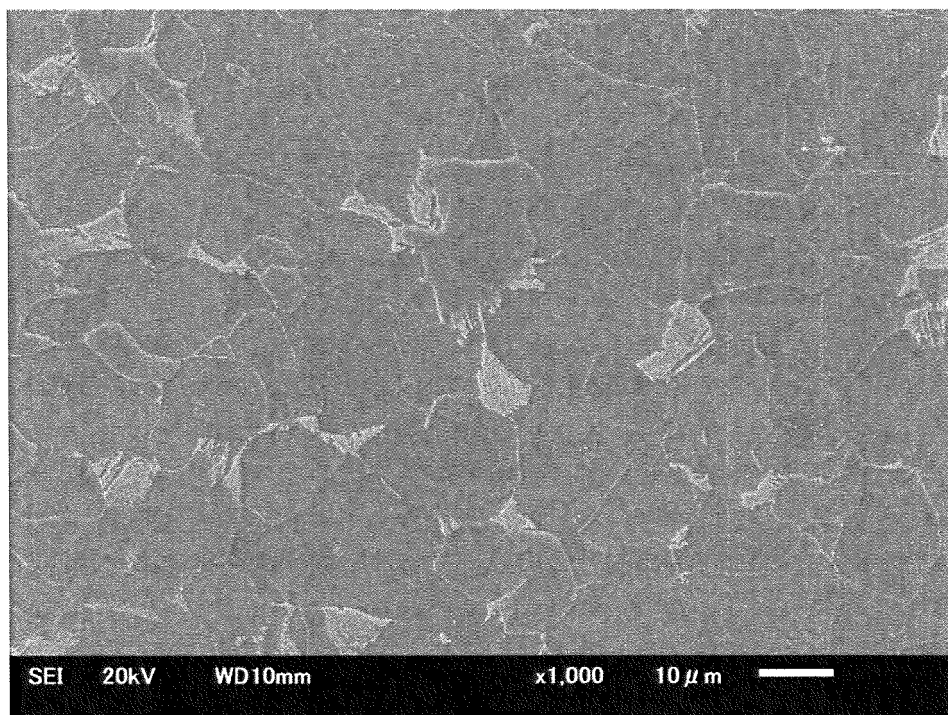


FIG.3A

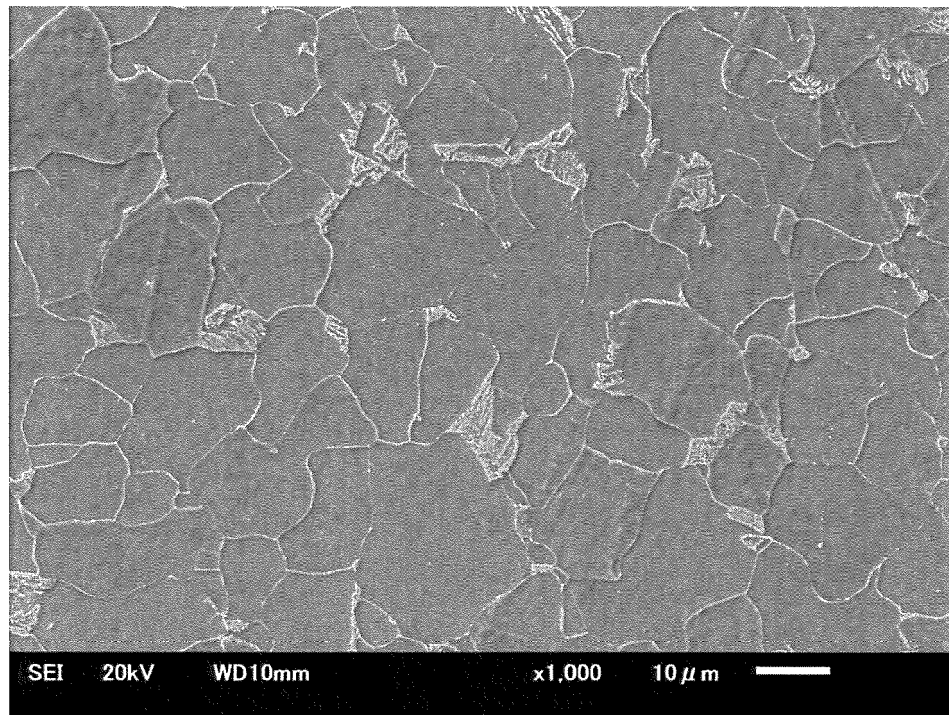
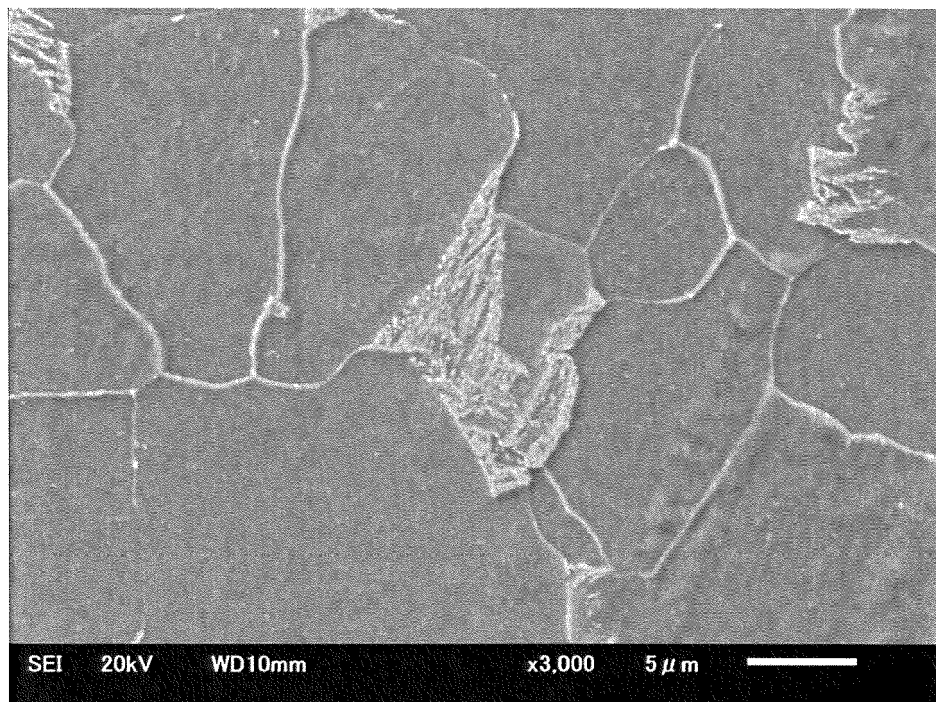


FIG.3B



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/075364

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C22C38/14(2006.01)i, C22C38/58(2006.01)i, C21D9/08(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00, C22C38/14, C22C38/58, C21D9/08

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016
Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

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.
X A	WO 2008/123025 A1 (Sumitomo Metal Industries, Ltd.), 16 October 2008 (16.10.2008), claims; paragraphs [0030] to [0050], [0058] to [0065]; examples; tables 1, 2 & US 2009/0032150 A1 claims; paragraphs [0030] to [0068], [0080] to [0088], examples; tables 1, 2 & EP 2000555 A1 & CA 2638681 A1 & CN 101541998 A & AU 2008207591 A1 & MX 2008012239 A	2, 4 1, 3
A	JP 2008-202128 A (Nippon Steel Corp.), 04 September 2008 (04.09.2008), (Family: none)	1-4

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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- JP 2002129283 A [0006]