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

(11) EP 3 680 358 A1

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

(43) Date of publication:
15.07.2020 Bulletin 2020/29

(21) Application number: **18853601.5**

(22) Date of filing: **07.09.2018**

(51) Int Cl.:
C22C 38/00 (2006.01) *C22C 38/02* (2006.01)
C22C 38/04 (2006.01) *C22C 38/06* (2006.01)
C22C 38/08 (2006.01) *C22C 38/12* (2006.01)
C22C 38/14 (2006.01) *C22C 38/16* (2006.01)
C22C 38/18 (2006.01) *C22C 38/42* (2006.01)
C22C 38/44 (2006.01) *C22C 38/46* (2006.01)
C22C 38/48 (2006.01) *C22C 38/50* (2006.01)
C22C 38/54 (2006.01) *C22C 38/58* (2006.01)
C21D 8/02 (2006.01) *C21D 1/18* (2006.01)
C21D 6/00 (2006.01)

(86) International application number:
PCT/JP2018/033286

(87) International publication number:
WO 2019/050010 (14.03.2019 Gazette 2019/11)

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

(30) Priority: **08.09.2017 JP 2017173275**

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(54) STEEL SHEET AND METHOD FOR PRODUCING SAME

(57) A high strength steel plate, having excellent toughness not only in an inside portion of the steel plate but also in a surface layer of the steel plate, can be stably produced. The steel plate has a chemical composition containing, in mass%, C: 0.080 % or more and 0.200 % or less, Si: 0.40 % or less, Mn: 0.50 % or more and 5.00 % or less, P: 0.015 % or less, S: 0.0050 % or less, Cr: 3.00 % or less, Ni: 5.00 % or less, Al: 0.080 % or less, N: 0.0070 % or less, and B: 0.0030 % or less, the balance being Fe and inevitable impurities, wherein an equivalent carbon content CeqIIW is 0.57 % or more, an area fraction of bainite in the surface layer is 10 % or more, and a yield stress is 620 MPa or more.

Printed by Jouve, 75001 PARIS (FR)

Description

TECHNICAL FIELD

[0001] The present disclosure relates to a thick steel plate having a thickness of 100 mm or more among steel plates used for steel structures such as buildings, bridges, shipbuilding, marine structures, construction machinery, tanks, and penstocks, and a method of producing the same.

BACKGROUND

[0002] When steel materials are used for structures such as buildings, bridges, shipbuilding, marine structures, construction machinery, tanks, and penstocks, the steel materials are joined by welding according to the shape of the structure to obtain a desired shape. In recent years, the size of such steel structures has been greatly increased, and the strength and thickness of steel materials used have also been increased. For example, Kouzaburou Ootani and four others, "Development of extremely thick (210 mm) 800N/mm2 grade steel plates for racks of jack-up rigs", Nippon Steel Technical Report, 1993, No. 348, pages 10 to 16 (NPL 1) reports an extremely thick steel plate having a thickness of 210 mm that is developed for racks of jack-up rigs. NPL 1 describes a chemical composition and production conditions for guaranteeing the toughness of the mid-thickness part of the thick steel plate.

CITATION LIST

Non-patent Literature

[0003] NPL 1: Kouzaburou Ootani and four others, "Development of extremely thick (210 mm) 800N/mm2 grade steel plates for racks of jack-up rigs", Nippon Steel Technical Report, 1993, No. 348, pages 10 to 16

SUMMARY

(Technical Problem)

[0004] A high strength steel plate having a thickness of 100 mm or more is usually produced by performing quenching and tempering after hot rolling to obtain high toughness in addition to high strength. When producing a thick steel plate in this way, the cooling rate in the quenching process after hot rolling is lower in an inside portion of the steel plate, which is inside a surface layer of the steel plate, than in the surface layer. Therefore, a microstructure with relatively low strength such as ferrite tends to be formed in the inside portion of the steel plate. In order to suppress the generation of such a low-strength microstructure in the inside portion of the steel plate, it is necessary to add a large amount of alloying element.

[0005] The surface layer of the steel plate here refers to a region on the front surface side and a region on the back surface side, which extend respectively from the front surface and the back surface of the steel plate to a position of at one quarter in height of the plate thickness (1/4 t, where "t" represents the plate thickness) in the thickness direction, and the portion inside the surface layer (including 1/4 t) is the inside portion of the steel plate.

[0006] In particular, in order to achieve the strength and toughness in the inside portion of the thick steel plate, it is important to form bainite or a mixed microstructure of bainite and martensite in the inside portion of the steel plate during quenching, and it is necessary to add a large amount of alloying elements such as Mn, Ni, Cr, and Mo.

[0007] On the other hand, when a large amount of the above-mentioned alloying elements is added, the surface layer of the steel plate, which has a higher cooling rate than the inside portion of the steel plate during quenching, is formed with a martensite microstructure inferior in toughness. Therefore, the toughness of the surface layer of the steel plate is lower than that of the inside portion of the steel plate even after tempering.

[0008] However, as NPL 1 does not mention the toughness deterioration in the surface layer of the steel plate that is rapidly cooled, and no attention has been paid on this problem so far.

[0009] It could thus be helpful to provide a method of stably producing a high strength steel plate having excellent toughness not only in the inside portion of the steel plate but also in the surface layer of the steel plate.

(Solution to Problem)

[0010] In order to solve the above problem, we have intensively studied thick steel plates having a yield stress of 620 MPa or more and a thickness of 100 mm or more with respect to microstructure control factors for suppressing a reduce in toughness in the surface layer of the steel plate and a reduce in strength in the inside portion of the steel plate, and found the following discoveries I to III.

[0011] I. In order to obtain high strength while maintaining good toughness in the inside portion of a steel plate where the cooling rate is significantly lower than the surface layer of the steel plate during quenching, it is important that the microstructure be a martensite microstructure and/or a bainite microstructure even if the quenching is performed at a low cooling rate. For this purpose, it is necessary to select an appropriate chemical composition and to make the equivalent carbon content 0.57 % or more.

[0012] II. When subjecting a steel plate having the selected chemical composition to quenching, a martensite microstructure that is disadvantageous for guaranteeing toughness is formed in the surface layer of the steel plate where the cooling rate is high during the quenching, and the microstructure unit of the martensite microstructure called block or packet once formed does not change even after tempering, which renders it difficult to guarantee stable toughness.

[0013] III. In order to suppress the formation of a tempered martensite single-phase microstructure that is disadvantageous to toughness, it is important to control the average cooling rate at a range of 0.2 °C/s to 10 °C/s when the surface layer of the steel plate and the inside portion of the steel plate are in a temperature range from (Ar_3 transformation point + 50) °C or higher to (Ar_3 transformation point - 20) °C or lower so that bainite is formed at a predetermined ratio or more in the surface layer of the steel plate.

[0014] The present disclosure is based on the above discoveries. The primary features of the present disclosure are as follows.

1. A steel plate comprising a chemical composition containing (consisting of), in mass%,
C: 0.080 % or more and 0.200 % or less,
Si: 0.40 % or less,
Mn: 0.50 % or more and 5.00 % or less,
P: 0.015 % or less,
S: 0.0050 % or less,
Cr: 3.00 % or less,
Ni: 5.00 % or less,
Al: 0.080 % or less,
N: 0.0070 % or less, and
B: 0.0030 % or less in a range satisfying the following formula (1),

$$[C] + [Mn]/6 + [Ni]/15 + [Cr]/15 \geq 0.57 \qquad (1)$$

where [] indicates a content of an element in the [] in mass%,
the balance being Fe and inevitable impurities, wherein
a surface layer of the steel plate has a microstructure where an area fraction of bainite is 10 % or more, and an inside portion of the steel plate, which is inside the surface layer, has a yield stress of 620 MPa or more.
2. The steel plate according to 1., wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Cu: 0.50 % or less,
Mo: 1.50 % or less,
Nb: 0.100 % or less,
V: 0.200 % or less, and
Ti: 0.005 % or more and 0.020 % or less in a range satisfying
the following formula (2) rather than the formula (1),

$$[C] + [Mn]/6 + ([Cu] + [Ni])/15 + ([Cr] + [Mo] + [V])/15 \geq 0.57 \qquad (2)$$

where [] indicates a content of an element in the [] in mass%.
3. The steel plate according to 1. or 2., wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Mg: 0.0005 % or more and 0.0100 % or less,
Ta: 0.010 % or more and 0.200 % or less,
Zr: 0.0050 % or more and 0.1000 % or less,
Y: 0.001 % or more and 0.010 % or less,

Ca: 0.0005 % or more and 0.0050 % or less, and
REM: 0.0005 % or more and 0.0200 % or less.
4. A method of producing a steel plate, comprising
preparing a steel material having a chemical composition containing (consisting of), in mass%,
C: 0.080 % or more and 0.200 % or less,
Si: 0.40 % or less,
Mn: 0.50 % or more and 5.00 % or less,
P: 0.015 % or less,
S: 0.0050 % or less,
Cr: 3.00 % or less,
Ni: 5.00 % or less,
Al: 0.080 % or less,
N: 0.0070 % or less, and
B: 0.0030 % or less in a range satisfying the following formula (1),

$$[C] + [Mn]/6 + [Ni]/15 + [Cr]/15 \geq 0.57 \qquad (1)$$

where [] indicates a content of an element in the [] in mass%,
the balance being Fe and inevitable impurities,
subjecting the steel material to hot rolling to obtain a hot rolled steel plate,
cooling the hot-rolled steel plate, and then heating the hot-rolled steel plate to a temperature range of AC_3 transformation point or higher and 1050 °C or lower, and
then subjecting the hot-rolled steel plate to cooling treatment where an average cooling rate is 0.2 °C/s to 10 °C/s in a temperature range from (Ar_3 transformation point + 50) °C or higher to (Ar_3 transformation point - 20) °C or lower to cool the hot-rolled steel plate to 350 °C or lower.
5. The method of producing a steel plate according to 4., wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Cu: 0.50 % or less,
Mo: 1.50 % or less,
Nb: 0.100 % or less,
V: 0.200 % or less, and
Ti: 0.005 % or more and 0.020 % or less in a range satisfying the following formula (2) rather than the formula (1),

$$[C] + [Mn]/6 + ([Cu] + [Ni])/15 + ([Cr] + [Mo] + [V])/15 \geq 0.57 \qquad (2)$$

where [] indicates a content of an element in the [] in mass%.
6. The method of producing a steel plate according to 4. or 5., wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Mg: 0.0005 % or more and 0.0100 % or less,
Ta: 0.010 % or more and 0.200 % or less,
Zr: 0.0050 % or more and 0.1000 % or less,
Y: 0.001 % or more and 0.010 % or less,
Ca: 0.0005 % or more and 0.0050 % or less, and
REM: 0.0005 % or more and 0.0200 % or less.

(Advantageous Effect)

[0015] According to the present disclosure, it is possible to stably produce a high strength steel plate having excellent toughness not only in the inside portion of the steel plate but also in the surface layer of the steel plate.

DETAILED DESCRIPTION

[Chemical composition]

[0016] The following describes the production conditions of a steel plate of an embodiment of the present disclosure. The reasons for limiting the chemical composition of steel are described first. In the present specification, when components are expressed in "%", it refers to "mass%" unless otherwise specified.

C: 0.080 % or more and 0.200 % or less

[0017] C is an element that is useful for obtaining the strength required for structural-use steel at low cost. To achieve this effect, the C content needs to be 0.080 % or more. On the other hand, when the C content exceeds 0.200 %, the toughness of base metal and weld is significantly deteriorated. Therefore, the upper limit is set to 0.200 %. The C content is preferably 0.080 % or more and 0.140 % or less.

Si: 0.40 % or less

[0018] Si is preferably added in an amount of 0.05 % or more for deoxidation. However, when the Si content exceeds 0.40 %, the toughness of base metal and heat-affected zone is significantly deteriorated. Therefore, the Si content is set to 0.40 % or less. The Si content is preferably 0.05 % or more and 0.30 % or less. The Si content is more preferably 0.05 % or more and 0.25 % or less.

Mn: 0.50 % or more and 5.00 % or less

[0019] Mn is added from the viewpoint of guaranteeing the strength of base metal. However, when the Mn content is less than 0.50 %, the effect is insufficient. On the other hand, when the Mn content exceeds 5.00 %, the toughness of base metal is deteriorated, and central segregation is promoted. Therefore, the upper limit is set to 5.00 %. The Mn content is preferably 0.60 % or more and 2.00 % or less. The Mn content is more preferably 0.60 % or more and 1.60 % or less.

P: 0.015 % or less

[0020] When the P content exceeds 0.015 %, the toughness of base metal and heat-affected zone is significantly deteriorated. Therefore, the P content is set to 0.015 % or less. The P content is preferably 0.010 % or less. It is difficult to reduce the content to less than 0.001 % in industrial-scale production, so that a content of 0.001 % or more is acceptable.

S: 0.0050 % or less

[0021] When the S content exceeds 0.0050 %, the toughness of base metal and heat-affected zone is significantly deteriorated. Therefore, the S content is set to 0.0050 % or less. The S content is preferably 0.0010 % or less. It is difficult to reduce the content to less than 0.0001 % in industrial-scale production, so that a content of 0.0001 % or more is acceptable.

Cr: 3.00 % or less

[0022] Cr is an element that is effective for increasing the strength of base metal, and Cr is preferably added in an amount of 0.10 % or more. However, a large amount of Cr deteriorates the weldability. Therefore, the Cr content is set to 3.00 % or less. The Cr content is preferably 0.10 % or more and 2.00 % or less.

Ni: 5.00 % or less

[0023] Ni is a beneficial element that improves the strength of steel and the toughness of heat-affected zone, and Ni is preferably added in an amount of 0.50 % or more. However, when Ni is added more than 5.00 %, the economic efficiency is significantly decreased. Therefore, the Ni content is set to 5.00 % or less. The Ni content is preferably 0.50 % or more and 4.00 % or less.

Al: 0.080 % or less

[0024] Al is added to sufficiently deoxidize the molten steel. However, when Al is added more than 0.080 %, a large amount of Al dissolves in the base metal and the toughness of base metal deteriorates. Therefore, the Al content is set to 0.080 % or less. The Al content is preferably 0.030 % or more and 0.080 % or less. The Al content is more preferably 0.030 % or more and 0.060 % or less.

N: 0.0070 % or less

[0025] N has an effect of refining the microstructure and improving the toughness of base metal and heat-affected zone by forming nitrides with Al or other elements. Therefore, N is preferably added in an amount of 0.0020 % or more. However, when N is added more than 0.0070 %, the amount of nitride precipitated in the base metal is increased, the toughness of base metal is significantly deteriorated, and coarse carbonitrides are formed in the heat-affected zone to deteriorate the toughness. Therefore, the N content is set to 0.0070 % or less. The N content is preferably 0.0050 % or less, and more preferably 0.0040 % or less. Note that the N content may be 0 %.

B: 0.0030 % or less

[0026] B has an effect of suppressing the ferrite transformation from grain boundaries and improving the quench hardenability by segregating at austenite grain boundaries. Therefore, B is preferably added in an amount of 0.0003 % or more. On the other hand, when B is added more than 0.0030 %, it precipitates as carbonitrides, deteriorates the quench hardenability, and causes a decrease in toughness. Therefore, the B content is set to 0.0030 % or less. The B content is preferably 0.0003 % or more and 0.0030 % or less. The B content is more preferably 0.0005 % or more and 0.0020 % or less.

Equivalent Carbon Content CeqIIW

[0027] In the present disclosure, in order to guarantee a yield stress of 620 MPa or more and good toughness in the inside portion of a steel plate, particularly in the inside portion of a steel plate having a thickness of 100 mm or more, it is necessary to design an appropriate chemical composition and to adjust the chemical composition to the range satisfying the following formula (1) regarding equivalent carbon content CeqIIW. This is because, in the case where the equivalent carbon content does not satisfy the following formula (1), ferrite, which is inferior in strength, or the like tends to be formed, rendering it difficult to stably guarantee a desired strength.

$$[C] + [Mn]/6 + [Ni]/15 + [Cr]/15 \geq 0.57 \qquad (1)$$

where each element in brackets indicates the content in mass% of the element.

[0028] The basic components of the present disclosure have been described above. The balance other than the above-mentioned components is Fe and inevitable impurities. In the present disclosure, other elements may be optionally added as appropriate.

[0029] Specifically, in order to further increase the strength and toughness, it is possible to contain at least one selected from the group consisting of Cu: 0.50 % or less, Mo: 1.50 % or less, Nb: 0.100 % or less, V: 0.200 % or less, and Ti: 0.005 % or more and 0.020 % or less.

[0030] In this case, the chemical composition is adjusted so that the equivalent carbon content CeqIIW is in the range satisfying the following formula (2) rather than the above formula (1).

$$[C] + [Mn]/6 + ([Cu] + [Ni])/15 + ([Cr] + [Mo] + [V])/15 \geq 0.57 \qquad (2)$$

where each element in brackets indicates the content in mass% of the element.

Cu: 0.50 % or less

[0031] Cu can improve the strength of steel without deteriorating the toughness. However, when Cu is added more than 0.50 %, cracking occurs in the surface layer of the steel plate during hot working. Therefore, when Cu is contained, the content is set to 0.50 % or less. The Cu content is preferably 0.03 % or more and 0.40 % or less.

Mo: 1.50 % or less

[0032] Mo is an element that effectively strengthens the base metal. However, when Mo is added more than 1.50 %, the hardness is increased, and the toughness is decreased due to precipitation of alloy carbides. Therefore, when Mo is contained, the content is set to 1.50 % or less. The Mo content is preferably 0.02 % or more and 0.80 % or less.

Nb: 0.100 % or less

[0033] Nb is useful because it has an effect of increasing the strength of base metal. However, when Nb is added more than 0.100 %, the toughness of base metal is significantly deteriorated. Therefore, when Nb is contained, the upper limit is set to 0.100 %. The Nb content is preferably 0.025 % or less. In addition, when the content is less than 0.003 %, the effect of improving the properties cannot be obtained. Therefore, when Nb is contained, the content is set to 0.003 % or more.

V: 0.200 % or less

[0034] V is effective in improving the strength and toughness of base metal and reducing solute N by precipitating as VN. However, when V is added more than 0.200 %, the toughness is deteriorated due to precipitation of hard VC. Therefore, when V is contained, the content is set to 0.200 % or less. The V content is preferably 0.010 % or more and 0.100 % or less.

Ti: 0.005 % or more and 0.020 % or less

[0035] Ti forms TiN during heating, effectively suppresses the coarsening of austenite, and improves the toughness of base metal and heat-affected zone. However, when Ti is added more than 0.020 %, the Ti nitride coarsens and the toughness of base metal decreases. Therefore, when Ti is contained, the content is set to 0.005 % or more and 0.020 % or less. The Ti content is preferably 0.008 % or more and 0.015 % or less.

[0036] In order to further improve the material properties, it is possible to contain at least one selected from the group consisting of Mg: 0.0005 % or more and 0.0100 % or less, Ta: 0.010 % or more and 0.200 % or less, Zr: 0.0050 % or more and 0.1000 % or less, Y: 0.001 % or more and 0.010 % or less, Ca: 0.0005 % or more and 0.0050 % or less, and REM: 0.0005 % or more and 0.0200 % or less.

Mg: 0.0005 % or more and 0.0100 % or less

[0037] Mg forms stable oxides at high temperatures, effectively suppresses the coarsening of prior γ grains in the heat-affected zone, and effectively improves the toughness of weld. However, when the content is less than 0.0005 %, a clear effect cannot be obtained, and when the content exceeds 0.0100 %, the amount of inclusions increases and the toughness decreases. Therefore, when Mg is contained, the content is set to 0.0005 % or more and 0.0100 % or less. The Mg content is preferably 0.0005 % or more and 0.0050 % or less.

Ta: 0.010 % or more and 0.200 % or less

[0038] Ta is effective in improving the strength. However, when the content is less than 0.010 %, a clear effect cannot be obtained, and when the content exceeds 0.200 %, the toughness decreases due to formation of precipitates. Therefore, when Ta is contained, the content is set to 0.010 % or more and 0.200 % or less.

Zr: 0.0050 % or more and 0.1000 % or less

[0039] Zr is an element effective in improving the strength. However, when the content is less than 0.0050 %, a clear effect cannot be obtained, and when the content exceeds 0.1000 %, coarse precipitates are formed to deteriorate the toughness. Therefore, when Zr is contained, the content is set to 0.0050 % or more and 0.1000 % or less.

Y: 0.001 % or more and 0.010 % or less

[0040] Y forms stable oxides at high temperatures, effectively suppresses the coarsening of prior γ grains in the heat-affected zone, and effectively improves the toughness of weld. However, when the content is less than 0.001 %, the effect cannot be obtained, and when the content exceeds 0.010 %, the amount of inclusions increases and the toughness decreases. Therefore, when Y is contained, the content is set to 0.001 % or more and 0.010 % or less.

Ca: 0.0005 % or more and 0.0050 % or less

[0041] Ca is an element useful for controlling the morphology of sulfide inclusions. To achieve this effect, the Ca content needs to be 0.0005 % or more. However, when Ca is added more than 0.0050 %, the cleanliness is lowered, and the toughness is deteriorated. Therefore, when Ca is contained, the content is set to 0.0005 % or more and 0.0050 % or less. The Ca content is preferably 0.0005 % or more and 0.0025 % or less.

REM: 0.0005 % or more and 0.0200 % or less

[0042] REM (rare earth metal), like Ca, has an effect of improving the material properties by forming oxides and sulfides in the steel. To achieve this effect, the REM content needs to be 0.0005 % or more. However, when REM is added more than 0.0200 %, the effect is saturated. Therefore, when REM is contained, the content is set to 0.0005 % or more and 0.0200 % or less. The REM content is preferably 0.0005 % or more and 0.0050 % or less.

[Microstructure]

[0043] In the present disclosure, it is important that the area fraction of bainite in the surface layer of the steel plate be 10 % or more. When the surface layer of the steel plate has such a microstructure, the surface layer of the steel plate can also obtain excellent toughness. The area fraction of bainite in the surface layer of the steel plate is preferably 20 % or more. The balance is tempered martensite, ferrite, or the like.

[0044] It is preferable that, in addition to the surface layer of the steel plate, the inside portion of the steel plate also have an area fraction of bainite of 10 % or more. When the inside portion of the steel plate also has such a microstructure, it is possible to obtain a steel plate where the difference in properties between the surface layer of the steel plate and the inside portion of the steel plate is small. The area fraction of bainite in the inside portion of the steel plate is more preferably 20 % or more.

[0045] The evaluation of the area fraction in the microstructure of the surface layer of the steel plate and the area fraction in the microstructure of the inside portion of the steel plate can be performed by collecting a sample of the cross section in the rolling direction of a quenched steel material, revealing the microstructure with a nital etching solution, observing five or more locations at 200 times magnification under an optical microscope, and determining the area fraction in each of the microstructures such as bainite by image analysis. For the surface layer of the steel plate, a sample of the cross section in the rolling direction having a thickness of 15 mm is collected centering on the position of 1/8 thickness (1/8 t). For the inside portion of the steel plate, a sample of the cross section in the rolling direction having a thickness of 15 mm is collected centering on the position of 3/8 thickness (3/8 t).

[0046] In order to obtain a microstructure where at least the area fraction of bainite in the surface layer of the steel plate is 10 % or more, it is necessary to subjecting a steel material whose chemical composition has been adjusted to the above range to hot rolling to obtain a hot-rolled steel plate, cooling the hot-rolled steel plate, then heating the steel plate to a temperature range of AC_3 transformation point or higher and 1050 °C or lower, and then subjecting the steel plate to cooling treatment where the average cooling rate in a temperature range from (Ar_3 transformation point + 50) °C or higher to (Ar_3 transformation point - 20) °C or lower is 0.2 °C/s to 10 °C/s to cool the steel plate to 350 °C or lower. It is important that both the surface layer of the hot-rolled steel plate and the inside portion of the steel plate satisfy the specified temperature conditions. Details will be described later.

[Toughness]

[0047] Researchers have not paid too much attention to the toughness of the surface layer of a steel plate so far. However, the surface layer is being required to have the same toughness as that of the inside portion of a steel plate in response to growing demands for improving the safety of structures. For the steel plate of the present disclosure, when the toughness difference between the surface layer of the steel plate and the inside portion of the steel plate is evaluated by ductile-brittle fracture appearance transition temperature (vTrs), the difference in vTrs is preferably within 20 °C. This is because in this case, the toughness of the surface layer of the steel plate and the toughness of the inside portion of the steel plate can be evaluated as substantially the same. The vTrs here is evaluated with the method described in JIS Z2242. The reason why the difference in vTrs is set within 20 °C is that, in the case of evaluating the toughness by vTrs, the value of the difference may be up to about 20 °C due to errors in the measurement of brittle fracture appearance ratio, even if the toughness is at the same level. Therefore, it is set 20 °C within which the toughness can be considered substantially equivalent.

[Yield stress]

[0048] In the present disclosure, the yield stress of the inside portion of the steel plate is 620 MPa or more. The reason is that, in order to contribute to increasing the size of a structure, it is required to have a yield stress of 620 MPa or more.
[0049] Next, a method of producing the steel plate of the present disclosure will be described. Unless otherwise specified, the temperature in the following description refers to the temperature of the mid-thickness part (1/2 t).

[Steel material]

[0050] Molten steel having the above-described chemical composition is obtained by steelmaking with a normal method such as using a converter, an electric heating furnace or a vacuum melting furnace, and is made into a steel material such as a slab or billet with a normal casting method such as a continuous casting method or an ingot casting method. If there are restrictions on, for example, rolling mill load, the steel material may be further forged or subjected to blooming to reduce the thickness of the steel material.

[Hot rolling]

[0051] The steel material is subjected to hot rolling. In order to achieve both the toughness of the surface layer of the steel plate and the strength and toughness of the inside portion of the steel plate, it is effective to promote the recrystallization in the γ region to refine the prior γ grains during the hot rolling. Therefore, the rolling finish temperature in the hot rolling is preferably Ar_3 point or higher.
[0052] The Ar_3 transformation point may be the value calculated from the formula (4) described later.

[Cooling after hot rolling]

[0053] The hot-rolled steel plate is subjected to air cooling or accelerated cooling. Accelerated cooling is particularly effective in improving the toughness. This is because accelerated cooling shortens the residence time at high temperature ranges as compared with the case of air cooling, refines crystal grains and suppresses coarsening of precipitates. Therefore, in the case of accelerated cooling, it is performed until the temperature is lower than Ar_3 point. The cooling during the accelerated cooling is performed with water or air blast, and in either case, the cooling rate in the steel plate surface is preferably 0.1 °C/s or more.

[Heating temperature after hot rolling: AC_3 transformation point or higher and 1050 °C or lower]

[0054] The cooled hot-rolled steel plate is heated to AC_3 transformation point or higher and 1050 °C or lower. The steel plate is heated to AC_3 transformation point or higher, because this makes the steel uniform into an austenite single phase. The reheating temperature is set to 1050 °C or lower, because a high reheating temperature exceeding 1050 °C causes coarsening of austenite grains, which significantly deteriorates the toughness of base metal. It is preferably AC_3 transformation point or higher and 1000 °C or lower. It is more preferably AC_3 transformation point or higher and 950 °C or lower.
[0055] The value calculated from the following formula (3) is used as the AC_3 transformation point.

$$Ac_3 = 937.2 - 476.5[C] + 56[Si] - 19.7[Mn] - 16.3[Cu] - 26.6[Ni] - 4.9[Cr] + 38.1[Mo] + 124.8[V] + 136.3[Ti] + 198.4[Al] + 3315[B] \quad (3)$$

where each element symbol in the formula (3) indicates the content (mass%) of each of the elements constituting the chemical composition in the steel material, and those not contained are calculated as zero.

[Cooling treatment: the average cooling rate in the range from (Ar_3 transformation point + 50) °C or higher to (Ar_3 transformation point - 20) °C or lower is 0.2 °C/s to 10 °C/s]

[0056] Cooling treatment is performed after the heating. During the cooling treatment, when the surface layer of the steel plate and the inside portion of the steel plate are being cooled to 350 °C or lower, it is important to perform the cooling treatment so that the average cooling rate of each of the surface layer of the steel plate and the inside portion of the steel plate in the temperature range from (Ar_3 transformation point + 50) °C or higher to (Ar_3 transformation point - 20) °C or lower is 0.2 °C/s to 10 °C/s. Performing such cooling treatment can form a microstructure where the area fraction of bainite is 10 % or more in the surface layer of the steel plate and significantly improve the toughness of the surface layer of the steel plate. In the same way, a microstructure with 10 % or more of bainite can also be formed in the inside portion of the steel plate.

[0057] The cooling rate can be controlled by, for example, adjusting the flow rate of water, performing the cooling intermittently, or performing air blast cooling.

[0058] Specifically, the average cooling rate in the surface layer of the steel plate and in the inside portion of the steel plate is controlled by deriving the cooling method, water adjustment and intermittent conditions by, for example, simulation to achieve the desired cooling rate.

[0059] The temperature in the surface layer of the steel plate and in the inside portion of the steel plate can be determined by, for example, simulation calculation based on the thickness, surface temperature, cooling conditions, and the like. For example, the temperature from the surface layer of the steel plate to the inside portion of the steel plate can be determined by calculating the temperature distribution in the thickness direction using the finite difference method.

[0060] The value calculated from the following formula (4) is used as the Ar_3 transformation point.

$$Ar_3 = 910 - 310[C] - 80[Mn] - 20[Cu] - 15[Cr] - 55[Ni] - 80[Mo] \quad (4)$$

where each element symbol in the formula (4) indicates the content (mass%) of each of the elements constituting the chemical composition in the steel material, and those not contained are calculated as zero.

[Cooling stop temperature: 350 °C or lower]

[0061] The stop temperature of the cooling is set to 350 °C or lower. This is because when the temperature is lowered to 350 °C or lower, the transformation of the whole steel plate is completed, and a uniform microstructure is obtained.

[0062] The cooling method is generally water cooling in industrial terms. However, the cooling method may be other than water cooling, such as gas cooling.

[Tempering]

[0063] After the above-described rapid cooling, tempering may be performed in a temperature range of 450 °C or higher and 700 °C or lower as necessary. When the temperature is lower than 450 °C, the effect of removing residual stress is small. On the other hand, when the temperature is higher than 700 °C, various carbides are precipitated, the microstructure of the base metal is coarsened, and the strength and the toughness are significantly deteriorated.

[0064] Steel may be repeatedly quenched in industrial terms for the purpose of improving the toughness of the steel. In the present disclosure, it is also acceptable to perform quenching repeatedly. Note that during the final quenching, it is preferable to perform cooling so that the average cooling rate of the surface layer of the steel plate and the inside portion of the steel plate is 0.2 °C/s or more and 10 °C/s or less in a temperature range from (Ar_3 transformation point + 50) °C or higher to (Ar_3 transformation point - 20) °C or lower, and then cool the steel plate to 350 °C or lower and temper the steel plate at 450 °C or higher and 700 °C or lower.

EXAMPLES

[0065] Steel Nos. 1 to 31 as listed in Table 1 were obtained by steelmaking and were made into slabs. Subsequently, the slabs were made into steel plates having a thickness of 100 mm or more and 240 mm or less under the production conditions listed in Table 2. Subsequently, the steel plates were subjected to cooling treatment and tempering treatment to obtain thick steel plates of Sample Nos. 1 to 37, and the thick steel plates were subjected to the following tests.

Table 1

Steel No.	Chemical composition (mass%) C	Si	Mn	P	S	Cr	Ni	Al	N	B	Cu	Mo	Nb	V	Ti	Mg	Ta	Zr	Y	Ca	REM	Ceq^{IIW} (%)	Ac_3 (°C)	Ar_3 (°C)	Remarks
1	0.084	0.23	1.22	0.006	0.0010	0.82	0.48	0.047	0.0032	0.0011	0.25	0.38	-	0.021	0.010	-	-	-	-	0.0023	-	0.58	896.6	712.3	Example
2	0.096	0.32	1.54	0.005	0.0011	0.88	0.82	0.068	0.0051	0.0012	0.21	0.33	-	0.032	-	-	-	-	-	-	0.0019	0.67	883.5	668.1	Example
3	0.108	0.21	1.13	0.006	0.0004	0.80	3.63	0.077	0.0063	0.0010	0.18	0.51	-	0.041	-	-	-	-	-	0.0025	-	0.82	815.0	530.1	Example
4	0.115	0.21	1.12	0.005	0.0006	0.88	2.45	0.063	0.0048	0.0010	0.19	0.52	-	0.042	-	-	-	-	-	0.0023	-	0.77	840.4	591.4	Example
5	0.118	0.20	0.98	0.007	0.0009	0.61	0.95	0.048	0.0038	0.0009	0.25	0.45	-	0.040	0.012	-	-	-	-	0.0026	-	0.58	876.8	692.6	Example
6	0.121	0.19	1.14	0.006	0.0005	0.98	2.06	0.033	0.0032	0.0010	0.20	0.49	0.011	0.039	0.011	-	-	-	-	0.0025	-	0.76	839.8	610.1	Example
7	0.126	0.19	1.13	0.006	0.0005	0.79	3.62	0.064	0.0027	0.0010	0.18	0.51	-	0.038	-	-	-	-	-	0.0022	-	0.84	802.6	525.2	Example
8	0.129	0.03	1.16	0.005	0.0005	0.95	1.99	0.039	0.0036	0.0009	0.21	0.49	-	0.041	0.011	-	-	-	-	0.0018	-	0.77	829.6	610.1	Example
9	0.132	0.06	1.14	0.005	0.0004	0.81	3.35	0.055	0.0046	0.0012	0.19	0.53	-	0.040	-	-	-	-	-	0.0019	-	0.83	799.1	535.3	Example
10	0.148	0.07	0.88	0.005	0.0060	0.85	2.23	0.046	0.0033	0.0010	0.45	0.39	-	0.036	-	-	-	-	-	0.0018	-	0.73	814.2	618.1	Example
11	0.082	0.15	2.83	0.006	0.0007	0.29	1.85	0.053	0.0045	0.0013	0.20	0.48	-	0.029	-	-	-	-	-	-	0.0078	0.85	833.6	509.7	Example
12	0.177	0.39	1.55	0.004	0.0005	0.94	1.82	0.041	0.0029	0.0008	-	-	-	-	-	-	-	-	-	-	-	0.74	801.9	616.9	Example
13	0.118	0.21	1.16	0.004	0.0006	0.93	2.15	0.046	0.0036	0.0009	0.19	0.50	-	0.042	0.009	-	-	-	-	0.0022	-	0.76	842.7	604.6	Example
14	0.190	0.24	1.11	0.005	0.0009	0.49	1.56	0.036	0.0022	0.0011	-	-	-	-	-	-	-	-	-	-	-	0.58	805.1	669.2	Example
15	0.131	0.21	0.91	0.005	0.0007	0.79	4.72	0.048	0.0029	0.0009	0.22	0.49	0.018	0.036	-	-	-	-	-	0.0018	-	0.88	771.3	481.5	Example
16	0.103	0.16	0.58	0.003	0.0005	2.73	-	0.043	0.0039	0.0010	-	-	-	-	-	-	-	-	-	-	-	0.75	883.6	789.6	Example
17	0.133	0.21	0.99	0.003	0.0005	0.36	3.82	0.061	0.0044	0.0012	0.18	0.45	-	0.183	-	0.0016	-	-	-	0.0019	-	0.76	815.8	534.5	Example
18	0.139	0.19	1.01	0.005	0.0008	0.93	2.43	0.078	0.0061	0.0014	0.20	0.41	-	-	-	-	0.063	-	-	0.0020	-	0.75	825.0	601.7	Example
19	0.116	0.21	1.13	0.006	0.0011	0.74	1.88	0.059	0.0036	0.0026	0.32	0.52	-	0.042	-	-	-	0.0039	-	0.0022	-	0.71	858.0	621.1	Example
20	0.120	0.19	1.24	0.005	0.0010	0.86	3.29	0.077	0.0067	0.0010	0.21	0.46	-	0.038	-	-	-	-	0.0042	0.0019	-	0.83	811.9	538.8	Example
21	0.081	0.18	0.73	0.006	0.0010	0.65	2.43	0.041	0.0039	0.0011	0.22	1.46	-	0.041	-	-	-	-	-	0.0022	-	0.81	895.4	561.9	Example
22	0.062	0.33	1.15	0.006	0.0011	1.45	0.45	0.028	0.0065	0.0007	-	-	-	-	-	-	-	-	-	-	-	0.57	892.3	752.3	Comparative Example
23	0.253	0.16	1.24	0.005	0.0011	1.04	0.59	0.048	0.0033	0.0012	0.26	0.43	-	0.036	0.018	-	-	-	-	0.0021	-	0.82	813.0	644.7	Comparative Example
24	0.141	0.49	1.16	0.005	0.0007	0.95	0.88	0.043	0.0022	0.0010	0.12	0.46	-	-	-	-	-	-	-	-	-	0.68	881.8	671.6	Comparative Example
25	0.083	0.36	0.28	0.012	0.0016	1.16	1.95	0.052	0.0036	0.0014	0.22	0.59	-	0.036	-	-	-	-	-	0.0023	-	0.63	893.1	685.6	Comparative Example
26	0.121	0.29	1.22	0.026	0.0014	0.95	0.55	0.042	0.0036	0.0010	0.26	0.48	-	0.039	-	-	-	-	-	-	0.0053	0.67	883.0	686.8	Comparative Example
27	0.151	0.22	1.26	0.011	0.0068	1.12	1.33	0.036	0.0028	0.0009	-	-	-	-	-	-	-	-	-	-	-	0.67	822.0	672.4	Comparative Example
28	0.123	0.27	1.43	0.006	0.0006	0.94	1.99	0.093	0.0027	0.0009	0.40	0.53	-	-	-	-	-	-	-	0.0022	-	0.81	843.1	583.5	Comparative Example
29	0.129	0.26	1.28	0.006	0.0009	1.14	2.13	0.046	0.0096	0.0009	-	-	-	-	-	-	-	-	-	-	-	0.71	814.9	633.4	Comparative Example
30	0.136	0.28	1.14	0.011	0.0022	0.81	1.83	0.045	0.0033	0.0048	0.28	0.45	-	-	-	-	-	-	-	0.0021	-	0.72	850.4	622.2	Comparative Example
31	0.120	0.13	0.99	0.013	0.0013	0.45	0.90	0.039	0.0030	0.0008	0.12	0.45	-	0.038	0.011	-	-	-	-	0.0019	-	0.54	873.5	699.0	Comparative Example

The values of Ceq^{IIW}, Ac_3, and Ar_3 are calculated from the formulae (1) to (3) as in the specification, respectively.

Underlines indicate the results being outside the range of the present disclosure.

[Tensile test]

[0066] Round bar tensile test pieces with a diameter of 12.5 mm were taken at a length of 50 mm in the direction perpendicular to the rolling direction from the 1/8 thickness (1/8 t) part and the 1/4 thickness (1/4 t) part of each steel plate, and their yield stress (YS) and tensile strength (TS) were measured. The yield stress (YS) and the tensile strength (TS) were measured according to JIS Z2241.

[Charpy impact test]

[0067] Fifteen 2-mm V-notch Charpy test pieces whose longitudinal direction was the rolling direction were taken from each steel plate at the position 2 mm below the surface layer of the steel plate and at the 1/4 thickness (1/4 t) part respectively. The vTrs (ductile-brittle fracture appearance transition temperature) of each test piece was evaluated according to JIS Z 2242.

[0068] The test results are listed in Table 2. From these results, it is understood that, for each of the steel plates of Examples (Sample Nos. 1 to 22) in which the chemical composition of the steel and the microstructure conform to the present disclosure, the YS of the 1/4 t part is 620 MPa or more, the TS of the 1/4 t part is 720 MPa or more, the toughness (vTrs) of the surface layer of the steel plate and the 1/4 t part are lower than -30 °C, and the difference in vTrs is within 20 °C. These results explain that the strength of the base metal is favorable and the difference in toughness between the surface layer of the steel plate and the inside portion of the steel plate is small, indicating the excellent toughness in the thickness direction throughout from the surface layer of the steel plate to the inside portion of the steel plate.

Table 2

Sample No.	Steel No.	Product thickness (mm)	Slab thickness (mm)	Heating temperature (°C)	Cooling after rolling	Stop cooling temperature (°C)	Quenching: Reheating temperature (°C)	Quenching: Cooling rate of surface layer *1 (°C/s)	Quenching: Cooling rate of inside portion *1 (°C/s)	Quenching: Stop cooling (°C)	Tempering (°C)	Surface layer: Area fraction of bainite (%)	Surface layer: Area fraction of martensite (%)	Surface layer: YS (MPa)	Surface layer: TS (MPa)	Surface layer: vTrs (°C)	Inside portion of steel plate (1/4 t): Area fraction of bainite (%)	Inside portion of steel plate (1/4 t): Area fraction of martensite (%)	Inside portion of steel plate (1/4 t): YS (MPa)	Inside portion of steel plate (1/4 t): TS (MPa)	Inside portion of steel plate (1/4 t): vTrs (°C)	vTrs difference *2	Remarks
1	1	100	310	1150	Standing to cool	≤100	930	9.0	1.5	100	600	15	80	680	762	-35	80	15	673	756	-40	Satisfied	Example
2	2	100	265	1250	Air blast cooling	600	930	7.0	1.5	100	620	25	70	703	792	-40	75	20	692	781	-50	Satisfied	Example
3	3	210	450	1250	Water cooling	450	900	3.0	0.4	150	650	50	45	733	842	-90	80	10	731	840	-95	Satisfied	Example
4	4	180	450	1250	Water cooling	400	900	1.5	0.6	100	630	60	35	726	805	-60	90	5	722	800	-75	Satisfied	Example
5	5	100	310	1150	Standing to cool	≤100	900	8.0	1.5	200	620	20	75	763	816	-40	80	15	761	815	-40	Satisfied	Example
6	6	150	265	1200	Standing to cool	≤100	900	4.0	0.8	100	635	45	50	753	869	-60	90	5	751	852	-65	Satisfied	Example
7	7	215	450	1200	Water cooling	400	900	0.5	0.4	150	645	90	5	791	865	-100	85	10	782	854	-110	Satisfied	Example
8	8	150	265	1200	Standing to cool	≤100	900	3.0	0.8	100	630	45	50	741	831	-65	90	5	738	829	-65	Satisfied	Example
9	8	150	265	1200	Standing to cool	≤100	900	1.5	0.8	300	-	45	50	836	1081	-35	90	5	845	1080	-35	Satisfied	Example
10	9	240	485	1200	Water cooling	500	880	2.0	0.3	150	650	60	35	745	929	-85	85	5	743	827	-95	Satisfied	Example
11	10	150	265	1150	Air blast cooling	400	900	5.0	0.8	100	630	35	60	780	954	-70	85	10	772	851	-65	Satisfied	Example
12	11	240	485	1250	Water cooling	500	900	0.5	0.3	100	660	90	5	733	921	-60	85	10	731	816	-65	Satisfied	Example
13	12	100	310	1150	Air blast cooling	400	880	9.5	1.5	150	580	10	85	658	940	-45	80	15	652	735	-55	Satisfied	Example
14	13	150	265	1150	Standing to cool	≤100	900	4.5	0.8	100	650	40	55	762	946	-70	85	10	759	845	-60	Satisfied	Example
15	14	100	310	1150	Air blast cooling	450	900	8.5	1.5	250	630	20	75	809	901	-60	80	15	806	896	-65	Satisfied	Example
16	15	240	485	1200	Air blast cooling	500	880	0.5	0.3	100	630	85	10	861	939	-115	70	20	856	938	-125	Satisfied	Example
17	16	100	265	1250	Air blast cooling	500	930	1.0	1.5	150	650	90	5	745	832	-30	80	15	729	815	-35	Satisfied	Example
18	17	240	485	1100	Water cooling	450	900	1.0	0.2	100	620	80	20	726	822	-100	80	10	722	816	-95	Satisfied	Example
19	18	180	450	1300	Water cooling	400	900	1.5	0.5	150	650	85	10	720	790	-80	80	10	716	783	-85	Satisfied	Example

Underlines indicate the results being outside the range of the present disclosure.

*1 Average cooling rate in the range of (Ar_3 transformation point + 50) °C to (Ar_3 transformation point - 20) °C

*2 The results where the vTrs difference from the surface layer exceeded 20 °C were evaluated as unsatisfied.

Table 2 (cont'd)

Sample No.	Steel No.	Product thickness (mm)	Slab thickness (mm)	Heating temperature (°C)	Cooling after rolling	Stop cooling temperature (°C)	Quenching: Reheating temperature (°C)	Quenching: Cooling rate of surface layer *1 (°C/s)	Quenching: Cooling rate of inside portion *1 (°C/s)	Quenching: Stop cooling (°C)	Tempering (°C)	Surface layer: Area fraction of bainite (%)	Surface layer: Area fraction of martensite (%)	Surface layer: YS (MPa)	Surface layer: TS (MPa)	Surface layer: vTrs (°C)	Inside portion of steel plate (1/4 t): Area fraction of bainite (%)	Inside portion of steel plate (1/4 t): Area fraction of martensite (%)	Inside portion of steel plate (1/4 t): YS (MPa)	Inside portion of steel plate (1/4 t): TS (MPa)	Inside portion of steel plate (1/4 t): vTrs (°C)	vTrs difference *2	Remarks
20	19	150	265	1250	Water cooling	350	900	2.0	0.8	150	630	75	20	748	830	-55	85	10	743	826	-50	Satisfied	Example
21	20	180	265	1300	Air blast cooling	500	900	2.0	0.6	150	650	55	40	669	751	-80	90	5	665	747	-85	Satisfied	Example
22	21	150	265	1200	Water cooling	450	930	1.5	0.8	100	630	60	40	864	946	-75	90	5	862	945	-80	Satisfied	Example
23	22	150	265	1150	Standing to cool	≤100	930	2.0	0.8	100	650	75	20	632	718	-20	75	5	582	673	-30	Satisfied	Comparative Example
24	23	150	265	1200	Standing to cool	≤100	900	1.5	0.8	100	630	85	10	815	878	-20	85	10	813	873	-25	Satisfied	Comparative Example
25	24	100	265	1150	Air blast cooling	500	930	5.5	1.5	150	620	40	55	769	846	-15	90	5	769	842	-30	Satisfied	Comparative Example
26	25	150	310	1150	Water cooling	450	930	6.0	0.8	100	650	30	65	585	661	-60	90	5	583	658	-30	Unsatisfied	Comparative Example
27	26	150	310	1150	Water cooling	400	930	5.5	0.8	150	630	45	50	732	820	-10	85	10	728	816	-15	Satisfied	Comparative Example
28	27	180	450	1200	Water cooling	500	900	4.5	0.6	100	630	50	45	746	840	-20	85	10	745	836	-5	Satisfied	Comparative Example
29	28	215	450	1200	Air blast cooling	400	900	3.0	0.4	150	630	65	30	760	820	-25	90	5	758	816	-15	Satisfied	Comparative Example
30	29	215	450	1200	Air blast cooling	450	900	2.0	0.3	150	640	70	25	716	779	-20	90	5	711	773	-30	Satisfied	Comparative Example
31	30	150	265	1200	Water cooling	450	900	4.5	0.8	100	630	50	45	736	811	-25	85	10	732	806	-20	Satisfied	Comparative Example
32	31	150	265	1150	Standing to cool	≤100	900	9.0	0.8	150	600	15	80	551	653	-45	85	10	545	650	-15	Unsatisfied	Comparative Example
33	8	150	265	1150	Standing to cool	≤100	1100	3.0	0.8	100	630	65	30	640	850	0	90	5	638	846	-25	Unsatisfied	Comparative Example
34	8	150	265	1150	Standing to cool	≤100	800	3.0	0.8	150	630	60	35	573	709	-15	80	15	572	703	-20	Satisfied	Comparative Example
35	8	150	265	1150	Standing to cool	≤100	900	12.0	0.8	100	630	5	90	740	833	-20	80	15	732	829	-50	Unsatisfied	Comparative Example
36	8	150	265	1150	Standing to cool	≤100	900	30.0	0.8	100	630	<5	95	751	841	-20	90	5	745	837	-55	Unsatisfied	Comparative Example
37	8	150	265	1250	Standing to cool	≤100	900	3.0	0.8	550	630	60	35	573	651	-55	80	15	572	645	-20	Unsatisfied	Comparative Example

Underlines indicate the results being outside the range of the present disclosure.

*1 Average cooling rate in the range of (Ar_3 transformation point + 50) °C to (Ar_3 transformation point - 20) °C

*2 The results where the vTrs difference from the surface layer exceeded 20 °C were evaluated as unsatisfied.

[0069] On the other hand, the steel plates of Comparative Examples (Sample Nos. 23 to 32) deviating from the chemical composition or the microstructure of the present disclosure are inferior in any of the following properties: the YS of the inside portion of the steel plate is less than 620 MPa, the TS is less than 720 MPa, or the toughness (vTrs) of the surface layer of the steel plate and the 1/4 t part is -30 °C or higher, or the vTrs difference exceeds 20 °C.

[0070] In addition, it is understood from Sample Nos. 33 to 37 that, for the steel plates where the chemical composition of the steel conforms to the present disclosure yet the production conditions do not conform to the present disclosure, they are inferior in one or more of the properties of YS, TS, toughness, and toughness difference.

INDUSTRIAL APPLICABILITY

[0071] According to the present disclosure, it is possible to obtain a thick steel plate having a thickness of 100 mm or more, a yield stress of 620 MPa or more in the base metal, excellent toughness in the surface layer of the steel plate, excellent strength and toughness in the inside portion of the steel plate, and excellent production stability, and to greatly contributes to increasing the size of steel structures and improving the safety of steel structures.

Claims

1. A steel plate comprising a chemical composition containing, in mass%,
C: 0.080 % or more and 0.200 % or less,
Si: 0.40 % or less,
Mn: 0.50 % or more and 5.00 % or less,
P: 0.015 % or less,
S: 0.0050 % or less,
Cr: 3.00 % or less,
Ni: 5.00 % or less,
Al: 0.080 % or less,
N: 0.0070 % or less, and
B: 0.0030 % or less in a range satisfying the following formula (1),

$$[C] + [Mn]/6 + [Ni]/15 + [Cr]/15 \geq 0.57 \qquad (1)$$

where [] indicates a content of an element in the [] in mass%,
the balance being Fe and inevitable impurities, wherein
a surface layer of the steel plate has a microstructure where an area fraction of bainite is 10 % or more, and
an inside portion of the steel plate, which is inside the surface layer, has a yield stress of 620 MPa or more.

2. The steel plate according to claim 1, wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Cu: 0.50 % or less,
Mo: 1.50 % or less,
Nb: 0.100 % or less,
V: 0.200 % or less, and
Ti: 0.005 % or more and 0.020 % or less in a range satisfying
the following formula (2) rather than the formula (1),

$$[C] + [Mn]/6 + ([Cu] + [Ni])/15 + ([Cr] + [Mo] + [V])/15 \geq 0.57 \qquad (2)$$

where [] indicates a content of an element in the [] in mass%.

3. The steel plate according to claim 1 or 2, wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Mg: 0.0005 % or more and 0.0100 % or less,
Ta: 0.010 % or more and 0.200 % or less,
Zr: 0.0050 % or more and 0.1000 % or less,

Y: 0.001 % or more and 0.010 % or less,
Ca: 0.0005 % or more and 0.0050 % or less, and REM: 0.0005 % or more and 0.0200 % or less.

4. A method of producing a steel plate, comprising
preparing a steel material having a chemical composition containing, in mass%,
C: 0.080 % or more and 0.200 % or less,
Si: 0.40 % or less,
Mn: 0.50 % or more and 5.00 % or less,
P: 0.015 % or less,
S: 0.0050 % or less,
Cr: 3.00 % or less,
Ni: 5.00 % or less,
Al: 0.080 % or less,
N: 0.0070 % or less, and
B: 0.0030 % or less in a range satisfying the following formula (1),

$$[C] + [Mn]/6 + [Ni]/15 + [Cr]/15 \geq 0.57 \qquad (1)$$

where [] indicates a content of an element in the [] in mass%,
the balance being Fe and inevitable impurities,
subjecting the steel material to hot rolling to obtain a hot rolled steel plate,
cooling the hot-rolled steel plate, and then heating the hot-rolled steel plate to a temperature range of AC_3 transformation point or higher and 1050 °C or lower, and
then subjecting the hot-rolled steel plate to cooling treatment where an average cooling rate is 0.2 °C/s to 10 °C/s in a temperature range from (Ar_3 transformation point + 50) °C or higher to (Ar_3 transformation point - 20) °C or lower to cool the hot-rolled steel plate to 350 °C or lower.

5. The method of producing a steel plate according to claim 4, wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Cu: 0.50 % or less,
Mo: 1.50 % or less,
Nb: 0.100 % or less,
V: 0.200 % or less, and
Ti: 0.005 % or more and 0.020 % or less in a range satisfying the following formula (2) rather than the formula (1),

$$[C] + [Mn]/6 + ([Cu] + [Ni])/15 + ([Cr] + [Mo] + [V])/15 \geq 0.57 \qquad (2)$$

where [] indicates a content of an element in the [] in mass%.

6. The method of producing a steel plate according to claim 4 or 5, wherein
the chemical composition further contains, in mass%, at least one selected from the group consisting of
Mg: 0.0005 % or more and 0.0100 % or less,
Ta: 0.010 % or more and 0.200 % or less,
Zr: 0.0050 % or more and 0.1000 % or less,
Y: 0.001 % or more and 0.010 % or less,
Ca: 0.0005 % or more and 0.0050 % or less, and
REM: 0.0005 % or more and 0.0200 % or less.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/033286

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C21D8/02(2006.01)i, C22C38/58(2006.01)i
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/162939 A1 (JFE STEEL CORPORATION) 29 October 2015, paragraphs [0016]-[0063], tables 1, 2 & US 2017/0044639 A1, paragraphs [0010]-[0103], tables 1, 2 & EP 3135787 A1	1-6
A	WO 2017/094593 A1 (KOBE STEEL, LTD.) 08 June 2017 & CN 108350540 A & KR 10-2018-0085791 A	1-6
A	JP 2014-177669 A (JFE STEEL CORPORATION) 25 September 2014 (Family: none)	1-6
A	JP 62-174322 A (KOBE STEEL, LTD.) 31 July 1987 (Family: none)	1-6
A	JP 2012-062558 A (JFE STEEL CORPORATION) 29 March 2012 & US 2013/0167985 A1 & EP 2617852 A1	1-6
A	JP 2012-062561 A (JFE STEEL CORPORATION) 29 March 2012 & US 2013/0276940 A1 & EP 2617853 A1	1-6
A	JP 2015-190008 A (JFE STEEL CORPORATION) 02 November 2015 (Family: none)	1-6

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 November 2018 (18.11.2018)	27 November 2018 (27.11.2018)

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

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

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- Development of extremely thick (210 mm) 800N/mm2 grade steel plates for racks of jack-up rigs. *Nippon Steel Technical Report,* 1993, 10-16 **[0002]**
- **KOUZABUROU OOTANI.** Development of extremely thick (210 mm) 800N/mm2 grade steel plates for racks of jack-up rigs. *Nippon Steel Technical Report,* 1993, 10-16 **[0003]**