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(54) **STEEL PLATE AND STEEL PIPE**

STAHLPLATTE UND STAHLROHR

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- **ZHANG JIMING ET AL: "Formation mechanism of nanoscale transformation twinning in ultra-low-carbon high-strength pipeline steels", JOURNAL OF MATERIAL SCIENCE, KLUWER ACADEMIC PUBLISHERS, DORDRECHT, vol. 54, no. 24, 22 August 2019 (2019-08-22), pages 14950 - 14960, XP036891892, ISSN: 0022-2461, [retrieved on 20190822], DOI: 10.1007/S10853-019-03930-W**
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Description

[Technical Field of the Invention]

5 **[0001]** The present invention relates to a steel plate and a steel pipe.

[Related Art]

10 **[0002]** In recent years, the mining conditions in oil wells and gas wells of crude oil, natural gas, and the like (hereinafter, oil wells and gas wells will be collectively referred to as simply "oil wells") have become harsh. As the mining depth increases, the mining environments of oil wells are more likely to contain CO₂, H₂S, Cl⁻, and the like, which makes crude oil and natural gas to be mined also contain a large amount of H₂S.

15 **[0003]** Therefore, requirements for the performance of line pipes that transport these crude oil and natural gas are becoming strict, and a demand for a steel pipe for a line pipe having high sulfide stress cracking resistance (hereinafter, also referred to as "SSC resistance") and hydrogen-induced crack resistance (hereinafter, also referred to as "HIC resistance") and a steel plate for a line pipe that becomes a material of such a steel pipe is increasing.

20 **[0004]** For steel that is used in an environment containing H₂S, there is a need to keep the maximum hardness of the steel low from the viewpoint of improving the SSC resistance. Therefore, for steel requiring sulfide resistance (SSC resistance or the like), improvement in techniques for suppressing the hardness has become an important issue.

25 **[0005]** For example, Patent Document 1 discloses a method for manufacturing high tensile strength steel having excellent SSC resistance and a 60 kgf/mm²-class tensile strength. In addition, Patent Document 2 discloses a thick steel plate having a tensile strength of 570 to 720 N/mm² and having a small hardness difference between a welded heat-affected zone and a base material and a method for manufacturing the same. Furthermore, Patent Document 3 describes a method for manufacturing a high-strength steel plate for a sour-gas-resistant line pipe having a X60-class or higher strength, the high-strength steel plate being capable of reducing surface hardness while preventing a decrease in the strength and the deterioration of DWTT characteristics.

30 **[0006]** According to Patent Documents 1 to 3, the hardness of the surface of the steel plate can be reduced by performing tempering after quenching. However, in these documents, a Vickers hardness test is performed in the hardness evaluation with the test force set to 98 N (10 kgf). As the test force becomes higher, the measurement region becomes larger. That is, the average hardness of the metallographic structure that is included in a wide region is measured. In addition, when the test force is high, the size of an indentation itself also becomes several hundred micrometers. Therefore, it is not possible to measure the hardness of the outermost layer of the steel plate, for example, in a range of several hundred micrometers from the surface layer.

35 **[0007]** However, as a result of the present inventors' studies, it was found that, even when the average hardness of the surface layer is suppressed to a certain extent, if a structure having high hardness is locally present, there is a concern that SSC may occur from the structure as a starting point. That is, since SSC is cracking occurring from the surface layer, it was found that, when a structure having high hardness is present in the outermost layer, there is a concern that SSC may occur from the structure as a starting point.

40 **[0008]** Therefore, in order to further improve the SSC resistance, there is a need to control the local maximum hardness that is obtained by performing a Vickers hardness test with a lower test force to be low. However, as described above, in Patent Documents 1 to 3, the Vickers hardness test was performed with the test force set to 98 N (10 kgf), but local hardness was not controlled.

45 **[0009]** Furthermore, for steel plates and steel pipes for line pipes that are used in cold regions, not only SSC resistance and HIC resistance but also low temperature toughness are required.

50 **[0010]** Patent Document 4 discloses a steel plate suitable for a line pipe for which the maximum hardness in the surface layer area is made to be 270 Hv or less to improve the SSC resistance and a steel pipe for which the steel plate is used as a base material. In addition, Patent Document 5 discloses a steel plate suitable for a line pipe for which the maximum hardness in the surface layer area is made to be 250 Hv or less to improve the SSC resistance and a steel pipe for which the steel plate is used as a base material.

55 **[0011]** However, in the techniques described in these documents, in the cooling of the steel plate, the cooling rate of the surface layer is made to be slow on an average using cooling including heat recuperation, thereby decreasing the hardness of the surface layer. Therefore, in these techniques, the microstructure control of the middle portion is not sufficiently performed, and there is a case where a stronger demand for low temperature toughness (DWTT) cannot be met.

60 **[0012]** Therefore, there has been a desire for a steel plate and a steel pipe each having low hardness in the surface layer and having excellent low temperature toughness (DWTT).

65 **[0013]** Patent Document 6 discloses an electric-resistance-welded steel pipe for a line pipe, in which the chemical composition of a matrix part contains, in % by mass, 0.04 to 0.12% of C, 0.01 to 0.50% of Si, 0.5 to 2.0% of Mn, 0.005 to

0.030% of Ti, 0.005 to 0.050% of Nb, 0.001 to 0.008% of N and a remainder made up by Fe and unavoidable impurities and, when the thickness of the matrix part is defined as t_B and the thickness of an electric-resistance-welded part is defined as t_S , the value determined by subtracting a value of the hardness of a $1/2t_B$ part in the matrix part from a value of the hardness of an outer surface layer part B that is located at a depth of 1 mm from the outer surface of the matrix part is 30 HV10 or less, the value determined by subtracting a value of the hardness of a $1/2t_S$ part in the electric-resistance-welded part from a value of the hardness of an outer surface layer S that is located at a depth of 1 mm from the outer surface of the electric-resistance-welded part is 0 to 30 HV10 inclusive, and each of t_B and t_S is 15 mm or more.

[Prior Art Document]

[Patent Document]

[0014]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. H2-8322
 [Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2001-73071
 [Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2002-327212
 [Patent Document 4] PCT International Publication No. WO 2019/058420 (also published as JP 6 344538 B1)
 [Patent Document 5] PCT International Publication No. WO 2019/058422
 [Patent Document 6] JP 6 587041 B1

[Non-Patent Document]

[0015] The Bainite Research Committee of The Iron and Steel Institute of Japan, "Atlas for Bainitic Microstructures Vol. 1," The Iron and Steel Institute of Japan, published in June 1992

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0016] An object of the present invention is to solve the above-described problems and to provide a steel plate and a steel pipe having excellent SSC resistance and HIC resistance and excellent low temperature toughness.

[Means for Solving the Problem]

[0017] The present invention is disclosed in the Appended Claims.

[0018] In the present invention, "HV0.1" means a "hardness symbol" in a case where a Vickers hardness test is performed with a test force set to 0.98 N (0.1 kgf) (refer to JIS Z 2244: 2009).

[Effects of the Invention]

[0019] According to the above-described aspects of the present invention, it become possible to obtain a steel plate and a steel pipe having excellent SSC resistance and HIC resistance and excellent low temperature toughness. Such a steel pipe is suitable for a use in line pipes, and such a steel plate is suitable as a material for steel pipes for line pipes.

[Embodiments of the Invention]

[0020] Hereinafter, each requirement of a steel plate according to an embodiment of the present invention (steel plate according to the present embodiment) and a steel pipe according to an embodiment of the present invention (steel pipe according to the present embodiment) will be described in detail.

<Steel plate>

[0021] First, the steel plate according to the present embodiment will be described.

1. Chemical composition

[0022] The reasons for limiting each element are as described below. In the following description, "%" regarding

amounts means "mass%". In addition, numerical value-limiting ranges expressed using "to" include values sandwiching "to" as the lower limit and the upper limit. On the other hand, numerical values expressed with 'more than' or 'less than' are not included in numerical ranges.

5 C: 0.020% to 0.080%

[0023] C is an element that improves the strength of steel. When the C content is less than 0.020%, the strength improvement effect cannot be sufficiently obtained. Therefore, the C content is set to 0.020% or more. The C content is preferably 0.030% or more.

10 **[0024]** On the other hand, when the C content exceeds 0.080%, the hardness of the surface layer increases, and SSC is likely to occur. Therefore, the C content is set to 0.080% or less. In order to secure the SSC resistance and suppress the deterioration of the weldability and the toughness, the C content is preferably 0.060% or less and more preferably 0.055% or less.

15 Si: 0.01% to 0.50%

[0025] Si is an element added for deoxidation. When the Si content is less than 0.01%, the deoxidation effect cannot be sufficiently obtained, and the manufacturing cost significantly increases. Therefore, the Si content is set to 0.01% or more. The Si content is preferably 0.05% or more and more preferably 0.10% or more.

20 **[0026]** On the other hand, when the Si content exceeds 0.50%, the toughness of the weld deteriorates. Therefore, the Si content is set to 0.50% or less. The Si content is preferably 0.40% or less and more preferably 0.30% or less.

Mn: 0.50% to 1.60%

25 **[0027]** Mn is an element that improves the strength and the toughness. When the Mn content is less than 0.50%, the effect of Mn contained cannot be sufficiently obtained. Therefore, the Mn content is set to 0.50% or more. The Mn content is preferably 1.00% or more and more preferably 1.20% or more.

[0028] On the other hand, when the Mn content exceeds 1.60%, the hydrogen-induced crack resistance (HIC resistance) deteriorates. Therefore, the Mn content is set to 1.60% or less. The Mn content is preferably 1.50% or less.

30 Nb: 0.001% to 0.100%

[0029] Nb is an element that forms a carbide or a nitride and contributes to improvement in the strength of steel. In addition, Nb has an action of expanding the non-recrystallization temperature range toward the high temperature range and is thus an element that contributes to improvement in the toughness by grain refinement. When the Nb content is less than 0.001%, the above-described effect cannot be sufficiently obtained. Therefore, the Nb content is set to 0.001% or more. The Nb content is preferably 0.005% or more and more preferably 0.010% or more.

35 **[0030]** On the other hand, when the Nb content exceeds 0.100%, coarse carbide or nitride are formed, and the HIC resistance and the toughness deteriorate. Therefore, the Nb content is set to 0.100% or less. The Nb content is preferably 0.080% or less and more preferably 0.060% or less.

N: 0.0010% to 0.0100%

45 **[0031]** N is an element that forms a nitride with Ti or Nb and contributes to the refinement of austenite grain sizes during heating. When the N content is less than 0.0010%, the above-described effect cannot be sufficiently obtained, and it requires a considerable manufacturing cost to set the N content to less than 0.0010% in commercial manufacturing steps. Therefore, the N content is set to 0.0010% or more. The N content is preferably 0.0020% or more.

[0032] On the other hand, when the N content exceeds 0.0100%, a coarse carbonitride is formed, and the HIC resistance and the toughness deteriorate. Therefore, the N content is set to 0.0100% or less. The N content is preferably 0.0060% or less.

Ca: 0.0001% to 0.0050%

55 **[0033]** Ca is an element that forms CaS, suppresses the formation of MnS that extends in a rolling direction, and contributes to improvement in the HIC resistance. When the Ca content is less than 0.0001%, the above-described effect cannot be sufficiently obtained. Therefore, the Ca content is set to 0.0001% or more. The Ca content is preferably 0.0005% or more and more preferably 0.0010% or more.

[0034] On the other hand, when the Ca content exceeds 0.0050%, an oxide piles up, and the HIC resistance

deteriorates. Therefore, the Ca content is set to 0.0050% or less. The Ca content is preferably 0.0045% or less and more preferably 0.0040% or less.

P: 0.030% or less

[0035] P is an element that is contained as an impurity. When the P content exceeds 0.030%, the SSC resistance and the HIC resistance deteriorate. In addition, in a case where welding is performed, the toughness of the weld deteriorates. Therefore, the P content is set to 0.030% or less. The P content is preferably 0.015% or less and more preferably 0.010% or less. An excess decrease in the P content leads to a significant increase in the manufacturing cost, and thus 0.001% is the substantial lower limit.

S: 0.0025% or less

[0036] S is an element that is contained as an impurity and forms MnS that extends in the rolling direction during hot rolling to impair the HIC resistance. When the S content exceeds 0.0025%, the HIC resistance significantly deteriorates. Therefore, the S content is set to 0.0025% or less. The S content is preferably 0.0015% or less and more preferably 0.0010% or less. An excess decrease in the S content leads to a significant increase in the manufacturing cost, and thus 0.0001% is a substantial lower limit.

Ti: 0.005% to 0.030%

[0037] Ti is an element that forms a nitride and contributes to the refinement of grains. When the Ti content is less than 0.005%, the above-described effect cannot be sufficiently obtained. Therefore, the Ti content is set to 0.005% or more. The Ti content is preferably 0.008% or more.

[0038] On the other hand, when the Ti content exceeds 0.030%, not only does the toughness deteriorate, but a coarse nitride is also formed, and the HIC resistance deteriorates. Therefore, the Ti content is set to 0.030% or less. The Ti content is preferably 0.020% or less.

Al: 0.010% to 0.040%

[0039] Al is an element added for deoxidation. When the Al content is less than 0.010%, the above-described effects cannot be sufficiently obtained. Therefore, the Al content is set to 0.010% or more. The Al content is preferably 0.015% or more.

[0040] On the other hand, when the Al content exceeds 0.040%, an Al oxide piles up, and the HIC resistance deteriorates. Therefore, the Al content is set to 0.040% or less. The Al content is preferably 0.035% or less.

O: 0.0040% or less

[0041] O is an impurity element that remains inevitably after deoxidation. When an O content exceeds 0.0040%, an oxide is formed to degrade the toughness and the HIC resistance. Therefore, the O content is set to 0.0040% or less. The O content is preferably 0.0030% or less. The O content is preferably as small as possible, but an excess decrease in the O content leads to a significant increase in the manufacturing cost. Therefore, 0.0010% is a substantial lower limit.

[0042]

Mo: 0% to 2.00%

Cr: 0% to 2.00%

Cu: 0% to 2.00%

Ni: 0% to 2.00%

$$0.05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2.00 \cdots (i)$$

[0043] Here, each element symbol in the formulae represents the amount (mass%) of each element contained in steel and is regarded as 0 (zero) in a case where the corresponding element is not contained.

[0044] Mo, Cr, Cu, and Ni are elements that contribute to improvement in hardenability. In order to adjust Ceq, which is an index of hardenability to be described below, the total amount of these elements is set to 0.05% or more. The total amount of these elements is preferably 0.07% or more and more preferably 0.10% or more.

[0045] On the other hand, when the total amount of Mo, Cr, Cu, and Ni exceeds 2.00%, the hardness of steel increases to

degrade the SSC resistance. Therefore, the total amount of Mo, Cr, Cu, and Ni is set to 2.00% or less. The total amount is preferably 1.00% or less and more preferably 0.90% or less. The amount of each of Mo, Cr, Cu, and Ni is preferably 1.00% or less and more preferably 0.50% or less.

5 W: 0% to 1.00%

[0046] W is an effective element for improvement in the strength of steel. Therefore, W may be contained as necessary. In order to obtain the above-described effect, the W content is preferably 0.01% or more and more preferably 0.05% or more.

10 **[0047]** However, when the W content exceeds 1.00%, there is a case where the hardness increases to degrade the SSC resistance and degrade the toughness. Therefore, even in a case where W is contained, the W content is set to 1.00% or less. The W content is preferably 0.50% or less and more preferably 0.30% or less.

V: 0% to 0.200%

15 **[0048]** V is an element that forms a carbide or a nitride and contributes to improvement in the strength of steel. Therefore, V may be contained as necessary. In order to obtain the above-described effect, the V content is preferably 0.010% or more and more preferably 0.030% or more.

20 **[0049]** However, when the V content exceeds 0.200%, the toughness of steel deteriorates. Therefore, even in a case where V is contained, the V content is set to 0.200% or less. The V content is preferably 0.100% or less and more preferably 0.080% or less.

Zr: 0% to 0.0500%

25 **[0050]** Similar to V, Zr is an element that forms a carbide or a nitride and contributes to improvement in the strength of steel. Therefore, Zr may be contained as necessary. In order to obtain the above-described effect, the Zr content is preferably 0.0001% or more and more preferably 0.0005% or more.

30 **[0051]** However, when the Zr content exceeds 0.0500%, there is a case where the toughness of steel deteriorates. Therefore, even in a case where Zr is contained, the Zr content is set to 0.0500% or less. The Zr content is preferably 0.0200% or less and more preferably 0.0100% or less.

Ta: 0% to 0.0500%

35 **[0052]** Similar to V, Ta is an element that forms a carbide or a nitride and contributes to improvement in the strength. Therefore, Ta may be contained as necessary. In order to obtain the above-described effect, the Ta content is preferably 0.0001 % or more and more preferably 0.0005% or more.

[0053] However, when the Ta content exceeds 0.0500%, there is a case where the toughness of steel deteriorates. Therefore, even in a case where Ta is contained, the Ta content is set to 0.0500% or less. The Ta content is preferably 0.0200% or less and more preferably 0.0100% or less.

40

B: 0% to 0.0020%

45 **[0054]** B is an element that is segregated at grain boundaries in steel to significantly contribute to improvement in the hardenability. Therefore, B may be contained as necessary. In order to obtain the above-described effect, the B content is preferably 0.0001% or more and more preferably 0.0005% or more.

[0055] However, when the B content exceeds 0.0020%, there is a case where the toughness of steel deteriorates. Therefore, even in a case where B is contained, the B content is set to 0.0020% or less. The B content is preferably 0.0015% or less and more preferably 0.0012% or less.

50 REM: 0% to 0.0100%

[0056] REM is an element that controls the form of a sulfide-based inclusion and contributes to improvement in the SSC resistance, the HIC resistance and the toughness. Therefore, REM may be contained as necessary. In order to obtain the above-described effect, the REM content is preferably 0.0001% or more and more preferably 0.0010% or more.

55 **[0057]** However, when the REM content exceeds 0.0100%, a coarse oxide is formed, which causes not only a decrease in the cleanliness of steel, but also the deterioration of the HIC resistance and the toughness. Therefore, even in a case where REM is contained, the REM content is set to 0.0100% or less. The REM content is preferably 0.0060% or less.

[0058] Here, REM refers to a total of 17 elements of Sc, Y, and lanthanoids, and the REM content means the total amount

of these elements.

Mg: 0% to 0.0100%

[0059] Mg is an element that forms a fine oxide to suppress the coarsening of grains and contribute to improvement in the toughness. Therefore, Mg may be contained as necessary. In order to obtain the above-described effect, the Mg content is preferably 0.0001% or more and more preferably 0.0010% or more.

[0060] However, when the Mg content exceeds 0.0100%, an oxide agglomerates and coarsens, the HIC resistance deteriorates, and the toughness deteriorates. Therefore, even in a case where Mg is contained, the Mg content is set to 0.0100% or less. The Mg content is preferably 0.0050% or less.

Hf: 0% to 0.0050%

[0061] Similar to Ca, Hf is an element that forms a sulfide, suppresses the formation of MnS extended in the rolling direction, and contributes to improvement in the HIC resistance. Therefore, Hf may be contained as necessary. In order to obtain the above-described effect, the Hf content is preferably 0.0001% or more and more preferably 0.0005% or more.

[0062] However, when the Hf content exceeds 0.0050%, an oxide increases, agglomerates, and coarsens, and the HIC resistance deteriorates. Therefore, even in a case where Hf is contained, the Hf content is set to 0.0050% or less. The Hf content is preferably 0.0040% or less and more preferably 0.0030% or less.

Re: 0% to 0.0050%

[0063] Similar to Ca, Re is an element that forms a sulfide, suppresses the formation of MnS extended in the rolling direction, and contributes to improvement in the HIC resistance. Therefore, Re may be contained as necessary. In order to obtain the above-described effect, the Re content is preferably 0.0001% or more and more preferably 0.0005% or more.

[0064] However, when the Re content exceeds 0.0050%, an oxide increases, agglomerates, and coarsens, and the HIC resistance deteriorates. Therefore, even in a case where Re is contained, the Re content is set to 0.0050% or less. The Re content is preferably 0.0040% or less and more preferably 0.0030% or less.

[0065] In the chemical composition of the steel plate according to the present embodiment, the remainder is Fe and impurities. Here, the "impurities" mean components that are mixed in from a raw material such as ore or a scrap or due to a variety of factors in manufacturing steps at the time of industrially manufacturing steel and are allowed to an extent that the steel plate according to the present embodiment is not adversely affected.

Ceq: 0.30 to 0.50

[0066] In the steel plate according to the present embodiment, after the amount of each element is controlled as described above, there is a need to set Ceq, which is calculated from the amount of each element, within a predetermined range. Ceq is a value that serves as an index of hardenability and is represented by the following formula (ii).

[0067] When Ceq is less than 0.30, a required strength cannot be obtained. On the other hand, when Ceq exceeds 0.50, the hardness of the surface layer becomes high, and the SSC resistance deteriorates. Therefore, Ceq is set to 0.30 to 0.50. Ceq is preferably 0.33 or more and preferably 0.45 or less.

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

[0068] Here, each element symbol in the formulae represents the amount (mass%) of each element contained in steel and is regarded as zero in a case where the corresponding element is not contained.

2. Metallographic structure

<Metallographic structure in thickness middle portion including, by area%, 0% to 80% of polygonal ferrite and one or two selected from acicular ferrite and bainite and remainder being M-A phase>

[0069] In the steel plate according to the present embodiment, the metallographic structure in a thickness middle portion includes, by area%, 0% to 80% of polygonal ferrite and one or two selected from acicular ferrite and bainite, and the remainder is an M-A phase.

[0070] When martensite is included in the metallographic structure in steel, the strength of the steel excessively increases, which makes it difficult to keep the hardness of the surface layer low. Therefore, the chemical composition of

steel is adjusted, particularly, the value of C_{eq} is set within an appropriate range, and controlled cooling is performed after hot rolling as described below, thereby suppressing the formation of martensite.

[0071] Therefore, in consideration of the balance between the strength and the hardness of the surface layer, as the metallographic structure in the thickness middle portion, a structure including polygonal ferrite, acicular ferrite and/or bainite is formed.

[0072] When the area ratio of the polygonal ferrite exceeds 80%, it becomes difficult to obtain a required strength, and the HIC resistance also deteriorates. Therefore, the area ratio of the polygonal ferrite is set to 80% or less. The area ratio of the polygonal ferrite is preferably 60% or less.

[0073] When polygonal ferrite is included in steel, it becomes possible to improve the toughness. Therefore, in a case where more excellent low temperature toughness is required, the area ratio of the polygonal ferrite is preferably set to 20% or more.

[0074] Incidentally, in a case where more excellent HIC resistance is required, as the metallographic structure in the thickness middle portion, a structure mainly including acicular ferrite and bainite is preferably formed. In this case, it is preferable to set the area ratio of the polygonal ferrite to less than 20% and to set the total area ratio of the acicular ferrite and the bainite to 80% or more. The total area ratio of the acicular ferrite and the bainite is more preferably 90% or more.

[0075] In the metallographic structure in the thickness middle portion, the remainder other than the polygonal ferrite, the acicular ferrite, and the bainite is an M-A phase. The M-A phase is preferably 5.0% or less. The M-A phase may not be included.

<Effective grain size in thickness middle portion: 15.0 μm or less>

[0076] In addition, the effective grain size in the thickness middle portion is 15.0 μm or less. When crystals in the thickness middle portion are refined, it becomes possible to secure favorable low temperature toughness. In the case of securing more favorable low temperature toughness, the effective grain size is preferably 10.0 μm or less.

<Metallographic structure in surface layer including, by area%, total of 95% or more of one or two selected from acicular ferrite and bainite and remainder being M-A phase>

[0077] In the steel plate according to the present embodiment, as the metallographic structure in the surface layer that is a range of 1.0 mm in the thickness direction from the surface, a structure including one or two selected from acicular ferrite and bainite with the remainder of an M-A phase is formed.

[0078] The cooling rate of the surface layer is relatively fast compared to that in steel, and martensite is likely to be formed in a cooling process after hot rolling. When this martensite remains in the final structure without being sufficiently affected by a tempering effect, the SSC resistance deteriorates. Therefore, as the metallographic structure in the surface layer, a structure mainly including acicular ferrite and/or bainite is formed. In addition, in order to set the maximum hardness of the surface layer within a range to be described below, it is desirable to set the hardness of the surface layer to be extremely uniform. When acicular ferrite or bainite is included in the surface layer, an effect on setting the hardness uniform can be obtained, which is preferable.

[0079] The total area ratio of the acicular ferrite and the bainite is preferably 97% or more, more preferably 98% or more, and still more preferably 99% or more and may be 100%.

[0080] In the metallographic structure in the surface layer, the remainder is an M-A phase. Here, the M-A phase may not be included.

[0081] Here, in the steel plate according to the present embodiment, "acicular ferrite" refers to a structure formed of one or more selected from quasi-polygonal ferrite (α_q), Widmanstetten ferrite (α_w), and granular bainite (α_B) as defined in Non-Patent Document 1. Bainite means a structure including bainitic ferrite (α_B) having a substructure in grains. In addition, the M-A phase (martensite-austenite constituent) means a complex of martensite ($a'm$) and austenite (γ).

[0082] The area ratio of each phase in the metallographic structure and the effective grain size in the thickness middle portion are obtained as described below.

[0083] First, two test pieces having an overall thickness are cut out from a position of a 1/4 position (1/4 width) of the plate width from one end portion in the width direction of the steel plate such that a cross section in the L (longitudinal) direction from a steel sample becomes an observed section and are each used for structure observation and for grain size measurement.

[0084] The test piece for structure observation is polished in a wet manner to finish the test piece into a mirror surface, and then a metallographic structure is revealed using an etching solution. As the etching solution, Nital is used. In addition, the structures of the surface layer and the thickness middle portion are observed at a magnification of 100 times to 1000 times using an optical microscope or SEM on the L-direction cross section, and each structure is confirmed. After that, the kind of each structure is confirmed at a magnification of 200 times or 500 times.

[0085] As described in Non-Patent Document 1, the polygonal ferrite α_p has a rounded polygonal shape and is a

recovered structure in which a substructure such as a lath or block that looks like cementite, residual austenite, an M-A phase, bainite, and martensite is not present in grains. The quasi-polygonal ferrite shows a complicated shape and is similar particularly to granular bainite in some cases, but, similar to the polygonal ferrite, does not include any substructure due to diffusion transformation, and is a structure that straddles prior austenite grain boundaries. The Widmanstetten ferrite is ferrite having a needle-like shape. The granular bainite shows a complicated shape and has no clear substructure recognized compared with bainite and is thus similar to the quasi-polygonal ferrite, but is different from the quasi-polygonal ferrite in that the granular bainite is a structure that includes cementite, residual austenite, and an M-A phase in grains or does not straddle prior austenite grain boundaries. However, in the present embodiment, since a structure formed of one or more of quasi-polygonal ferrite, Widmanstetten ferrite, and granular bainite is defined as acicular ferrite, there is no need to distinguish quasi-polygonal ferrite and granular bainite.

[0086] The bainite is a structure including bainitic ferrite having a substructure in grains. Bainite can be distinguished into upper bainite including residual austenite or an M-A phase between lath-shaped bainitic ferrite (BI type), upper bainite including cementite between lath-shaped bainitic ferrite (BII type), lath-shaped lower bainite including cementite in lath-shaped bainitic ferrite (BIII type), and lower bainite including cementite in plate-shaped bainitic ferrite; however, in the present embodiment, all of them are included in bainite.

[0087] Therefore, each structure is determined based on the above-described characteristics at the time of determination.

[0088] For the M-A phase, the test piece for structure observation is polished in a wet manner to finish the test piece into a mirror surface, and then a metallographic structure is revealed using an etching solution. As the etching solution, LePera is used. In addition, on the L-direction cross section, the structure is observed at a magnification of 500 times using an optical microscope, and the area ratio is measured.

[0089] In the test piece for grain size measurement, the thickness middle portion is observed using a SEM-EBSD device, a region surrounded by high-angle grain boundaries with an inclination angle of 15° or more is defined as a grain, and the grain size of the grain is obtained, thereby obtaining the effective grain size. Specifically, a region surrounded by grain boundaries with an angle difference of 15° or more measured with OIM Analysis of TSL Solutions, which is EBSD analysis software, is defined as a grain, and the average diameter of a circle having the same area as the grain (equivalent circle diameter) is regarded as the grain size. Here, a region having an equivalent circle diameter of 0.5 μm or less is ignored. In the present embodiment, among the average grain sizes calculated with the OIM Analysis, the average value by the Area Fraction method is used as the effective grain size. In addition, regarding the polygonal ferrite fraction, the area ratio of the polygonal ferrite may be measured based on the difference in shape in the observation using an optical microscope or SEM as described above; however, since there is no substructure such as a lath or block that looks like bainite or martensite in polygonal ferrite grains, the same polygonal ferrite fraction can be obtained by measuring the area ratio of a structure having no intragranular angle difference, which is attributed to the lath or block. In the case of measuring the area ratio of a structure having no intragranular angle difference, a region where the angle difference up to the secondary proximity by the KAM (Karnel Average Misorientation) method in which OIM Analysis of TSL Solutions is used is 1° or less is defined as the polygonal ferrite, and the polygonal ferrite fraction is obtained.

[0090] The step interval at the time of EBSD measurement is set to 0.5 μm so that the angle difference between substructures such as a lath or a block in the bainite structure is measured.

3. Mechanical properties

Maximum hardness of surface layer: 250 HV0.1 or less

[0091] As described above, in order to improve the SSC resistance, it is necessary to keep the maximum hardness of the surface layer steel low. In addition, even when the average hardness of the surface layer in a relatively wide range is suppressed, if a structure having high hardness is locally present, there is a concern that SSC may occur from the structure as a starting point. Therefore, in the present embodiment, the hardness in the surface layer is evaluated by a Vickers hardness test in which the test force is set to 0.98 N (0.1 kgf). When the maximum hardness of the surface layer is 250 HV0.1 or less, the SSC resistance improves. Therefore, the maximum hardness of the surface layer is set to 250 HV0.1 or less.

[0092] In the present embodiment, the maximum hardness of the surface layer, which is a range from the surface to a depth of 1.0 mm, is measured as described below.

[0093] First, 300 mm x 300 mm steel plates are cut out by gas cutting from 1/4, 1/2, and 3/4 positions of the plate width in the width direction of the steel plate from an end portion of the steel plate in the width direction, and block test pieces having a length of 20 mm and a width of 20 mm are collected by mechanical cutting from the center of the cut-out steel plates and polished by mechanical polishing. In one block test piece, the hardness is measured with a Vickers hardness meter (load: 0.1 kgf) at a total of 100 points (10 points at 1.0 mm intervals in the width direction at each of 10 depth points at 0.1 mm intervals in the plate thickness direction from a position 0.1 mm deep from the surface in the plate thickness direction as a

starting point). That is, the hardness is measured at a total of 300 points in three block test pieces.

[0094] Even when there is one measurement point where the hardness exceeds 250 HV as a result of the measurement, the point is regarded as an abnormal point and is not adopted unless two or more abnormal points continuously appear in the plate thickness direction, and the next highest value is regarded as the maximum hardness. On the other hand, in a case where there are two or more measurement points with hardness of more than 250 HV continuously present in the plate thickness direction, the highest value thereof is adopted as the maximum hardness.

Tensile strength: 480 MPa or more

[0095] In the steel plate according to the present embodiment, the tensile strength is not particularly limited; however, for line pipes that are used in H₂S environments where the steel plate according to the present embodiment is assumed to be used, it is ordinary to use X52, X60, or X65-grade materials in many cases. In order to satisfy such a requirement, the tensile strength is preferably 480 MPa or more and more preferably 500 MPa or more.

[0096] On the other hand, when the tensile strength exceeds 700 MPa, there is a case where the SSC resistance or the HIC resistance deteriorates. Therefore, the tensile strength is preferably 700 MPa or less.

[0097] The tensile strength is obtained by working a round bar-like tensile test piece such that the longitudinal direction of the test piece becomes parallel to the width direction of the steel plate and performing a tensile test according to API 5L.

4. Plate thickness

[0098] The plate thickness of the steel plate according to the present embodiment is not particularly limited. However, from the viewpoint of improving the transport efficiency of a fluid flowing through a line pipe that has been produced using the steel plate according to the present embodiment, the plate thickness is preferably 16.0 mm or more and more preferably 19.0 mm or more.

[0099] On the other hand, the hardness of the surface layer is increased by work hardening during the forming of a steel pipe, and, normally, as the wall thickness increases, the hardness of the surface layer increases. In addition, when the wall thickness is increased, it becomes difficult to refine crystals in the thickness middle portion. Therefore, the plate thickness is preferably 35.0 mm or less, more preferably 30.0 mm or less, and still more preferably 25.0 mm or less.

<Steel pipe>

[0100] Next, a steel pipe according to the present embodiment will be described.

1. Base material portion

<Chemical composition, metallographic structure, and mechanical characteristics>

[0101] The steel pipe according to the present embodiment has a base material portion made of a tubular steel plate and a weld that is provided at an abutment portion of the steel plate and extends in the longitudinal direction of the steel plate. Such a steel pipe can be obtained by working the steel plate according to the present embodiment into a tubular shape and welding the abutment portion.

[0102] Therefore, the reasons for limiting the chemical composition, metallographic structure, and the maximum hardness of the surface layer of the base material portion (steel plate) of the steel pipe according to the present embodiment are the same as those for the steel plate according to the present embodiment.

[0103] However, as an observed section of the metallographic structure in the steel pipe, two test pieces having an overall thickness are cut out from a position at 90° from a seam weld in the steel pipe such that a cross section in the L (longitudinal) direction becomes the observed section and are each used for structure observation and for grain size measurement. The 90° position corresponds to the 114 or 3/4 position of the plate width of the steel plate.

[0104] In addition, the maximum hardness of the surface layer is measured by the following method.

[0105] First, 300 mm x 300 mm steel plates are each cut out by gas cutting from a three o'clock, six o'clock, or nine o'clock position in a case where the weld of the steel pipe is defined at zero o'clock (position at 90°, 180°, or 270° from the seam weld), and block test pieces having a length of 20 mm and a width of 20 mm are collected by mechanical cutting from the center of the cut-out steel plates and polished by mechanical polishing. In one block test piece, the hardness is measured with a Vickers hardness meter (load: 0.1 kgf) at a total of 100 points (10 points at 1.0 mm intervals in the width direction at each of 10 depth points at 0.1 mm intervals in the plate thickness direction from 0.1 mm deep from the surface as a starting point). That is, the hardness is measured at a total of 300 points in three block test pieces.

[0106] As a result of the measurement, unless two or more measurement points with hardness of more than 250 HV continuously appear in the wall thickness direction, the maximum hardness of the surface layer is determined to be 250

HV0.1 or less.

Tensile strength: 480 MPa or more

- 5 **[0107]** In the steel pipe according to the present embodiment, the tensile strength is not particularly limited; however, for line pipes that are used in H₂S environments, it is ordinary to use X52, X60, or X65-grade materials in many cases. In order to satisfy such a requirement, the tensile strength is preferably 480 MPa or more and more preferably 500 MPa or more.
- [0108]** On the other hand, when the tensile strength exceeds 700 MPa, there is a case where the SSC resistance or the HIC resistance deteriorates. Therefore, the tensile strength is preferably 700 MPa or less.
- 10 **[0109]** The tensile strength is obtained by collecting a round bar-like test piece from a position at 180° from the seam portion of the steel pipe such that the longitudinal direction becomes parallel to the width direction of the steel plate and performing a tensile test according to API 5L.

Wall thickness

- 15 **[0110]** The wall thickness of the steel pipe according to the present embodiment is not particularly limited. However, from the viewpoint of improving the transport efficiency of a fluid flowing through a line pipe, the wall thickness is preferably 16.0 mm or more and more preferably 19.0 mm or more.
- [0111]** On the other hand, the hardness of the surface layer is increased by work hardening during the forming of a steel pipe, and, normally, as the wall thickness increases, the hardness of the surface layer increases. In addition, when the wall thickness is increased, it becomes difficult to refine crystals in the thickness middle portion. Therefore, the wall thickness is preferably 35.0 mm or less, more preferably 30.0 mm or less, and still more preferably 25.0 mm or less.

2. Weld

- 25 **[0112]** Ordinarily, steel pipes are welded such that the weld becomes thicker than the base material portion. The weld has a higher strength than the base material portion after welding, and, as long as the hardness of the weld is set to 250 Hv or less as described in NACE MR0175/ISO15156-2 in order to suppress the occurrence of SSC, the weld of the steel pipe according to the embodiment is not particularly limited when obtained by SAW welding or the like under normal conditions.
- 30 For example, in a case where the steel plate according to the present embodiment is used as a material, the steel plate is welded by SAW welding or the like using 3 electrodes or 4 electrodes with a heat input within a condition range of 2.0 kJ/mm to 10 kJ/mm depending on the plate thickness, whereby the maximum hardness becomes 250 Hv or less, which is preferable. In addition, after welding, a tempering treatment (seam heat treatment) in which the weld is heated may be performed.
- 35 **[0113]** Since the steel pipe is welded after controlled cooling, there is no case where the surface layer of the weld is hardened by the controlled cooling. Therefore, the hardness of the weld may be measured with a load of 0.1 kgf in the same manner as for the hardness of the base material portion, but may be measured with a load of 10 kgf or a load of 5 kgf as described in NACE MR0175/ISO15156-2.

40 <|Manufacturing method>

- [0114]** As long as the steel plate according to the present embodiment and the steel pipe according to the present embodiment have the above-described configuration, the effects can be obtained; however, for example, a manufacturing method as described below makes it possible to stably obtain the steel plate and the steel pipe, which is preferable. That is,
- 45 the steel plate and the steel pipe can be manufactured by the following method, but the manufacturing method thereof is not limited to this method.

[0115] That is, the steel plate according to the present embodiment can be obtained by a manufacturing method including the following steps.

- 50 (I) Hot rolling step
 (II) First cooling step
 (III) Holding step
 (IV) Second cooling step (performed as necessary)
 (V) Third cooling step
 55 (VI) Fourth cooling step
- In addition, the steel pipe according to the present embodiment can be obtained by a manufacturing method further including the following steps in addition to the above-described steps.
- (VII) Forming step

(VIII) Welding step

[0116] Preferable conditions for each step will be described.

5 [Hot rolling step]

[0117] After steel having the above-described chemical composition is melted in a furnace, a slab produced by casting is heated and hot-rolled.

10 [0118] In the hot rolling step, it is preferable that the heating temperature before hot rolling is set to 1000°C to 1300°C, the finish rolling start temperature of the hot rolling is set to Ar3 to 900°C, and the finish rolling finishing temperature is set to Ar3°C or higher.

[0119] When the heating temperature exceeds 1300°C, grains become coarse, and there is a concern that it may become impossible to obtain a predetermined effective grain size. On the other hand, when the heating temperature is lower than 1000°C, there is a possibility that it may not be possible to secure a predetermined finish rolling temperature.

15 [0120] In addition, when the rolling start temperature exceeds 900°C, the grains become coarse, and there is a concern that it may become impossible to obtain a predetermined effective grain size. On the other hand, when the rolling start temperature is lower than Ar3°C, there is a possibility that it may not be possible to secure a predetermined finish rolling temperature.

[0121] When the finish rolling finishing temperature is lower than Ar3°C, worked ferrite is formed. When there is a steelmaking defect, the worked ferrite causes cracking during use, and thus, in a case where worked ferrite is formed, there is a need to perform strict control in the steelmaking stage. Therefore, the finish rolling finishing temperature is set to Ar3°C or higher. Ar3 varies with the chemical composition, the heating temperature, the hot rolling conditions, and the plate thickness (cooling rate during air cooling), but is approximately 760°C to 790°C as long as the chemical composition, the plate thickness, and the strength are within the range of the steel plate according to the present embodiment.

25 [0122] As described above, in the steel plate and the steel pipe according to the present embodiment, it is necessary to satisfy both the refinement of the grain sizes in the middle portion of the plate thickness (wall thickness in the steel pipe) and the reduction of the maximum hardness in the surface layer. In order to form a fine structure in the middle portion of the plate thickness (wall thickness), the cooling rate is desirably increased after the end of the hot rolling. However, in a case where the cooling rate is fast, there is a concern that the hardness of the surface layer may increase. Therefore, in order to satisfy both, controlled cooling after the end of the hot rolling is important.

[0123] Specifically, it becomes possible to manufacture a steel plate having the above-described metallographic structure by performing a first cooling step, a holding step, a second cooling step, a third cooling step, and a fourth cooling step, which will be described below, in order on the steel plate (hot rolled steel plate) after the hot rolling step. Here, the second cooling step is optional and may not be performed.

35 [First cooling step]

[0124] After the end of the hot rolling, accelerated cooling is performed at an average cooling rate of 30 °C/s or faster from a temperature of Ar3°C or higher, for example, 790°C to 830°C, to a bainitic transformation region of a Bs point to an Ms point in terms of the surface temperature of the steel plate. The accelerated cooling up to the above-described bainitic transformation region makes it possible to suppress the formation of polygonal ferrite and martensite in the metallographic structure of the surface layer of the steel plate.

45 [0125] When the cooling stop temperature in the first cooling step becomes higher than the Bs point, there is a concern that polygonal ferrite may be formed in the metallographic structure of the surface layer in the following holding step. On the other hand, when the cooling stop temperature in the first cooling step is lower than the Ms point, there is a concern that martensite may be formed in the metallographic structure of the surface layer. In addition, even when the average cooling rate is slower than 30 °C/s, there is a concern that polygonal ferrite may be formed in the middle of cooling. The upper limit of the average cooling rate is not particularly limited.

[0126] The average cooling rate in the first cooling step is a cooling rate calculated by dividing a change in the surface temperature by the difference between the cooling start time and the cooling end time.

50 [0127] Here, the Bs point (°C) is represented by the following formula (iii) and means the formation start temperature of acicular ferrite and bainite.

$$Bs = 830 - 270 \times C - 90 \times Mn - 37 \times Ni - 70 \times Cr - 83 \times Mo \dots (iii)$$

55 [0128] Here, each element symbol in the formulae represents the amount (mass%) of each element contained in steel and is regarded as zero in a case where the corresponding element is not contained.

[0129] In addition, the Ms point can be calculated by the following formula (iv).

$$Ms = 545 - 330 \times C + 2 \times Al - 14 \times Cr - 13 \times Cu - 23 \times Mn - 5 \times Mo - 4 \times Nb - 13 \times Ni - 7 \times Si + 3 \times Ti + 4 \times V \quad (iv)$$

[0130] Here, each element symbol in the formulae represents the amount (mass%) of each element contained in steel and is regarded as zero in a case where the corresponding element is not contained.

[Holding step]

[0131] After the first cooling step, the temperature of the surface layer is retained within a temperature range of the Ms point to the Bs point (bainitic transformation region) by performing slow cooling. The temperature is retained within the above-described bainitic transformation region for 3.0 seconds or longer, thereby controlling the metallographic structure in the surface layer to be a metallographic structure mainly including acicular ferrite and bainite. When the holding temperature is lower than the Ms point, martensite is formed, and it is not possible to set the maximum hardness of the surface layer to 250 HV0.1 or less. On the other hand, when the holding temperature range is higher than the Bs point, since polygonal ferrite is formed, and carbon is concentrated from the polygonal ferrite having a low carbon solid solubility limit to untransformed austenite, martensite is formed in the subsequent step (a second cooling step and/or a third cooling step), and it is not possible to set the maximum hardness of the surface layer to 250 HV0.1 or less.

[0132] In addition, when the holding time is not sufficient, untransformed austenite transforms into martensite in the subsequent step, and it is not possible to set the maximum hardness of the surface layer to 250 HV0.1 or less. Therefore, in order to control the metallographic structure to a metallographic structure mainly including acicular ferrite and bainite, in the holding step, the temperature of the surface layer is retained in the bainitic transformation region for 3.0 seconds or longer.

[0133] In the present step, in order to retain the temperature of the surface layer in the bainitic transformation region for 3.0 seconds or longer while performing slow cooling, it is extremely important to perform accelerated cooling at an average cooling rate of 30 °C/s or faster to the bainitic transformation region of the Bs point to the Ms point in the first cooling step. When cooling is performed at a fast average cooling rate of 30 °C/s or faster in the first cooling step, the temperature of the thickness middle at the start of the holding step is maintained at a temperature higher than the temperature of the surface layer for a certain period of time. Therefore, the surface layer after the first cooling step tends to be reheated (the temperature is increased) by heat conduction with the thickness middle. Here, slow cooling is performed with an amount of water small enough to suppress the heat recuperation by heat conduction, which makes it possible to retain the temperature of the surface layer in the bainitic transformation region for 3.0 seconds or longer.

[0134] As described above, during the first cooling step and the holding step, the surface layer is cooled and retained as described above, but the thickness middle portion is slowly cooled. The temperature of the thickness middle portion at the completion of the holding step is preferably 700°C or higher, and the average cooling rate of the thickness middle portion during the first cooling step and the holding step is preferably 15 °C/s or slower.

[Second cooling step]

[0135] After the control of the metallographic structure in the surface layer is completed by the holding step, the cooling of the surface and heat recuperation by which the surface temperature after the heat recuperation becomes 550°C or higher are repeated two or more times in the second cooling step, whereby it is possible to control the cooling rate of the center and to increase the polygonal ferrite fraction. When the fraction of fine polygonal ferrite grains, which are formed in this second cooling step, is increased, it is possible to refine the average grain size in the entire metallographic structure of a complex structure that is obtained in the end. In addition, it is possible to cause the surface layer of the steel plate to be self-tempered by heat recuperation, and consequently, there is also an effect of reducing the maximum hardness of the surface layer.

[0136] Therefore, in a case where it is desired to obtain more excellent low temperature toughness, the second cooling step is preferably performed.

[0137] When the steel plate is cooled in an accelerated manner, the surface temperature is cooled to a low temperature compared with the internal temperature. The surface temperature is reheated such that the difference between the internal temperature and the surface temperature becomes small due to heat conduction from the inside when the accelerated cooling is temporarily stopped. Since the center temperature is cooled by heat conduction attributed to the temperature difference from the surface layer, when the temperature of the surface layer is reheated, the cooling rate of the center decreases. Therefore, when the heat recuperation and cooling of the surface layer are repeated, it is possible to control the cooling rate of the center and to increase the polygonal ferrite fraction. For example, when the surface temperature is decreased to 500°C or lower by the accelerated cooling after the holding step, and the cooling and heat recuperation of the

surface layer, which reheats the surface layer to 550°C or higher, is repeated two or more times, it is possible to retain the center temperature in the ferritic transformation region and to efficiently increase the polygonal ferrite fraction.

[0138] When the cooling and heat recuperation is performed less than twice in the second cooling step, there is a concern that it may not be possible to secure a sufficient transformation time to increase the polygonal ferrite fraction in the thickness middle portion. In addition, since the heat recuperation of the surface of the steel plate is caused by heat conduction with the internal temperature, in a case where the heat recuperation temperature is less than 550°C, the thickness middle portion is also retained in the bainitic transformation region, and there is a concern that the polygonal ferrite fraction may not be increased.

[Third cooling step]

[0139] After the control of the metallographic structure in the surface layer is completed by the holding step or after the polygonal ferrite fraction in the thickness middle portion is increased in the second cooling step, accelerated cooling is performed at an average cooling rate of 10 °C/s or faster. At this time, the surface temperature is cooled in an accelerated manner to the Ms point or lower, and the final heat recuperation temperature after the stop of the cooling is set to the Bs point or lower. When accelerated cooling is performed immediately after the end of the microstructure control of the surface layer, it becomes possible to promote the cooling of the inside and to form a structure including fine acicular ferrite and/or bainite in the thickness middle portion.

[0140] When the average cooling rate is slower than 10 °C/s, there is a concern that grains in the thickness middle portion may become coarse. Therefore, in the third cooling step, the surface temperature of the steel plate is cooled in an accelerated manner to the Ms point or lower for the purpose of increasing the average cooling rate. When the surface temperature of the steel plate is cooled to the Ms point or lower, it is possible to increase the cooling rate of the thickness middle portion by heat conduction. In ordinary accelerated cooling methods, when the steel plate is rapidly cooled to the Ms point or lower, the hardness of the surface of the steel plate increases; however, in the manufacturing method of the present embodiment, since the control of the metallographic structure in the surface of the steel plate is completed, the hardness of the surface layer of the steel plate does not increase even when the surface of the steel plate is rapidly cooled to the Ms point or lower. Therefore, it is possible to increase the average cooling rate without setting the upper limit to the cooling rate on the surface of the steel plate.

[0141] The average cooling rate is an average cooling rate of the wall thickness middle portion that is obtained by dividing a change in the temperature of the thickness middle portion by the cooling time (the difference between the cooling start time and the cooling end time). The change in the temperature of the thickness middle portion can be obtained from the surface temperature by heat conduction calculation.

[0142] The thickness middle portion is cooled in an accelerated manner by heat conduction with the surface; however, when the cooling is stopped, the surface is reheated by heat conduction with the thickness middle portion. Since the heat recuperation proceeds until the temperature of the surface coincides with the thickness middle portion, the final heat recuperation temperature after the cooling corresponds to the cooling stop temperature in the thickness middle portion. When the final heat recuperation temperature is set to the Bs point or lower, it is possible to form a structure including fine acicular ferrite and/or bainite in the thickness middle portion. When the final heat recuperation temperature becomes higher than the Bs point, the generated polygonal ferrite grows, and the structure becomes coarse.

[Others]

[0143] During the third cooling step, if necessary, the cooling may be temporarily stopped and the surface temperature of the steel plate may be set to the Ms point or higher once or more by heat recuperation. When the steel plate is cooled in an accelerated manner, the surface temperature is cooled to a low temperature compared with the internal temperature. The surface temperature can be reheated by heat conduction with the internal temperature when the accelerated cooling is temporarily stopped. For example, even when the surface temperature decreases to 400°C or lower by the accelerated cooling, if the internal temperature at the time of stopping the cooling is 700°C or higher, the steel plate can be reheated to a temperature of 550°C or higher by imparting an appropriate heat recuperation time.

[0144] When the steel plate is reheated, a high self-tempering effect can be obtained compared with a case where normal accelerated cooling is performed, and thus it is possible to decrease the hardness of the surface layer. Even after that, the accelerated cooling is intermittently performed, which makes it possible to repeat cooling and heat recuperation. The heat recuperation is more preferably performed, for example, twice or more.

[Fourth cooling step]

[0145] After the third cooling step, cooling is performed to 300°C or lower such that the average cooling rate until 300°C becomes 200 °C/hr or faster. When the average cooling rate until 300°C is slower than 200 °C/hr, it is not possible to obtain

a predetermined strength.

(Forming step)

[0146] The steel plate according to the present embodiment is formed into a tubular shape, both end portions of the steel plate formed in a tubular shape are abutted and welded (seam-welded), thereby forming the steel pipe according to the present embodiment.

[0147] The forming of the steel plate according to the present embodiment into the steel pipe is not limited to specific forming method. For example, the steel pipe can be manufactured by performing UO pipe making. In the UO pipe making method, for example, a rolled steel plate (material) having an edge portion grooved by cutting is C-pressed to form the rolled steel plate into a C shape, then, U-pressed to form the steel plate into a U shape, and furthermore, O-pressed to form the steel plate into an O shape, thereby forming the steel plate into a cylindrical shape.

(Welding step)

[0148] After the steel plate is formed, seams (seam portions), which are end portions, are abutted and temporarily welded, the inner surfaces are welded, the outer surfaces are welded, and furthermore, pipe expansion is performed as necessary. The welding is also not limited to specific welding, but is preferably submerged arc welding (SAW). As long as the maximum hardness of the weld of the steel pipe according to the present embodiment is within the above-described range, welding conditions and the like are not limited. However, in a case where the steel plate according to the present embodiment is used as a material, the steel plate is welded by SAW welding or the like using 3 electrodes or 4 electrodes with a heat input within a condition range of 2.0 kJ/mm to 10 kJ/mm depending on the plate thickness, whereby the maximum hardness of the surface layer becomes 250 HV0.1 or less, which is preferable.

[0149] In the manufacturing method of the steel pipe according to the present embodiment, a seam heat treatment in which the weld is heated to the Ac1 point (°C) or lower and tempered may be performed.

[0150] Hereinafter, the present invention will be more specifically described with examples, but the present invention is not limited to these examples.

[Examples]

(Example 1)

[0151] Steels having a chemical composition shown in Table 1-1 and Table 1-2 were melted and continuously cast into steel pieces. At this time, the thicknesses were set to 300 mm for the kinds of steel J to N and to 240 mm for the other kinds of steel A to I and O to S. The obtained steel pieces were heated up to a temperature range of 1100°C to 1250°C, hot-rolled in a recrystallization temperature range exceeding 900°C, and subsequently, hot-rolled (finish-rolled) in a non-recrystallization temperature range of Ar3 to 900°C, and the hot rolling was ended at temperatures shown in Table 2-1 and Table 2-3, which are equal to or higher than the temperature (°C) of Ar3 as shown in Table 2-1 and Table 2-3.

[0152] After that, on some examples, a first cooling step, a holding step, a third cooling step, and a fourth cooling step were performed in order under conditions shown in Table 2-1 to Table 2-4, and then the steel pieces were cooled to room temperature while cooling and heat recuperation were repeated, thereby manufacturing steel plates (a second cooling step was not performed).

[0153] In addition, on the other examples, the first cooling step, the holding step, the second cooling step, the third cooling step, and the fourth cooling step were performed in order under conditions shown in Table 2-1 to Table 2-4, and the steel pieces were cooled to room temperature, thereby manufacturing steel plates. In the second cooling step, the surface temperatures of all of the steel plates were once decreased to 500°C or lower in cooling before heat recuperation.

[Table 1-1]

Kind of steel	Chemical composition (mass%, remainder: Fe and impurity)											
	C	Si	Mn	Nb	N	Ca	P	S	Ti	Al	O	Mo
A	0.047	0.23	1.45	0.030	0.0033	0.0023	0.007	0.0002	0.011	0.027	0.0015	
B	0.043	0.23	1.41	0.031	0.0021	0.0018	0.007	0.0006	0.011	0.025	0.0025	0.10
C	0.050	0.23	1.46	0.030	0.0022	0.0021	0.006	0.0006	0.010	0.021	0.0015	0.07
D	0.049	0.23	1.42	0.028	0.0039	0.0021	0.007	0.0002	0.010	0.033	0.0015	0.11

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(continued)

Kind of steel	Chemical composition (mass%, remainder: Fe and impurity)											
	C	Si	Mn	Nb	N	Ca	P	S	Ti	Al	O	Mo
E	0.047	0.22	1.45	0.030	0.0033	0.0027	0.007	0.0002	0.011	0.025	0.0011	0.07
F	0.046	0.22	1.44	0.029	0.0031	0.0022	0.008	0.0003	0.011	0.020	0.0014	0.09
G	0.040	0.33	1.25	0.012	0.0033	0.0031	0.009	0.0002	0.011	0.022	0.0012	
H	0.047	0.23	1.44	0.023	0.0022	0.0019	0.006	0.0002	0.014	0.032	0.0015	0.08
I	0.059	0.18	1.42	0.021	0.0034	0.0015	0.007	0.0003	0.012	0.040	0.0016	0.07
J	0.046	0.23	1.46	0.030	0.0033	0.0020	0.008	0.0004	0.012	0.029	0.0012	
K	0.050	0.30	1.47	0.035	0.0032	0.0025	0.008	0.0006	0.012	0.033	0.0010	
L	0.050	0.30	1.47	0.035	0.0035	0.0025	0.008	0.0006	0.012	0.033	0.0010	
M	0.050	0.24	1.37	0.033	0.0033	0.0020	0.006	0.0005	0.009	0.029	0.0015	0.01
N	0.060	0.15	1.15	0.013	0.0033	0.0020	0.006	0.0002	0.012	0.032	0.0012	
O	0.047	0.33	1.20	0.014	0.0022	0.0023	0.007	0.0002	0.011	0.025	0.0020	0.14
P	0.090 *	0.23	1.45	0.025	0.0033	0.0023	0.007	0.0002	0.011	0.025	0.0015	0.10
Q	0.040	0.20	1.20	0.031	0.0021	0.0018	0.007	0.0006	0.011	0.025	0.0022	
R	0.065	0.33	1.59	0.025	0.0022	0.0023	0.007	0.0003	0.011	0.025	0.0020	0.30
S	0.052	0.33	1.50	0.025	0.0022	0.0023	0.007	0.0003	0.011	0.025	0.0020	0.70
* indicates that values fail to satisfy the regulation of the present invention.												
† $0.05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2.0 \dots\dots(i)$												
‡ $\text{Ceq} = \text{C} + \text{Mn}/6 + (\text{Ni} + \text{Cu})/15 + (\text{Cr} + \text{Mo} + \text{V})/5 \dots\dots(ii)$												
Blank cells indicate that the corresponding elements are intentionally not added.												

[Table 1-2]

Kind of steel	Chemical composition (mass%, remainder: Fe and impurity)									Value of middle expression in formula (i)†	Ceq‡
	Cr	Cu	Ni	W	V	Zr	Ta	B	Ohters		
A	0.30									0.30	0.35
B	0.20									0.30	0.34
C	0.17							0.0002		0.24	0.34
D	0.21						0.0032			0.32	0.35
B		0.23	0.20	0.05						0.50	0.33
F	0.30	0.02	0.10							0.51	0.37
G	0.50	0.01	0.21						Hf: 0.0005	0.72	0.36
H	0.28	0.01	0.02						Mg: 0.0053	0.39	0.36
I	0.17	0.18	0.10						REM: 0.0010	0.63	0.36
J	0.25				0.034	0.0051			REM: 0.0012	0.25	0.35

(continued)

Kind of steel	Chemical composition (mass%, remainder: Fe and impurity)									Value of middle expression in formula (i) [†]	Ceq [‡]
	Cr	Cu	Ni	W	V	Zr	Ta	B	Ohters		
K	0.26				0.035					0.26	0.35
L	0.26	0.13	0.13		0.035				Re: 0.0005	0.51	0.37
M	0.22	0.20	0.18		0.042					0.61	0.36
N	0.15	0.33	0.43		0.020					0.91	0.34
O	0.43		0.23							0.80	0.38
P	0.20									0.30	0.39
Q		0.20	0.20							0.40	0.27 *
R	0.50	0.25	0.25							1.30	0.52 *
S	0.40	0.50	0.50					0.0010		2.10 *	0.59 *
* indicates that values fail to satisfy the regulation of the present invention. [†] $0.05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2.0 \quad \cdots (i)$ 1 $\text{Ceq} = \text{C} + \text{Mn}/6 + (\text{Ni} + \text{Cu})/15 + (\text{Cr} + \text{Mo} + \text{V})/5 \quad \cdots (ii)$ Blank cells indicate that the corresponding elements are intentionally not added.											

[Table 2-1]

Test No.	Kind of steel	Hot rolling conditions			First cooling conditions		Holding conditions		Second cooling conditions	
		Heating temperature (°C)	Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)	Surface layer average cooling rate (°C/s)	Surface layer cooling stop temperature (°C)	Average holding temperature (°C)	Holding time (s)	Number of times of heat recuperation (times)	First heat recuperation highest temperature (°C)
1	A	1200	855	812	98	660	630	4.5	2	610
2	A	1250	855	816	70	630	600	9.0	0	-
3	A	1180	855	818	60	700	680	5.0	0	-
4	A	1180	860	818	110	320	580	3.5	1	550
5	A	1200	860	820	90	660	640	2.0	0	
6	A	1150	850	806	98	660	580	4.0	2	560
7	B	1200	855	815	78	660	635	4.0	2	590
8	B	1180	860	820	100	650	620	5.5	1	600
9	B	1130	850	805	98	650	620	5.5	0	-
10	B	1180	855	815	98	665	700	8.0	1	670
11	B	1180	850	810	110	450	450	3.5	2	570
12	B	1180	860	819	98	660	630	1.0	2	610
13	B	1130	850	809	98	660	630	4.0	3	540
14	C	1200	860	818	98	630	600	7.0	1	560
15	D	1200	855	816	98	650	620	4.5	2	600
16	E	1200	860	820	98	660	630	3.5	2	610
17	F	1180	855	811	98	610	580	6.0	2	590
18	G	1150	845	801	98	610	580	6.0	2	580
19	H	1180	855	813	98	630	600	5.5	2	580
20	1	1180	845	800	98	630	600	5.5	2	580
21	J	1200	855	817	98	660	630	4.5	2	610
22	K	1180	855	815	98	660	630	4.5	2	610
23	L	1180	850	811	98	660	630	4.5	2	610

(continued)

Test No.	Kind of steel	Hot rolling conditions			First cooling conditions		Holding conditions		Second cooling conditions	
		Heating temperature (°C)	Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)	Surface layer average cooling rate (°C/s)	Surface layer cooling stop temperature (°C)	Average holding temperature (°C)	Holding time (s)	Number of times of heat recuperation (times)	First heat recuperation highest temperature (°C)
24	M	1150	855	814	98	660	630	4.5	2	610
25	N	1150	845	802	98	660	630	4.5	2	610
26	O	1150	845	800	98	630	600	5.5	2	580
27	P	1200	850	806	110	500	480	4.5	0	-
28	R	1200	855	815	98	580	590	4.0	2	610
29	S	1200	850	805	98	500	500	4.5	2	610

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[Table 2-2]

Test No.	Kind of steel	Second cooling conditions		Third cooling conditions			Fourth cooling conditions	Bs#1 (°C)	Ms#2 (°C)
		Second heat recuperation highest temperature (°C)	Third heat recuperation highest temperature (°C)	Average cooling rate (°C/s)	Surface layer cooling stop temperature (°C)	Final heat recuperation temperature (°C)	Average cooling rate until 300°C (°C/hr)		
1	A	500	-	50	275	450	821	666	490
2	A	-	-	45	250	450	727	666	490
3	A	-	-	55	275	450	821	666	490
4	A	-	-	50	250	450	727	666	490
5	A	-	-	50	250	450	727	666	490
6	A	420	-	50	200	450	586	666	490
7	B	520	-	45	280	480	727	669	493
8	B	-	-	55	210	430	668	669	493
9	B	-	-	60	180	430	586	669	493
10	B	-	-	60	180	430	586	669	493
11	B	510	-	45	250	450	727	669	493
12	B	530	-	55	210	430	668	669	493
13	B	450	350	55	210	430	668	669	493
14	C	-	-	50	230	450	668	667	491
15	D	510	-	50	250	450	727	665	491
16	E	500	-	50	250	450	727	674	489
17	F	480	-	45	200	450	586	656	489
18	G	480	-	45	200	450	586	664	491
19	H	480	-	50	200	450	586	661	490
20	I	480	-	50	200	450	586	665	485
21	J	510	-	50	260	450	778	669	491
22	K	510	-	50	259	450	778	666	489
23	L	510	-	50	220	450	627	662	486
24	M	510	-	50	200	450	586	670	487
25	N	510	-	50	200	450	586	684	486
26	O	480	-	50	230	450	668	659	490
27	P	-	-	50	250	450	727	653	477
28	R	510	-	50	250	450	727	600	470
29	S	510	-	50	250	450	727	576	469
#1 Bs = 830 - 270C - 90Mn - 37Ni - 70Cr - 83Mo ... (iii)									
#2 Ms = 545 - 330C + 2Al + 7Co - 14Cr - 13Cu - 23Mn - 5Mo - 4Nb - 13Ni - 7Si + 3Ti + 4V ... (iv)									

[Table 2-3]

Test No.	Kind of steel	Hot rolling conditions			First cooling conditions		Holding conditions		Second cooling conditions	
		Heating temperature (°C)	Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)	Surface layer average cooling rate (°C/s)	Surface layer cooling stop temperature (°C)	Average holding temperature (°C)	Holding time (s)	Number of times of heat recuperation (times)	First heat recuperation highest temperature (°C)
101	A	1150	845	802	98	660	630	4.5	3	610
102	A	1150	850	806	70	630	600	9.0	2	610
103	A	1150	835	790	10	630	630	3.0	2	570
104	A	1130	850	808	60	700	680	5.0	2	610
105	A	1130	850	808	110	320	580	3.0	2	610
106	A	1150	850	810	90	660	640	2.0	2	610
107	A	1200	855	816	98	660	580	4.0	3	650
108	B	1150	845	805	78	660	635	4.0	2	590
109	B	1130	850	810	100	650	620	5.5	3	600
110	B	1130	845	800	110	450	450	3.5	2	610
111	C	1150	850	808	98	610	580	6.0	3	590
112	D	1150	845	806	98	650	620	4.5	2	600
113	E	1150	850	810	98	660	630	3.5	3	610
114	F	1130	845	801	98	610	580	6.0	3	590
115	G	1100	835	791	98	610	580	6.0	3	580
116	H	1130	845	803	98	630	600	5.5	3	580
117	1	1130	835	790	98	630	600	5.5	3	580
118	J	1150	850	807	98	660	630	4.5	2	610
119	K	1130	850	805	98	660	630	4.5	2	610
120	L	1130	845	801	98	660	630	4.5	3	610
121	M	1100	845	804	98	660	630	4.5	3	610
122	N	1100	835	792	98	660	630	4.5	3	610
123	O	1100	835	790	98	630	600	5.5	3	580

(continued)

Test No.	Kind of steel	Hot rolling conditions			First cooling conditions		Holding conditions		Second cooling conditions	
		Heating temperature (°C)	Finish rolling start temperature (°C)	Finish rolling finishing temperature (°C)	Surface layer average cooling rate (°C/s)	Surface layer cooling stop temperature (°C)	Average holding temperature (°C)	Holding time (s)	Number of times of heat recuperation (times)	First heat recuperation highest temperature (°C)
124	P	1150	845	796	110	500	480	4.5	3	610
125	Q	1110	865	825	98	690	680	4.5	2	610

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[Table 2-4]

Test No.	Kind of steel	Second cooling conditions		Third cooling conditions			Fourth cooling conditions	Bs#1 (°C)	Ms#2 (°C)
		Second heat recuperation highest temperature (°C)	Third heat recuperation highest temperature (°C)	Average cooling rate (°C/s)	Surface layer cooling stop temperature (°C)	Final heat recuperation temperature (°C)	Average cooling rate until 300°C (°C/hr)		
101	A	570	555	50	275	450	821	666	490
102	A	560	-	45	250	450	727	666	490
103	A	550	-	50	300	450	950	666	490
104	A	570	-	55	275	450	821	666	490
105	A	560	-	50	250	450	727	666	490
106	A	560	-	50	250	450	727	666	490
107	A	560	555	5	270	520	586	666	490
108	B	570	-	45	230	430	727	669	493
109	B	560	560	55	280	500	668	669	493
110	B	560	-	45	250	450	727	669	493
111	C	570	555	50	230	450	668	667	491
112	D	570	-	50	250	450	727	665	491
113	E	570	480	50	250	450	727	674	489
114	F	570	550	45	200	450	586	656	489
115	G	560	550	45	270	520	586	664	491
116	H	560	450	50	200	450	586	661	490
117	I	560	550	50	200	450	586	665	485
118	J	560	-	50	260	450	778	669	491
119	K	560	-	50	259	450	778	666	489
120	L	560	550	50	220	450	627	662	486
121	M	570	560	50	200	450	586	670	487
122	N	560	550	50	200	450	586	684	486
123	O	570	560	50	230	450	668	659	490
124	<u>P</u>	580	550	50	250	450	727	653	477
125	<u>Q</u>	580	-	50	250	450	727	704	498
#1 Bs = 830 - 270C - 90Mn - 37Ni - 70Cr - 83Mo ... (i)									
#2 Ms = 545 - 330C + 2Al + 7Co - 14Cr - 13Cu - 23Mn - 5Mo - 4Nb - 13Ni - 7Si + 3Ti + 4V ... (ii)									

[0154] From the above-described steel plates, test pieces for structure observation, test pieces for grain size measurement, tensile test pieces, test pieces for hardness measurement, DWTT test pieces, impact test pieces, SSC test pieces, and an HIC test pieces were collected and used for corresponding tests.

<Structure observation>

[0155] In the test piece for structure observation, a test piece was collected from a position of a W/4 position in the plate

width direction such that an L-direction cross section became an observed section, polished in a wet manner to finish the test piece into a mirror surface, and then Nital-etched to reveal the metallographic structure. In addition, on to the L-direction cross section, the structure was observed at 4 visual fields using an optical microscope at a magnification of 500 times, and the area ratios of each structure in the surface layer (a position 0.1 mm from the surface) and in the thickness middle portion were measured.

<Measurement of effective grain size>

[0156] In addition, in the test piece for grain size measurement, a test piece was collected from the same position as for the test piece for structure observation such that an L-direction cross section became an observed section, the thickness middle portion was observed using a SEM-EBSD device, and the grain sizes of grains surrounded by high-angle grain boundaries with an inclination angle of 15° or more were obtained, thereby obtaining an average effective grain size.

<Tensile test>

[0157] For a tensile test, according to API 5L, a round bar-like tensile test piece was worked such that the longitudinal direction of the test piece became parallel to the width direction of the steel plate, and a tensile test was performed. From the result, the tensile strength (MPa) was obtained.

[0158] When the tensile strength was 480 MPa or more, the steel plate was determined to have a preferable strength as a steel plate for a line pipe.

<Hardness test>

[0159] Next, the maximum hardness of the surface layer was measured using the test piece for hardness measurement. Specifically, 300 mm x 300 mm steel plates were cut out by gas cutting from 1/4, 1/2, and 3/4 positions in the width direction of the steel plate from an end portion of the steel plate in the width direction, and block test pieces having a length of 20 mm and a width of 20 mm were collected by mechanical cutting from the center of the cut-out steel plates and polished by mechanical polishing. In one block test piece, the hardness was measured with a Vickers hardness meter (load: 0.1 kgf) at a total of 100 points (10 points at 1.0 mm intervals in the width direction at each of 10 depth points at 0.1 mm intervals in the plate thickness direction from 0.1 mm deep from the surface as a starting point). That is, the hardness was measured at a total of 300 points in three block test pieces. Even when there was one measurement point where the hardness exceeded 250 HV as a result of the measurement, the point was regarded as an abnormal point and was not adopted unless two or more abnormal points continuously appeared in the plate thickness direction, and the next highest value was regarded as the maximum hardness. On the other hand, in a case where there were two or more measurement points with hardness of more than 250 HV continuously present in the plate thickness direction, the highest value thereof was adopted as the maximum hardness.

<DWTT test>

[0160] The DWTT test piece was collected from a 1/4 position in the width direction of the steel plate such that the longitudinal direction of the test piece became parallel to the width direction of the steel plate. A DWTT test was performed using this DWTT test piece at test temperatures of -20°C and -30°C, and the DWTT shear fracture area was measured. The DWTT test was performed according to API standard 5L3.

[0161] When the DWTT shear fracture area after the DWTT test was 85% or more, the toughness at the test temperatures was determined as excellent.

<Charpy impact test>

[0162] The impact test piece was made into a 10 mm-wide test piece having a 2 mm V notch. Three test pieces described above were cut out from a 1/4 position in the width direction of the steel plate such that the longitudinal direction of the test piece became parallel to the width direction of the steel plate, a Charpy impact test was performed at -100°C, and three average absorbed energies were obtained.

[0163] When the average absorbed energy after the Charpy impact test was 150 J or more, the toughness at -100°C or higher was determined as excellent.

<SSC test>

[0164] As an SSC test, a 4-point bending test in which the inner surface of the steel pipe was used as a test surface to

evaluate the SSC sensitivity of the outermost layer was performed according to NACE TM 0316. The test pieces were collected from a center in the width direction and from a 1/4 position in the width direction of the steel plate such that the longitudinal direction of the test piece became parallel to the width direction of the steel plate. At that time, the load stress was set to correspond to 90% of the actual YS (yield strength) of the test piece, and, as a testing solution, NACE Solution A regulated in NACE TM 0177 was used. Specifically, the test piece was immersed for 720 hours under a condition in which 0.1 MPa of hydrogen sulfide was saturated in a solution containing 5% salt and 0.5% acetic acid, and then the presence or absence of the occurrence of SSC was observed. The other conditions followed NACE TM 0177. In addition, test pieces in which SSC did not occur were determined as pass (OK), and test pieces in which SSC occurred were determined as fail (NG).

<HIC test>

[0165] The HIC test piece was made into an overall thickness test piece having a length of 100 mm and a width of 20 mm. In addition, an HIC test was performed according to NACE TM 0284. Specifically, the test piece was immersed for 96 hours under a condition in which 0.1 MPa of hydrogen sulfide was saturated in a solution containing 5% salt and 0.5% acetic acid, and then the crack area ratio was obtained. Test pieces for which the crack area ratio was 6% or less were determined as pass (OK), and test pieces for which the crack area ratio was more than 6% were determined as fail (NG). In addition, test pieces for which the crack area ratio was 3% or less were determined as particularly excellent (Ex).

[0166] These results are summarized in Table 3-1 to Table 3-4.

[Table 3-1]

Test No.	Kind of steel	Plate thickness (mm)	Metallographic structure						
			Middle portion					Surface layer	
			Kind#3	F area ratio (%)	AF+B area ratio (%)	Effective grain size (μm)	M-A area ratio (%)	Kind#3	M-A area ratio (%)
1	A	17.5	F, AF, B	8	91.0	11.6	1.0	AF, B	0.2
2	A	20.0	F, AF, B	5	94.0	12.2	1.0	AF, B	0.8
3	A	17.5	F, AF, B	5	94.0	11.4	1.0	F, B, M	0.9
4	A	20.0	F, AF, B	7	92.0	11.7	1.0	AF,B,M	0.1
5	A	20.0	F, AF, B	3	96.0	11.9	1.0	AF, B, M	0.0
6	A	25.0	F, AF, B	10	89.0	10.8	1.0	AF, B	0.1
7	B	20.0	AF, B	-	98.4	12.5	1.6	AF, B	0.5
8	B	22.0	AF, B	-	99.2	11.8	0.8	AF, B	0.3
9	B	25.0	AF, B	0	99.2	11.3	0.8	AF, B	0.3
10	B	25.0	F, AF, B	9	90.2	10.8	0.8	F, B, M	0.7
11	B	20.0	F, AF, B	7	92.1	12.0	0.9	B, M	0.1
12	B	22.0	AF, B	0	99.2	11.8	0.8	AF, B, M	0.0
13	B	22.0	F, AF, B	6	93.2	11.0	0.8	AF, B	0.2
14	C	22.0	AF, B	0	99.1	12.1	0.9	AF, B	0.4
15	D	20.0	F, AF, B	6	93.0	11.7	1.0	AF, B	0.2
16	B	20.0	F, AF, B	3	96.2	11.9	0.8	AF, B	0.1
17	F	25.0	F, AF, B	15	83.7	11.5	1.3	AF, B	0.3
18	G	25.0	F, AF, B	15	83.8	11.5	1.2	AF, B	0.3
19	H	25.0	F, AF, B	13	85.9	11.2	1.1	AF, B	0.3
20	I	25.0	F, AF, B	14	84.8	11.2	1.2	AF, B	0.3
21	J	19.0	F, AF, B	9	90.0	11.5	1.0	AF, B	0.2

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(continued)

Test No.	Kind of steel	Plate thickness (mm)	Metallographic structure						
			Middle portion					Surface layer	
			Kind ^{#3}	F area ratio (%)	AF+B area ratio (%)	Effective grain size (μm)	M-A area ratio (%)	Kind ^{#3}	M-A area ratio (%)
22	K	19.1	F, AF, B	10	89.0	11.4	1.0	AF, B	0.2
23	L	23.0	F, AF, B	5	93.8	11.8	1.2	AF, B	0.2
24	M	25.0	F, AF, B	8	90.9	11.6	1.1	AF, B	0.2
25	N	25.0	F, AF, B	12	87.1	11.3	0.9	AF, B	0.2
26	O	22.0	F, AF, B	5	93.7	11.8	1.3	AF, B	0.3
27	P *	20.0	F, AF, B	5	93.5	11.8	1.5	AF, B, M	0.2
28	R*	20.0	AF, B, M *	0	97.0	12.1	3.0	AF, B, M	0.2
29	S *	20.0	AF, B, M *	0	96.3	12.1	3.7	AF, B, M	0.3
* indicates that values fail to satisfy the regulation of the present invention. #3 AF: acicular ferrite, B: bainite, F: polygonal ferrite, M: martensite									

[Table 3-2]

Test No.	Kind of steel	Plate thickness (mm)	Mechanical characteristics		DWTT -20°C (%)	Charpy absorption energy (J)	SSC resistance	HIC resistance	
			Tensile strength (MPa)	Maximum hardness of surface layer (HV0.1)					
1	A	17.5	587	208	100	447	OK	Ex	Present In-vention Exam-ple
2	A	20.0	591	217	95	459	OK	Ex	
3	A	17.5	591	273 *	98	459	NG	Ex	Comparative Example
4	A	20.0	588	255 *	95	451	NG	Ex	
5	A	20.0	594	263 *	92	467	NG	Ex	
6	A	25.0	558	205	100	447	OK	Ex	Present In-vention Exam-ple
7	B	20.0	576	207	90	479	OK	Ex	
8	B	22.0	614	215	93	479	OK	Ex	
9	B	25.0	575	220	98	454	OK	Ex	
10	B	25.0	601	275 *	88	443	NG	Ex	Comparative Example
11	B	20.0	588	273 *	95	451	NG	Ex	
12	B	22.0	614	260 *	90	479	NG	Ex	
13	B	22.0	581	208	98	448	OK	Ex	
14	C	22.0	599	220	90	479	OK	Ex	
15	D	20.0	590	218	93	455	OK	Ex	
16	E	20.0	594	205	92	467	OK	Ex	
17	F	25.0	576	210	88	419	OK	Ex	
18	G	25.0	576	211	90	419	OK	Ex	

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(continued)

Test No.	Kind of steel	Plate thickness (mm)	Mechanical characteristics		DWTT -20°C (%)	Charpy absorption energy (J)	SSC resistance	HIC resistance	
			Tensile strength (MPa)	Maximum hardness of surface layer (HV0.1)					
19	H	25.0	579	210	86	427	OK	Ex	Present In-vention Exam-ple
20	I	25.0	578	223	87	423	OK	Ex	
21	J	19.0	585	208	88	443	OK	Ex	
22	K	19.1	584	211	90	439	OK	Ex	
23	L	23.0	591	210	87	459	OK	Ex	
24	M	25.0	587	218	87	447	OK	Ex	
25	N	25.0	581	225	88	431	OK	Ex	
26	O	22.0	591	212	90	459	OK	Ex	
27	P*	20.0	680	285 *	85	459	NG	NG	Comparative Example
28	R*	20.0	650	270 *	87	479	NG	NG	
29	S *	20.0	638	265 *	88	479	NG	NG	

* indicates that values fail to satisfy the regulation of the present invention.
^{#3} AF: acicular ferrite, B: bainite, F: polygonal ferrite, M: martensite

[Table 3-3]

Test No.	Kind of steel	Plate thickness (mm)	Metallographic structure						
			Middle portion					Surface layer	
			Kind ^{#3}	F area ratio (%)	AF+B area ratio (%)	Effective grain size (μm)	M-A area ratio (%)	Kind ^{#3}	M-A area ratio (%)
101	A	17.5	F, AF, B	50	49.0	8.7	1.0	AF, B	0.2
102	A	20.0	F, AF, B	38	61.0	9.3	1.0	AF, B	0.8
103	A	15.0	F, AF, B	35	64.0	9.5	1.0	F, AF, M	0.1
104	A	17.5	F, AF, B	36	63.0	9.4	1.0	F, B, M	0.3
105	A	20.0	F, AF, B	37	62.0	9.4	1.0	AF, B, M	0.1
106	A	20.0	F, AF, B	38	61.0	9.3	1.0	AF, B, M	0.0
107	A	25.0	F, AF, B	65	33.0	22.0 *	2.0	AF, B	0.5
108	B	20.0	F, AF, B	32	67.2	9.6	0.8	AF, B	0.2
109	B	22.0	F, AF, B	58	40.3	8.3	1.7	AF, B	0.5
110	B	20.0	F, AF, B	43	56.1	9.1	0.9	B, M	0.1
111	C	22.0	F, AF, B	42	57.1	9.1	0.9	AF, B	0.3
112	D	20.0	F, AF, E	37	62.0	9.4	1.0	AF, B	0.2
113	E	20.0	F, AF, B	38	61.2	9.3	0.8	AF, B	0.1
114	F	25.0	F, AF, B	42	56.7	9.1	1.3	AF, B	0.3

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(continued)

Test No.	Kind of steel	Plate thickness (mm)	Metallographic structure						
			Middle portion					Surface layer	
			Kind# ³	F area ratio (%)	AF+B area ratio (%)	Effective grain size (μm)	M-A area ratio (%)	Kind# ³	M-A area ratio (%)
115	G	25.0	F, AF, B	52	45.4	8.6	2.6	AF, B	0.6
116	H	25.0	F, AF, B	40	58.9	9.2	1.1	AF, B	0.3
117	I	25.0	F, AF, B	48	51.8	8.8	0.2	AF, B	0.3
118	J	19.0	F, AF, B	38	61.0	9.3	1.0	AF, B	0.2
119	K	19.1	F, AF, B	41	58.0	9.2	1.0	AF, B	0.2
120	L	23.0	F, AF, B	46	52.8	8.9	1.2	AF, B	0.2
121	M	25.0	F, AF, E	47	51.9	8.9	1.1	AF, B	0.2
122	N	25.0	F, AF, B	44	55.1	9.0	0.9	AF, B	0.2
123	O	22.0	F, AF, B	42	56.7	9.1	1.3	AF, B	0.3
124	P *	20.0	F, AF, B	35	63.5	9.5	1.5	AF, B, M	0.2
125	Q *	20.0	F, AF, B	68	31.9	9.9	0.1	F, AF, B	0.2
* indicates that values fail to satisfy the regulation of the present invention. # ³ AF: acicular ferrite, B: bainite, F: polygonal ferrite, M: martensite									

[Table 3-4]

Test No.	Kind of steel	Plate thickness (mm)	Mechanical characteristics		DWTT -20°C (%)	DWTT -30°C (%)	Charpy absorption energy (J)	ssc resistance	HIC resistance	
			Tensile strength (MPa)	Maximum hardness of surface layer (HV0.1)						
101	A	17.5	538	208	100	100	328	OK	OK	Present Invention Example
102	A	20.0	546	217	98	95	340	OK	OK	
103	A	15.0	519	270 *	96	92	340	NG	OK	Comparative Example
104	A	17.5	547	273 *	98	94	342	NG	OK	
105	A	20.0	545	255 *	97	95	341	NG	OK	
106	A	20.0	548	263 *	97	92	340	NG	OK	
107	A	25.0	485	205	35	16	167	OK	OK	Present Invention Example
108	B	20.0	568	207	96	90	346	OK	OK	
109	B	22.0	520	215	100	98	320	OK	OK	Comparative Example
110	B	20.0	542	273 *	100	98	335	NG	OK	
111	C	22.0	549	220	100	95	336	OK	OK	Present Invention Example
112	D	20.0	546	218	97	93	341	OK	OK	
113	E	20.0	548	205	98	94	340	OK	OK	
114	F	25.0	535	210	98	88	336	OK	OK	
115	G	25.0	505	211	100	93	326	OK	OK	
116	H	25.0	538	210	98	86	338	OK	OK	
117	I	25.0	533	223	100	90	330	OK	OK	
118	J	19.0	542	208	100	100	340	OK	OK	
119	K	19.1	540	211	100	100	337	OK	OK	
120	L	23.0	542	210	98	92	332	OK	OK	
121	M	25.0	539	218	95	87	331	OK	OK	
122	N	25.0	537	225	96	88	334	OK	OK	
123	O	22.0	544	212	99	96	336	OK	OK	

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(continued)

Test No.	Kind of steel	Plate thickness (mm)	Mechanical characteristics		DWTT -20°C (%)	DWTT -30°C (%)	Charpy absorption energy (1)	ssc resistance	HIC resistance	
			Tensile strength (MPa)	Maximum hardness of surface layer (HV0.1)						
124	P*	20.0	632	285 *	92	85	343	NG	NG	Comparative Example
125	Q *	20.0	448	160	95	85	310	OK	OK	

* indicates that values fail to satisfy the regulation of the present invention.

#3 AF: acicular ferrite, B: bainite, F: polygonal ferrite, M: martensite

[0167] As is clear from Table 3-1 to Table 3-4, in Test Nos. 1, 2, 6 to 9, 13 to 26, 101, 102, 108, 109, and 111 to 123 in which the regulations of the present invention were all satisfied, the maximum hardness of the surface layer was 250 HV0.1 or less, and no cracking by the SSC test was observed. In addition, the DWTT shear fracture areas obtained after the DWTT test at -20°C were 85% or more, the absorbed energies of the Charpy impact test at -100°C were 150 J or more, the tensile strengths were also 480 MPa or more, and the crack area ratios after the HIC test were also 6% or less.

[0168] In Test Nos. 1, 2, 6 to 9, and 13 to 26, since the polygonal ferrite area ratios were less than 20%, and the steel plates had a structure mainly including acicular ferrite and bainite, the crack area ratio after the HIC test was also 3% or less, which shows that the steel plates were particularly excellent in terms of the HIC resistance. In addition, in Test Nos. 101, 102, 108, 109, and 111 to 123, since the polygonal ferrite area ratios were 20% or more, and the effective grain sizes were 10.0 μm or less, the DWTT shear fracture areas obtained after the DWTT test at -30°C were also 85% or more, the absorbed energies of the Charpy impact test at -100°C were 150 J or more, and the low temperature toughness was particularly excellent.

[0169] In contrast, Test Nos. 3 to 5, 10 to 12, 27 to 29, 103 to 107, 110, 124, and 125 did not satisfy any of the regulations of the present invention.

[0170] In Test Nos. 3, 10, 103, and 104, since the surface layer average cooling rates were slower than 30 °C/s or the holding temperatures exceeded the Bs point in the first cooling step, martensite was formed in the surface layers. As a result, it was not possible to reduce the maximum hardness of the surface layers to 250 HV0.1 or less.

[0171] In Test Nos. 4, 11, 105, and 110, since the surface layer cooling stop temperatures were lower than the Ms point in the first cooling step, martensite was formed, and it was not possible to reduce the maximum hardness of the surface layers to 250 HV0.1 or less.

[0172] In Test Nos. 5, 12, and 106, since the holding times in the holding step were shorter than the effective time for acicular ferrite/bainitic transformation to proceed, residual austenite that had not been transformed in the holding step became martensite in the subsequent cooling, and it was not possible to reduce the maximum hardness of the surface layers to 250 HV0.1 or less.

[0173] In Test No. 107, since the average cooling rate in the third cooling step was slower than 10 °C/s, the effective grain size in the thickness middle portion became coarse, and the DWTT shear fracture area decreased.

[0174] In Test Nos. 27 and 124, since the C contents were higher than the regulated range, the maximum hardness of the surface layers exceeded 250 HV0.1. In addition, in Test No. 125, since the value of Ceq was lower than the regulated range, the polygonal ferrite fraction exceeded 20%, and a sufficient strength could not be obtained.

[0175] Furthermore, in Test No. 28, the value of Ceq was higher than the regulated range, and, in Test No. 29, since the total amount of Mo, Cr, Cu, and Ni was higher than the regulated range, even when the same cooling step as in the present invention was imparted, martensite was formed, and it was not possible to reduce the maximum hardness of the surface layer to 250 HV0.1 or less.

(Example 2)

[0176] Among the steel plates obtained in Example 1, the steel plates that had obtained favorable characteristics were formed into a tubular shape by the UO pipe making method, welded from the inner and outer surfaces of steel pipes by submerged arc welding, and expanded to produce UOE steel pipes. As the welding conditions, 3 electrodes were used on the inner surface side, 4 electrodes were used on the outer surface side, and the heat input was set within a range of 2.0 kJ/mm to 10 kJ/mm depending on the plate thickness.

[0177] On the obtained steel pipes, similar to the steel plates, metallographic structure observation, effective grain size measurement, tensile tests, surface layer hardness measurement, DWTT tests, Charpy impact tests, SSC tests, and HIC tests were performed.

[0178] However, as an observed section of the metallographic structure in the steel pipe, two test pieces having an overall thickness were cut out from a position at 90° from a seam weld in the steel pipe such that a cross section in the L (longitudinal) direction becomes the observed section and were each used for structure observation and for grain size measurement. The structures were observed and the effective grain sizes were measured using these test pieces by the same methods as in Example 1.

[0179] In addition, for the measurement of the maximum hardness of the surface layer, 300 mm x 300 mm steel plates were each cut out by gas cutting from a three o'clock, six o'clock, or nine o'clock position in a case where the weld of the steel pipe was defined at zero o'clock (position at 90°, 180°, or 270° from the seam weld), and block test pieces having a length of 20 mm and a width of 20 mm were collected by mechanical cutting from the center of the cut-out steel plates and polished by mechanical polishing. In one block test piece, the hardness is measured with a Vickers hardness meter (load: 0.1 kgf) at a total of 100 points (10 points at 1.0 mm intervals in the width direction at each of 10 depth points at 0.1 mm intervals in the plate thickness direction from 0.1 mm deep from the surface as a starting point). That is, the hardness was measured at a total of 300 points in three block test pieces.

[0180] In addition, a DWTT test piece was collected from a position at 90° from the seam weld of the steel pipe.

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[0181] In addition, a Charpy impact test piece was collected from a position at 90° from the seam weld of the steel pipe.

[0182] As the tensile test piece, a round bar-like test piece was collected from a position at 180° from the seam portion of the steel pipe such that the longitudinal direction became parallel to the width direction of the steel plate, and a tensile test was performed according to API 5L.

5 **[0183]** In addition, an SSC test and an HIC test were performed in the same manner as in Example 1.

[0184] The results are shown in Table 4-1 and Table 4-2.

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[Table 4-1]

Steel pipe No.	Steel plate test No.	Kind of steel	Outer diameter (mm)	Wall thickness (mm)	Metallographic structure								Mechanical characteristics		DWT -20°C (%)	Charpy absorption energy (J)	SSC resistance	HIC resistance	
					Middle portion				Surface layer		Tensile strength (MPa)	Maximum hardness of surface layer (HV0.1)							
					Kind#5	F area ratio (%)	AF + B area ratio (%)	Effective grain size (μm)	M-A area ratio (%)	I Kind#5			M-A area ratio (%)						
P1	2	A	1016	20.0	F, AF, B	5	94.0	12.2	1.0	AF, B	0.8	603	221	93	450	OK	Ex	Present Invention Example	
P2	7	B	813	20.0	AF, B		98.4	12.5	1.6	AF, B	0.5	589	212	88	468	OK	Ex	Present Invention Example	
P3	8	B	914	22.0	AF, B		99.2	11.8	0.8	AF, B	0.3	628	220	91	468	OK	Ex	Present Invention Example	
P4	9	B	1016	25.0	AF, B	0	99.2	11.3	0.8	AF, B	0.3	588	225	96	444	OK	Ex	Present Invention Example	
P5	14	C	914	22.0	AF, B		99.1	12.1	0.9	AF, B	0.4	612	225	88	468	OK	Ex	Present Invention Example	
P6	15	D	813	20.0	F, AF, B	6	93.0	11.7	1.0	AF, B	0.2	603	223	91	445	OK	Ex	Present Invention Example	
P7	16	E	559	20.0	F,AF, B	3	96.2	11.9	0.8	AF, B	0.1	611	211	89	454	OK	Ex	Present Invention Example	
P8	18	G	914	25.0	F, AF, B	15	83.8	11.5	1.2	AF, B	0.3	590	216	88	409	OK	Ex	Present Invention Example	

(continued)

Steel pipe No.	Steel plate test No.	Kind of steel	Outer diameter (mm)	Wall thick- ness (mm)	Metallographic structure						Mechanical characteristics		DWT -20°C (%)	Charpy absorp- tion energy (J)	SSC resis- tance	HIC resis- tance	
					Middle portion			Surface layer			Tensile strength (MPa)	Maxi- mum hardness of surface layer (HV0.1)					
					Kind#5	F area ratio (%)	AF + B area ratio (%)	Effective grain size (μm)	M-A area ratio (%)	I Kind#5 I	M-A area ratio (%)						
P9	22	K	1016	19.1	F, AF, B	10	89.0	11.4	1.0	AF, B	0.2	595	215	88	431	OK	Ex
P10	26	O	1016	22.0	F, AF, B	5	93.7	11.8	1.3	AF, B	0.3	604	216	88	449	OK	Ex
#5 AF: acicular ferrite, B: bainite, F: polygonal ferrite, M: martensite																	

[Table 4-2]

Steel pipe No.	Steel plate test No.	Kind of steel	Outer diameter (mm)	Wall thickness (mm)	Metallographic structure								Mechanical characteristics		DWT-T -20°C (%)	DWT-T -30°C (%)	Charpy absorption energy (J)	SSC resistance	HIC resistance	
					Middle portion				Surface layer		Tensile strength (MPa)	Maximum hardness of surface layer (HV0.1)								
					Kin- d#5	F area ratio (%)	AF + B area ratio (%)	Effective grain size (μm)	M-A area ratio (%)	Kin- d#5			M-A area ratio (%)							
P10-1	101	A	813	17.5	F, AF, B	50	49.0	8.7	1.0	AF, B	0.2	549	212	98	98	321	OK	OK	Present Invention Example	
P10-2	102	A	1016	20.0	F, AF, B	38	61.0	9.3	1.0	AF, B	0.8	557	221	96	93	333	OK	OK	Present Invention Example	
Pla3	108	B	914	20.0	F, AF, B	32	67.2	9.6	0.8	AF, B	0.2	580	211	94	88	339	OK	OK	Present Invention Example	
P10-4	109	B	1016	22.0	F, AF, B	58	40.3	8.3	1.7	AF, B	0.5	531	220	98	96	313	OK	OK	Present Invention Example	
P10-5	111	C	914	22.0	F, AF, B	42	57.1	9.1	0.9	AF, B	0.3	561	225	98	93	329	OK	OK	Present Invention Example	
P10-6	112	D	813	20.0	F, AF, B	37	62.0	9.4	1.0	AF, B	0.2	558	223	95	91	333	OK	OK	Present Invention Example	

(continued)

Steel pipe No.	Steel plate test No.	Kind of steel	Outer diameter (mm)	Wall thick- ness (mm)	Metallographic structure						Mechanical characteristics		DWT- T -20°C (%)	DWT- T -30°C (%)	Charpy absorp- tion energy (J)	SSC resis- tance	HIC resis- tance		
					Middle portion			Surface layer			Tensile strength (MPa)	Maxi- mum hard- ness of surface layer (HV0.1)							
					Kin- d#5	F area ratio (%)	AF + B area ratio (%)	Effec- tive grain size (μm)	M-A area ratio (%)	Kin- d#5									M-A area ratio (%)
P10- 7	113	E	559	20.0	F, AF, B	38	61.2	9.3	0.8	AF, B	0.1	564	211	95	91	331	OK	Present Inven- tion Ex- ample	
P10- 8	115	G	914	25.0	F, AF, B	52	45.4	8.6	2.6	AF, B	0.6	517	216	98	91	318	OK	Present Inven- tion Ex- ample	
P10- 9	118	J	1016	19.0	F, AF, B	38	61.0	9.3	1.0	AF, B	0.2	553	212	98	98	333	OK	Present Inven- tion Ex- ample	
P110	120	L	1016	23.0	F, AF, B	46	52.8	8.9	1.2	AF, B	0.2	554	215	96	90	325	OK	Present Inven- tion Ex- ample	

#5 AF: acicular ferrite, B: bainite, F: polygonal ferrite, M: martensite

#5 AF: acicular ferrite, B: bainite, F: polygonal ferrite, M: martensite

[0185] As is clear from Table 4-1 and Table 4-2, the steel pipes manufactured using the steel plate having excellent SSC resistance and HIC resistance and high low temperature toughness had excellent SSC resistance and HIC resistance and high low temperature toughness.

5 [Industrial Applicability]

[0186] According to the present invention, it become possible to obtain a steel plate and a steel pipe having excellent SSC resistance and HIC resistance and high low temperature toughness. Therefore, the steel plate and the steel pipe according to the present invention can be suitably used as line pipes for transporting crude oil and natural gas containing a large amount of H₂S.

Claims

15 **1.** A steel plate comprising, as a chemical composition, by mass%:

C: 0.020% to 0.080%;

Si: 0.01% to 0.50%;

Mn: 0.50% to 1.60%;

20 Nb: 0.001% to 0.100%;

N: 0.0010% to 0.0100%;

Ca: 0.0001% to 0.0050%;

P: 0.030% or less;

S: 0.0025% or less;

25 Ti: 0.005% to 0.030%;

Al: 0.010% to 0.040%;

O: 0.0040% or less;

Mo: 0% to 2.00%;

Cr: 0% to 2.00%;

30 Cu: 0% to 2.00%;

Ni: 0% to 2.00%;

W: 0% to 1.00%;

V: 0% to 0.200%;

Zr: 0% to 0.0500%;

35 Ta: 0% to 0.0500%;

B: 0% to 0.0020%;

REM: 0% to 0.0100%;

Mg: 0% to 0.0100%;

Hf: 0% to 0.0050%;

40 Re: 0% to 0.0050%; and

a remainder: Fe and impurities,

wherein the following formula (i) is satisfied,

Ceq represented by the following formula (ii) is 0.30 to 0.50,

45 a metallographic structure in a thickness middle portion includes, by area%, 0% to 80% of polygonal ferrite and one or two selected from acicular ferrite and bainite, a remainder is an M-A phase, and an effective grain size is 15.0 μm or less,

a metallographic structure in a surface layer that is a range of 1.0 mm in a thickness direction from a surface includes, by area%, a total of 95% or more of one or two selected from acicular ferrite and bainite, and a remainder is an M-A phase, and

50 a maximum hardness in the surface layer is 250 HV0.1 or less,

wherein the area% of polygonal ferrite, the area% of acicular ferrite and bainite, and the effective grain size are determined according to the methods described in the description, and the maximum hardness in the surface layer is evaluated by a Vickers hardness test according to JIS Z 224:2009 in which the test force is set to 0.98 N (0.1 kgf),

$$0.05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2.00 \cdots (i)$$

$$C_{eq} = C + Mn/6 + (Ni + Cu)/15 + (Cr + Mo + V)/5 \cdots (ii)$$

here, each element symbol in the formulae represents an amount (mass%) of each element contained in steel and is regarded as zero in a case where a corresponding element is not contained.

2. The steel plate according to claim 1, wherein an area% of the polygonal ferrite in the metallographic structure of the thickness middle portion is 0% to less than 20%.

3. The steel plate according to claim 1, wherein an area% of the polygonal ferrite in the metallographic structure of the thickness middle portion is 20% to 80%, and the effective grain size is 10.0 μm or less.

4. The steel plate according to any one of claims 1 to 3, further comprising, as the chemical composition, by mass%, one or more selected from:

W: 0.01% to 1.00%;
V: 0.010% to 0.200%;
Zr: 0.0001% to 0.050%;
Ta: 0.0001% to 0.0500%; and
B: 0.0001% to 0.0020%.

5. The steel plate according to any one of claims 1 to 4, further comprising, as the chemical composition, by mass%, one or more selected from:

REM: 0.0001% to 0.0100%;
Mg: 0.0001% to 0.0100%;
Hf: 0.0001% to 0.0050%; and
Re: 0.0001% to 0.0050%.

6. A steel pipe comprising:

a base material portion made of a tubular steel plate; and
a weld that is provided at an abutment portion of the steel plate and extends in a longitudinal direction of the steel plate,

wherein the steel plate contains, as a chemical composition, by mass%,

C: 0.020% to 0.080%;
Si: 0.01% to 0.50%;
Mn: 0.50% to 1.60%;
Nb: 0.001% to 0.100%;
N: 0.0010% to 0.0100%;
Ca: 0.0001% to 0.0050%;
P: 0.030% or less;
S: 0.0025% or less;
Ti: 0.005% to 0.030%;
Al: 0.010% to 0.040%;
O: 0.0040% or less;
Mo: 0% to 2.00%;
Cr: 0% to 2.00%;
Cu: 0% to 2.00%;
Ni: 0% to 2.00%;
W: 0% to 1.00%;
V: 0% to 0.200%;
Zr: 0% to 0.0500%;
Ta: 0% to 0.0500%;
B: 0% to 0.0020%;
REM: 0% to 0.0100%;

Mg: 0% to 0.0100%;

Hf: 0% to 0.0050%;

Re: 0% to 0.0050%; and

a remainder: Fe and impurities,

wherein the following formula (i) is satisfied,

Ceq represented by the following formula (ii) is 0.30 to 0.50,

a metallographic structure in a wall thickness middle portion includes, by area%, 0% to 80% of polygonal ferrite and one or two selected from acicular ferrite and bainite, a remainder is an M-A phase, and an effective grain size is 15.0 μm or less,

a metallographic structure in a surface layer that is a range of 1.0 mm in a thickness direction from a surface includes, by area%, a total of 95% or more of one or two selected from acicular ferrite and bainite, and a remainder is an M-A phase, and

a maximum hardness in the surface layer is 250 HV0.1 or less,

wherein the area% of polygonal ferrite, the area% of acicular ferrite and bainite, and the effective grain size are determined according to the methods described in the description, and the maximum hardness in the surface layer is evaluated by a Vickers hardness test according to JIS Z 224:2009 in which the test force is set to 0.98 N (0.1 kgf),

$$0.05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2.00 \quad \cdots (i)$$

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

here, each element symbol in the formulae represents an amount (mass%) of each element contained in steel and is regarded as zero in a case where a corresponding element is not contained.

7. The steel pipe according to claim 6,
wherein an area% of the polygonal ferrite in the metallographic structure of the wall thickness middle portion is 0% to less than 20%.
8. The steel pipe according to claim 6,
wherein an area% of the polygonal ferrite in the metallographic structure of the wall thickness middle portion is 20% to 80%, and the effective grain size is 10.0 μm or less.

Patentansprüche

1. Stahlplatte umfassend, als eine chemische Zusammensetzung, in Masse-%:

C: 0,020% bis 0,080%;

Si: 0,01% bis 0,50%;

Mn: 0,50% bis 1,60%;

Nb: 0,001% bis 0,100%;

N: 0,0010% bis 0,0100%;

Ca: 0,0001% bis 0,0050%;

P: 0,030% oder weniger;

S: 0,0025% oder weniger;

Ti: 0,005% bis 0,030%;

Al: 0,010% bis 0,040%;

O: 0,0040% oder weniger;

Mo: 0% bis 2,00%;

Cr: 0% bis 2,00%;

Cu: 0% bis 2,00%;

Ni: 0% bis 2,00%;

W: 0% bis 1,00%;

V: 0% bis 0,200%;

Zr: 0% bis 0,0500%;

Ta: 0% bis 0,0500%;

B: 0% bis 0,0020%;

REM: 0% bis 0,0100%;

Mg: 0% bis 0,0100%;

Hf: 0% bis 0,0050%;

Re: 0% bis 0,0050%; und

einen Rest: Fe und Verunreinigungen,

wobei die folgende Formel (i) erfüllt ist,

Ceq, dargestellt durch die folgende Formel (ii), 0,30 bis 0,50 beträgt,

eine metallographische Struktur in einem mittleren Dickenabschnitt umfasst, in Flächenprozent, 0% bis 80% von polygonalem Ferrit und ein oder zwei, ausgewählt aus nadelförmigem Ferrit und Bainit, ein Rest eine M-A-Phase ist, und eine effektive Korngröße 15,0 μm oder weniger beträgt,

eine metallographische Struktur in einer Oberflächenschicht, die in einer Dickenrichtung ein Bereich von 1,0 mm von einer Oberfläche ausgehend ist, umfasst, in Flächenprozent, insgesamt 95% oder mehr von einem oder zwei, die ausgewählt sind aus nadelförmigem Ferrit und Bainit, und ein Rest eine M-A-Phase ist, und

eine maximale Härte in der Oberflächenschicht 250 HV_{0,1} oder weniger beträgt,

wobei das Flächenprozent von polygonalem Ferrit, das Flächenprozent von nadelförmigem Ferrit und Bainit und die effektive Korngröße gemäß den in der Beschreibung beschriebenen Verfahren bestimmt werden, und die maximale Härte in der Oberflächenschicht durch einen Vickers-Härtetest gemäß JIS Z 224:2009 ermittelt wird, bei dem die Prüfkraft auf 0,98 N (0,1 kgf) eingestellt wird,

$$0,05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2,00 \quad \cdots (i)$$

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

hierbei steht jedes Elementsymbol in den Formeln für eine Menge (Masse-%) jedes im Stahl enthaltenen Elements und wird als Null betrachtet, wo ein entsprechendes Element nicht enthalten ist.

2. Stahlplatte nach Anspruch 1,

wobei ein Flächenprozent des polygonalen Ferrits in der metallografischen Struktur des mittleren Dickenabschnitts 0% bis weniger als 20% beträgt.

3. Stahlplatte nach Anspruch 1,

wobei ein Flächenprozent des polygonalen Ferrits in der metallografischen Struktur des mittleren Dickenabschnitts 20% bis 80% beträgt, und die effektive Korngröße 10,0 μm oder weniger beträgt.

4. Stahlplatte gemäß einem der Ansprüche 1 bis 3, ferner umfassend, als chemische Zusammensetzung, in Masse-%, eines oder mehrere, ausgewählt aus:

W: 0,01 % bis 1,00%;

V: 0,010% bis 0,200%;

Zr: 0,0001% bis 0,050%;

Ta: 0,0001% bis 0,0500%; und

B: 0,0001% bis 0,0020%.

5. Stahlplatte gemäß einem der Ansprüche 1 bis 4, ferner umfassend, als chemische Zusammensetzung, in Masse-%, eines oder mehrere, ausgewählt aus:

REM: 0,0001% bis 0,0100%;

Mg: 0,0001% bis 0,0100%;

Hf: 0,0001% bis 0,0050% und

Re: 0,0001% bis 0,0050%.

6. Stahlrohr, umfassend:

einen Grundmaterialabschnitt, der aus einer Stahlrohrplatte hergestellt ist; und

eine Schweißnaht, die an einem Anschlagabschnitt der Stahlplatte vorgesehen ist und sich in einer Längsrichtung der Stahlplatte erstreckt,

wobei die Stahlplatte enthält, als eine chemische Zusammensetzung, in Masse-%:

5 C: 0,020% bis 0,080%;
 Si: 0,01% bis 0,50%;
 Mn: 0,50% bis 1,60%;
 Nb: 0,001% bis 0,100%;
 N: 0,0010% bis 0,0100%;
 Ca: 0,0001% bis 0,0050%;
 10 P: 0,030% oder weniger;
 S: 0,0025% oder weniger;
 Ti: 0,005% bis 0,030%;
 Al: 0,010% bis 0,040%;
 O: 0,0040% oder weniger;
 15 Mo: 0% bis 2,00%;
 Cr: 0% bis 2,00%;
 Cu: 0% bis 2,00%;
 Ni: 0% bis 2,00%;
 W: 0% bis 1,00%;
 V: 0% bis 0,200%;
 20 Zr: 0% bis 0,0500%;
 Ta: 0% bis 0,0500%;
 B: 0% bis 0,0020%;
 REM: 0% bis 0,0100%;
 Mg: 0% bis 0,0100%;
 25 Hf: 0% bis 0,0050%;
 Re: 0% bis 0,0050%; und
 einen Rest: Fe und Verunreinigungen,
 wobei die folgende Formel (i) erfüllt ist,
 30 C_{eq} , dargestellt durch die folgende Formel (ii), 0,30 bis 0,50 beträgt,
 eine metallographische Struktur in einem mittleren Dickenabschnitt umfasst, in Flächenprozent, 0% bis 80%
 von polygonalem Ferrit und ein oder zwei, ausgewählt aus nadelförmigem Ferrit und Bainit, ein Rest eine M-
 A-Phase ist, und eine effektive Korngröße 15,0 μm oder weniger beträgt,
 eine metallographische Struktur in einer Oberflächenschicht, die in einer Dickenrichtung ein Bereich von 1,0
 mm von einer Oberfläche ausgehend ist, umfasst, in Flächenprozent, insgesamt 95% oder mehr von einem
 35 oder zwei, die ausgewählt sind aus nadelförmigem Ferrit und Bainit, und ein Rest eine M-A-Phase ist, und
 eine maximale Härte in der Oberflächenschicht 250 HV_{0,1} oder weniger beträgt,
 wobei das Flächenprozent von polygonalem Ferrit, das Flächenprozent von nadelförmigem Ferrit und Bainit
 und die effektive Korngröße gemäß den in der Beschreibung beschriebenen Verfahren bestimmt werden,
 und die maximale Härte in der Oberflächenschicht durch einen Vickers-Härtetest gemäß JIS Z 224:2009
 40 ermittelt wird, bei dem die Prüfkraft auf 0,98 N (0,1 kgf) eingestellt wird,

$$0,05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2,00 \cdots (i)$$

$$45 \quad C_{eq} = C + \text{Mn}/6 + (\text{Ni} + \text{Cu})/15 + (\text{Cr} + \text{Mo} + \text{V})/5 \cdots (ii)$$

hierbei steht jedes Elementsymbol in den Formeln für eine Menge (Masse-%) jedes im Stahl enthaltenen Elements und wird als Null betrachtet, wo ein entsprechendes Element nicht enthalten ist.

- 50 7. Stahlrohr nach Anspruch 6,
wobei das Flächenprozent des polygonalen Ferrits in der metallografischen Struktur des mittleren Wanddickenab-
schnitts 0% bis weniger als 20% beträgt.
- 55 8. Stahlrohr nach Anspruch 6,
wobei ein Flächenprozent des polygonalen Ferrits in der metallografischen Struktur des mittleren Wanddickenab-
schnitts 20% bis 80% beträgt, und die effektive Korngröße 10,0 μm oder weniger beträgt.

Revendications

1. Plaque d'acier comprenant, à titre de composition chimique, en %m :

5 C : 0,020 % à 0,080 % ;
 Si : 0,01 % à 0,50 % ;
 Mn : 0,50 % à 1,60 % ;
 Nb : 0,001 % à 0,100 % ;
 N : 0,0010 % à 0,0100 % ;
 10 Ca : 0,0001 % à 0,0050 % ;
 P : 0,030 % ou moins ;
 S : 0,0025 % ou moins ;
 Ti : 0,005 % à 0,030 % ;
 Al : 0,010 % à 0,040 % ;
 15 O : 0,0040 % ou moins ;
 Mo : 0 % à 2,00 % ;
 Cr : 0 % à 2,00 % ;
 Cu : 0 % à 2,00 % ;
 Ni : 0 % à 2,00 % ;
 20 W : 0 % à 1,00 % ;
 V : 0 % à 0,200 % ;
 Zr : 0 % à 0,0500 % ;
 Ta : 0 % à 0,0500 % ;
 B : 0 % à 0,0020 % ;
 25 métal de terres rares : 0 % à 0,0100 % ;
 Mg : 0 % à 0,0100 % ;
 Hf : 0 % à 0,0050 % ;
 Re : 0 % à 0,0050 % ; et
 un reste : Fe et des impuretés,
 30 dans laquelle la formule (i) suivante est satisfaite,
 Ceq représenté par la formule (ii) suivante est 0,30 à 0,50,
 une structure métallographique dans une portion médiane d'épaisseur inclut, en %aire, 0 % à 80 % de ferrite
 polygonale et un ou deux éléments sélectionnés parmi une ferrite aciculaire et une bainite, un reste étant une
 phase M-A, et une taille de grain effective étant 15,0 μm ou moins,
 35 une structure métallographique dans une couche de surface qui est dans une plage de 1,0 mm dans une direction
 d'épaisseur par rapport à une surface inclut, en %aire, un total de 95 % ou plus d'un ou de deux éléments
 sélectionnés parmi une ferrite aciculaire et une bainite, et un reste étant une phase M-A, et
 une dureté maximum de la couche de surface est 250 HV0.1 ou moins,
 40 dans laquelle le %aire de ferrite polygonale, le %aire de ferrite aciculaire et de bainite, et la taille de grain effective
 sont déterminés selon des méthodes décrites dans la description, et la dureté maximum dans la couche de
 surface est évaluée par un essai de dureté Vickers selon la norme industrielle japonaise JIS Z 224:2009 dans
 lequel la force d'essai est fixée à 0,98 N (0,1 kgf),

$$0,05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2,00 \cdots (i)$$

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

50 ici, chaque symbole d'élément dans les formules représente une quantité (%m) de chaque élément contenu dans
 l'acier et est considéré comme égal à zéro dans un cas où un élément correspondant n'est pas contenu.

2. Plaque d'acier selon la revendication 1,

dans laquelle un %aire de la ferrite polygonale dans la structure métallographique de la portion médiane d'épaisseur
 est de 0 % à moins de 20 %.

3. Plaque d'acier selon la revendication 1,

dans laquelle un %aire de la ferrite polygonale dans la structure métallographique de la portion médiane d'épaisseur
 est de 20 % à 80 %, et la taille de grain effective est de 10,0 μm ou moins.

4. Plaque d'acier selon l'une quelconque des revendications 1 à 3, comprenant en outre, à titre de composition chimique, en %m, un ou plusieurs éléments sélectionnés parmi :

W: 0,01 % à 1,00 % ;
V : 0,010 % à 0,200 % ;
Zr : 0,0001 % à 0,050 % ;
Ta : 0,0001 % à 0,0500 % ; et
B : 0,0001 % à 0,0020 %.

5. Plaque d'acier selon l'une quelconque des revendications 1 à 4, comprenant en outre, à titre de composition chimique, en %m, un ou plusieurs éléments sélectionnés parmi :

métal de terres rares : 0,0001 % à 0,0100 % ;
Mg : 0,0001 % à 0,0100 % ;
Hf : 0,0001 % à 0,0050 % ; et
Re : 0,0001 % à 0,0050 %.

6. Tube d'acier comprenant :

une portion en matériau de base faite d'une plaque d'acier tubulaire ; et
une soudure qui est prévue au niveau d'une portion de butée de la plaque d'acier et qui s'étend dans une direction longitudinale de la plaque d'acier,
dans lequel la plaque d'acier contient, à titre de composition chimique, en %m :

C : 0,020 % à 0,080 % ;
Si : 0,01 % à 0,50 % ;
Mn : 0,50 % à 1,60 % ;
Nb: 0,001 % à 0,100 % ;
N : 0,0010 % à 0,0100 % ;
Ca : 0,0001 % à 0,0050 % ;
P : 0,030 % ou moins ;
S : 0,0025 % ou moins ;
Ti : 0,005 % à 0,030 % ;
Al: 0,010 % à 0,040 % ;
O : 0,0040 % ou moins ;
Mo : 0 % à 2,00 % ;
Cr: 0 % à 2,00 % ;
Cu : 0 % à 2,00 % ;
Ni : 0 % à 2,00 % ;
W : 0 % à 1,00 % ;
V : 0 % à 0,200 % ;
Zr : 0 % à 0,0500 % ;
Ta : 0 % à 0,0500 % ;
B : 0 % à 0,0020 % ;
métal de terres rares : 0 % à 0,0100 % ;
Mg : 0 % à 0,0100 % ;
Hf : 0 % à 0,0050 % ;
Re : 0 % à 0,0050 % ; et

un reste : Fe et des impuretés,

dans lequel la formule (i) suivante est satisfaite,

Ceq représenté par la formule (ii) suivante est 0,30 à 0,50,

une structure métallographique dans une portion médiane d'épaisseur de paroi inclut, en %aire, 0 % à 80 % de ferrite polygonale et un ou deux éléments sélectionnés parmi une ferrite aciculaire et une bainite, un reste étant une phase M-A, et une taille de grain effective étant 15,0 μ m ou moins,

une structure métallographique dans une couche de surface qui est dans une plage de 1,0 mm dans une direction d'épaisseur par rapport à une surface inclut, en %aire, un total de 95 % ou plus d'un ou de deux éléments sélectionnés parmi une ferrite aciculaire et une bainite, et un reste étant une phase M-A, et une dureté maximum de la couche de surface est 250 HV0.1 ou moins,

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dans lequel le %aire de ferrite polygonale, le %aire de ferrite aciculaire et de bainite, et la taille de grain effective sont déterminés selon des méthodes décrites dans la description, et la dureté maximum de la couche de surface est évaluée par un essai de dureté Vickers selon la norme industrielle japonaise JIS Z 224:2009 dans lequel la force d'essai est fixée à 0,98 N (0,1 kgf),

$$0,05 \leq \text{Mo} + \text{Cr} + \text{Cu} + \text{Ni} \leq 2,00 \cdots (i)$$

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

ici, chaque symbole d'élément dans les formules représente une quantité (%m) de chaque élément contenu dans l'acier et est considéré comme égal à zéro dans un cas où un élément correspondant n'est pas contenu.

7. Tube d'acier selon la revendication 6,
dans lequel un %aire de la ferrite polygonale dans la structure métallographique de la portion médiane d'épaisseur de paroi est de 0 % à moins de 20 %.
8. Tube d'acier selon la revendication 6,
dans lequel un %aire de la ferrite polygonale dans la structure métallographique de la portion médiane d'épaisseur de paroi est de 20 % à 80 %, et la taille de grain effective est de 10,0 μm ou moins.

REFERENCES CITED IN THE DESCRIPTION

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