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(54) STEEL MATERIAL, MANUFACTURING METHOD THEREFOR, AND TANK

(57) A steel material and a production method therefor, and a tank are provided. In a steel material of the present invention, FCC accounts for 95% or more of a microstructure in terms of area fraction, a (110)[001] texture strength at a 1/2 plate thickness position is less than 10.0, a hardness at the 1/2 plate thickness position is less than 300 HV, and a Charpy impact absorbed energy at the 1/2 plate thickness position in a C direction at -196°C is 41 J or more.

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Description

Technical Field

[0001] The present invention relates to a steel material suitable for serving as a structural steel, such as a liquefied gas storage tank, used in an ultra-low temperature environment, and a production method therefor. The present invention also relates to a tank that uses this steel material.

Background Art

[0002] In order to use a hot rolled steel plate as a material for a liquefied gas storage structure, the steel plate is required to have high strength and excellent low-temperature toughness since the service environment involves a very low temperature. For example, when a hot rolled steel plate is to be used in a storage of a liquefied natural gas, excellent toughness must be secured at a boiling point of the liquefied natural gas, -164°C, or lower. If the low-temperature toughness of the steel material is poor, the soundness as an ultra-low temperature storage structure may not be able to be maintained, and thus the steel material applied thereto is strongly required to have improved low-temperature toughness. In the description below, temperatures including an ultra-low temperature range of - 164°C or lower are generally referred to as "low temperature".

[0003] To meet such requirements, austenite stainless steel in which austenite, which is not brittle at low temperature, constitutes the steel plate microstructure, 9% Ni steel, and 5000-series aluminum alloys have been used. However, due to high alloying cost and production cost, there is increasing demand for an inexpensive steel material that has excellent low-temperature toughness.

[0004] In this regard, for example, Patent Literature 1 has proposed, as a novel steel material that replaces existing low-temperature steel, a high-Mn steel that contains a large amount of a relatively inexpensive austenite-stabilizing element, Mn, to be used as a structural steel for a low-temperature environment.

[0005] Patent Literature 1 proposes a technology of obtaining low-temperature toughness in a weld heat affected zone by controlling the carbide area fraction to 5% or less, etc.

Citation List

Patent Literature

[0006] PTL 1: Japanese Unexamined Patent Application Publication (Translation of PCT Application) No. 2015-508452

Summary of Invention

Technical Problem

[0007] Regarding the austenite steel material described in Patent Literature 1, the cooling rate of the welded heat affected zone is limited to 10°C/s or more from the viewpoint of suppressing carbides. When a steel plate having a thickness of less than 10 mm is cooled at 10°C/s or more, the steel plate is likely to undergo warping and strain, and this requires additional steps such as shape correction, and degrades the productivity. In general, the low-temperature toughness in the rolling width direction (C direction) tends to be inferior to the low-temperature toughness in the rolling direction (L direction); however, Patent Literature 1 does not examine the low-temperature toughness in the C direction.

[0008] Furthermore, a liquefied gas storage structure (for example, a liquefied natural gas storage tank) is constructed by welding steel materials. Since inner pressure by the liquefied natural gas is applied to the inner wall of the liquefied gas storage tank (hereinafter may be referred to as a tank), tensile stress occurs in the tank-constituting steel materials not only in the rolling direction (L direction) and the plate width direction (C direction) but also in all directions inside the steel plate plane (hereinafter, these directions may be referred to as "all directions"). Furthermore, tensile stress in the L direction and the C direction occurs also in the weld zones of the tank. Thus, when a steel material is to be used as a material for the tank, the base material (base material portion) and the weld zones must have properties that can withstand the load caused by the tensile stress in all directions, in particular, in the L direction and the C direction. As mentioned above, in the present invention, "all directions" refer to all directions including directions perpendicular to the rolling direction and parallel to the rolling direction.

[0009] A steel material to be used in the aforementioned usage is also known to exhibit toughness degradation known as strain aging embrittlement after plastic deformation that occurs not only at the material preparation stage but also during working and unintended accidents.

[0010] The present invention has been made in view of the issues described above, and an object thereof is to provide a steel material having excellent low-temperature toughness and a production method therefor, and a tank.

[0011] Here, the "welded heat affected zone" refers to a coarse grain heat affected zone (CGHAZ) where degradation of toughness occurs in general steel material.

[0012] In addition "excellent low-temperature toughness" means that, in a steel material, the Charpy impact absorbed energy (vE_{-196}) at -196°C at a 1/2 plate thickness position is 41 J or more in all directions. Usually, the Charpy impact absorbed energy in the C direction is the lowest compared to those in the L direction and the Z direction (plate thickness direction). Thus, in the present invention, the case in which the absorbed energy (vE_{-196}) in the C direction is at least 41 J is considered as having "excellent low-temperature toughness". Note that this "41 J" is a proposed spec for the absorbed energy at -196°C in the L direction of a high-Mn steel drafted as of 2019 by International Association of Classification Societies (IACS), and 27 J is being proposed as the absorbed energy in the C direction. According to the present invention, the spec in the L direction can also be satisfied in the C-direction Charpy impact test.

Solution to Problem

[0013] To address the issues described above, the inventors of the present invention have focused on austenite steel materials (for example, high-Mn steel materials) and conducted extensive studies on the chemical composition, the microstructure, and the production method of the steel materials (steel plates), and various factors that determine the properties of a weld zone obtained by welding the steel material. As a result, the following findings a to d have been found.

a. In order to improve the Charpy impact absorbed energy at -196°C, it is critical that development of a (110)[001] texture, which has the smallest surface atomic density in a face-centered cubic structure (FCC), be suppressed, and the hardness be controlled to less than 300 HV. It is effective for improving the absorbed energy to perform hot rolling under appropriate conditions and control the (110)[001] texture strength to less than 10.0. Preferably, the (110)[001] texture strength is less than 9.0.

b. Since a high-Mn austenite steel contains a large amount of Mn, there are more sulfide inclusions than there are in carbon steel. Furthermore, since the sulfide inclusions elongate in the rolling direction, the C-direction fracture surface in the Charpy impact test specimen generally has a larger sulfide inclusion area fraction than an L-direction fracture surface. Since sulfide inclusions are one factor for fracture initiating points, the low-temperature toughness would be degraded if the cleanliness for sulfide inclusions is 1.0% or more after hot rolling. Thus, it is effective to decrease the cleanliness for sulfide inclusions in order to improve the low-temperature toughness of a high-Mn steel.

c. In hot rolling, performing cross rolling under appropriate conditions can realize b described above in the C direction also.

d. Unlike carbon steel, a high-Mn steel does not undergo transformation during welding and thus the microstructure before welding is maintained after welding.

[0014] The present invention has been made on the basis of the findings described above and additional investigations, and can be summarized as follows.

[1] A steel material in which:

FCC accounts for 95% or more of a microstructure in terms of area fraction,
a (110) [001] texture strength at a 1/2 plate thickness position is less than 10.0,
a hardness at the 1/2 plate thickness position is less than 300 HV, and
a Charpy impact absorbed energy at the 1/2 plate thickness position in a C direction at -196°C is 41 J or more.

[2] The steel material described in [1], in which the Charpy impact absorbed energy at the 1/2 plate thickness position in the C direction at -196°C is 41 J or more after strain aging.

[3] The steel material described in [1] or [2], in which a Charpy impact absorbed energy in a coarse grain heat affected zone in the C direction at -196°C is 41 J or more.

[4] The steel material described in any one of [1] to [3], having a chemical composition including, in terms of mass%,

C: 0.100% or more and 0.700% or less,
Si: 0.05% or more and 1.00% or less,
Mn: 20.0% or more and 40.0% or less,
P: 0.030% or less,
S: 0.0050% or less,
Al: 5.00% or less,
Cr: 7.0% or less,

N: 0.0500% or less,
O: 0.0050% or less,
Ti: less than 0.005%,
Nb: less than 0.005%,
at least one selected from Ca: 0.0100% or less, Mg: 0.0100% or less, and REM: 0.0200% or less, and
the balance being iron and incidental impurities,
in which, in the microstructure, a cleanliness for a sulfide inclusion is less than 1.0%.

[5] The steel material described in [4], in which the chemical composition further includes, in terms of mass%, at least one selected from:

Cu: 1.0% or less,
Ni: 1.0% or less,
Mo: 2.0% or less,
V: 2.0% or less, and
W: 2.0% or less.

[6] The steel material described in [4] or [5], in which the sulfide inclusion is MnS.
[7] A production method for the steel material described in any one of [1] to [6], the production method including: heating a steel slab to a temperature range of 1100°C or higher and 1300°C or lower; hot-rolling the steel slab under such conditions that a cross rolling ratio calculated from formula (1) is 20 or less, a rolling reduction at a finish rolling final pass is 30% or less, and a finish rolling delivery temperature is 750°C or higher; and then performing cooling,

cross rolling ratio = reduction ratio in rolling direction/ reduction ratio in direction perpendicular to rolling direction ··· (1).

[8] A tank constructed by welding the steel material described in any one of [1] to [6],
in which a Charpy impact absorbed energy in a coarse grain heat affected zone in the C direction at -196°C is 41 J or more.

Advantageous Effects of Invention

[0015] The present invention can provide a steel material having excellent low-temperature toughness, and a production method therefor. Moreover, the steel material of the present invention is suitable for use as a material of a steel structure (such as a liquefied gas storage tank) used in a low-temperature environment, and thus a tank having excellent low-temperature toughness in a base material and a welded heat affected zone after welding can be provided. Thus, the present invention can significantly contribute to improving the soundness and lifetime of the steel structure, and offers a prominent industrial advantage. Moreover, since the production method of the present invention does not cause productivity degradation or increase the production cost, a production method with significant economic advantages can be provided.

Description of Embodiments

[0016] The present invention will now be described in detail. It should be understood that the embodiments below do not limit the present invention.
[0017] First, the technical idea of the present invention is described in detail.
[0018] As mentioned above, an austenite steel material (for example, a high-Mn steel material) is available as an inexpensive steel material having excellent low-temperature toughness. In order to use this high-Mn steel material as a material for a steel structure (for example, a tank) to be used in a low-temperature environment, the tank inner wall and weld zones are required to have properties that can withstand the inner pressure of the gas to be stored, in particular, properties that can withstand the load caused by tensile stress acting not only in the L direction and the C direction but also in all directions.
[0019] Since a high-Mn steel material (this means a steel plate having a Mn content of 20.0 to 40.0 mass% here) is an austenite steel material, basically, brittle fractures do not occur, and most fractures are ductile fractures. In contrast,

in an ordinary steel (this means a low-carbon steel plate having a BCC crystal structure at room temperature), ductile fracture is irrelevant to the texture, and the shelf energy (maximum absorbed energy) of the ordinary steel is 200 J or more and may even exceed 300 J depending on the conditions. In other words, since an ordinary steel has sufficiently large absorbed energy, there has been no need to investigate the absorbed energy of ordinary steel unless a brittle fracture surface is formed.

[0020] The results of studies conducted by the inventors of the present invention have revealed that when a high-Mn steel material is subjected to a Charpy impact test at an ultra-low temperature of -196°C, there are cases in which the absorbed energy in the L direction is about 100 J and the absorbed energy in the C direction is lower than 41 J even though involved fracture is ductile. This means that when tensile impact stress acts in a direction perpendicular to the rolling direction on a base material and weld zones of a tank constructed by welding a high-Mn steel material, fractures can easily occur.

[0021] In other words, the inner pressure of the liquefied natural gas are applied to the inner wall and the weld zones of the tank in the L direction, the C direction, and all directions inside the inner surfaces (inner wall) of all steel materials constituting the tank; thus, it is necessary that a sufficient toughness value be obtained with respect to all directions. A rolled steel material is known to exhibit the lowest toughness when a Charpy impact test specimen is taken in the C direction with respect to the rolling direction. Thus, it is critical that the toughness value of the C-direction Charpy impact test be improved.

[0022] Here, the "C direction" refers to a direction perpendicular to the rolling direction (L direction). The "C-direction Charpy impact test" refers to the case in which the longitudinal direction of the Charpy impact test specimen is parallel to the C direction and the notch faces in the rolling direction. In the present application, the "rolling direction" refers to the rolling direction with the largest total rolling reduction amount among various rolling directions.

[0023] The inventors of the present invention have then further investigated the cause thereof, and have newly found that such a difference in absorbed energy is attributable to the rolling texture (a texture formed by rolling), in other words, the relationship between ductile fractures and the texture. The relationship between ductile fractures and the texture will now be described.

[0024] In the present invention, the direction in which the Charpy test specimen is impacted in the Charpy impact test has been focused. The direction of impact is studied for an L-direction Charpy test specimen (here, the notch faces in the C direction) taken from a steel plate in such a way that the longitudinal direction of the Charpy test specimen is the rolling direction, and a C-direction Charpy test specimen (here, the notch faces in the L direction) taken from a steel plate in such a way that the longitudinal direction of the Charpy test specimen is perpendicular to the rolling direction.

[0025] As mentioned above, there is a tendency that the higher the (110) texture, the lower the toughness. The absorbed energy cannot be predicted from the texture; thus, although the reason is not exactly clear, the (110) [001] texture is considered to have some influence as described below. In this texture, the (100) faces align in the C direction and the (110) faces align in the L direction. Thus, although a satisfactory value is obtained in the L-direction Charpy impact test in which the notch faces in the C direction, a poor value is obtained in the C-direction Charpy impact test in which the notch faces in the L direction. According to Japanese Industrial Standards (JIS), the C-direction Charpy impact absorbed energy is specified as 27 J or more, and even such a low value is acceptable. However, since stress acts on the tank constructed therefrom in all directions as described above, an absorbed energy comparable to that in the L direction is preferably obtained in the C direction also.

[0026] In an austenite steel material, the base material does not undergo transformation when heated; thus, the texture of a weld zone obtained by welding the austenite steel material is almost the same as the base material, in other words, remains unchanged. Thus, it is critical that the texture be elaborately controlled during the production of an austenite steel material that serves as the base material.

[0027] In the present invention, during the hot rolling step described below, a (110) [001] texture, which is easily formed during typical rolling, and a different texture in which another orientation is developed by cross rolling that involves rotating the workpiece by 90 degrees are mixed as equally as possible so as to decrease the strength of the (110)[001] texture (in other words, preclude development of the (110) [001] texture). Here, in a face-centered cubic structure (FCC), the (110) face has the smallest surface atomic density, and the surface with the smallest surface atomic density is the weakest bonding surface. In a ductile fracture, such a weakest bonding surface is prone to breaking, and thus the absorbed energy is considered to be low. Thus, it is considered that, by precluding the development of the (110)[001] texture, the Charpy absorbed energy in the L direction and the C direction can be equalized.

[0028] Furthermore, the results of the studies conducted by the inventors of the present invention have revealed that a high-Mn steel material exhibits a Charpy impact absorbed energy of less than 41 J in the C direction at -196°C after strain aging when the hardness is 300 HV or more. Although the detailed mechanism is not clear, it is considered that since a high hardness indicates a high dislocation density, carbon (C) contained in a large amount in the high-Mn steel has pinned many more dislocations.

[0029] Next, the steel material of the present invention is described.

[0030] In the steel material of the present invention, the FCC structure accounts for 95% or more of the microstructure

in terms of area fraction at normal pressure, the (110)[001] texture strength at the 1/2 plate thickness position is less than 10.0, the hardness at the 1/2 plate thickness position is less than 300 HV, and the Charpy impact absorbed energy in the C direction at -196°C at the 1/2 plate thickness position is 41 J or more.
Moreover, in the steel material of the present invention, the Charpy impact absorbed energy in the C direction at - 196°C can be 41 J or more after strain aging and in a coarse grain heat affected zone caused by welding.
The microstructure can have a cleanliness for sulfide inclusions of less than 1.0%.
[0031] The reasons for limiting the microstructure as described above in the present invention will now be described.

[Microstructure of steel material]

[0032] Microstructure at normal pressure: FCC structure accounts for 95% or more in terms of area fraction
[0033] In the present invention, the "microstructure at normal pressure" means a microstructure in the temperature range of 1300°C to -273°C at a pressure of 1 atm. For a high-Mn steel material, the FCC accounts for 95% or more of the microstructure in terms of area fraction in the temperature range of 1300°C or lower (for example, 1250°C).
[0034] As described above, when the steel material has a body-centered cubic (BCC) crystal structure, this steel material can undergo brittle fracture in a low temperature environment, and thus is not suitable for use in a low temperature environment. Thus, when the use in a low temperature environment is expected, the base phase of the steel material is required to have a face-centered cubic (FCC) crystal structure. In the present invention, the "base phase is austenite" means that the austenite phase accounts for 95% or more of the entire microstructure in terms of area fraction. The austenite phase preferably accounts for 97% or more. The balance other than the austenite phase is a ferrite phase and/or a martensite phase. The total area fraction of the phases constituting the balance other than the austenite phase is preferably 5% or less.
[0035] In the present invention, the area fraction of the austenite etc., can be measured by the method described in Examples below.

(110) [001] texture strength: less than 10.0

[0036] In the present invention, as described above, it is critical that hot rolling be performed under appropriate conditions in order to improve the low temperature toughness of the steel material (base material) and the welded heat affected zones. In this manner, in particular, the (110)[001] texture strength in the microstructure can be decreased, and Charpy absorbed energy in the C direction and the L direction can be equalized.
[0037] When the (110) [001] texture strength in the microstructure at the 1/2 plate thickness position is 10.0 or more, cracks readily propagate. As a result, the absorbed energy decreases. Thus, the (110) [001] texture strength is to be less than 10.0. Preferably, the (110) [001] texture strength is 9.0 or less. More preferably, the (110) [001] texture strength is 6.0 or less. The (110)[001] texture strength in the microstructure at the 1/2 plate thickness position is preferably 1.0 or more otherwise the absorbed energy decreases in the L direction. More preferably, the (110)[001] texture strength is 4.0 or more.

Hardness: less than 300 HV

[0038] When the hardness at the 1/2 plate thickness position is 300 HV or more, the ductility and the absorbed energy decrease. Thus, the hardness is to be less than 300 HV. Preferably, the hardness is 280 HV or less. More preferably, the hardness is 260 HV or less. The hardness at the 1/2 plate thickness position is preferably 200 HV or more otherwise the strength of the steel material decreases. More preferably, the hardness is 220 HV or more.

Cleanliness for sulfide inclusions: less than 1.0% (preferable condition)

[0039] When the cleanliness for sulfide inclusions in the microstructure at the 1/2 plate thickness position is 1.0% or more, fracture initiates from sulfide inclusions As a result, the absorbed energy may decrease. Thus, the cleanliness for sulfide inclusions is preferably less than 1.0%. More preferably, the cleanliness for sulfide inclusions is 0.8% or less. Yet more preferably, the cleanliness for sulfide inclusions is 0.6% or less. Although the lower limit of the cleanliness is not particularly limited, 0.1% or more is preferable from the production cost viewpoint.
[0040] The cleanliness is calculated from formula (2) below.

$$d = (n/p \times f) \times 100 \cdots (2)$$

Here, in formula (2) above, p: the total number of grating points in a visual field, f: the number of visual fields, and n: the

number of grating point centers occupied by inclusions in f visual fields.
Thus, the cleanliness is a value obtained by calculating the area percentage occupied by the sulfide inclusions at the 1/2 plate thickness position of the steel material, and indicates the sulfide inclusions in the C direction. Examples of the sulfide inclusions include MnS.

[0041] The aforementioned (110)[001] texture strength: less than 10.0, hardness: less than 300 HV, and cleanliness for sulfide inclusions: less than 1.0% can be realized by performing hot rolling under the conditions described below.

[0042] In the present invention, the aforementioned texture strength, hardness, and cleanliness for sulfide inclusions can be measured by the methods described in Examples below.

[0043] The steel material of the present invention having the aforementioned microstructure has excellent low temperature toughness.

[0044] Here, the Charpy impact absorbed energy at -196°C is measured not only on the steel material (base material) having the aforementioned microstructure but also after strain aging and in a welded heat affected zone.

[0045] When the microstructure at the 1/2 plate thickness position of the steel material has a (110) [001] texture strength of less than 10.0 and a hardness of less than 300 HV, an absorbed energy (vE_{-196}) of 41 J or more can be realized at the 1/2 plate thickness position of the steel material in all directions including the C direction and the L direction. In this manner, even in a weld zone where the steel material of the present invention is welded, an absorbed energy (vE_{-196}) of 41 J or more can be realized in the C direction of the coarse grain heat affected zone. Moreover, an absorbed energy (vE_{-196}) of 41 J or more can be realized in the C direction after strain aging that involves applying a pre-strain and an aging process to the steel material of the present invention under designated conditions (for example, the conditions described in Examples).
Note that the welding conditions such as a preferable heat input etc., are the same as the preferable welding conditions for a tank described below, and the description therefor is omitted here.

[0046] When the cleanliness for sulfide inclusions at the 1/2 plate thickness position of the steel material is controlled to less than 1.0% in addition to the texture strength and the hardness described above, an absorbed energy (vE_{-196}) of 41 J or more can be further effectively obtained also in the C direction in which a lower value is generally exhibited.

[0047] Next, preferable ranges of the chemical composition of the steel material (austenite steel material) of the present invention are described. In a structure (for example, a tank) constructed by using and welding the austenite steel material (for example, a high-Mn steel material) of the present invention , the base material and the weld zone have the same chemical composition and microstructure (however, the austenite grain size in the weld zone is larger).

[Chemical composition]

[0048] In the present invention, an austenite steel material and a steel slab used in producing the austenite steel material have the aforementioned chemical composition. The chemical composition of the austenite steel material of the present invention and the reasons for limitations will now be described. Unless otherwise noted, the notation "%" regarding the chemical composition means "mass%".

C: 0.100% or more and 0.700% or less

[0049] Carbon (C) is an inexpensive austenite-stabilizing element and is a critical element for obtaining austenite. In order to achieve this effect, the C content is preferably 0.100% or more. Meanwhile, at a C content exceeding 0.700%, Cr carbides are excessively formed, and the low-temperature toughness may be degraded. Thus, the C content is preferably 0.100% or more and 0.700% or less. The C content is more preferably 0.200% or more and more preferably 0.600% or less. The C content is yet more preferably 0.250% or more and yet more preferably 0.550% or less.

Si: 0.05% or more and 1.00% or less

[0050] Si acts as a deoxidizing agent, is necessary for steel making, and has an effect of strengthening the steel material through solid-solution strengthening as a solute in the steel. In order to achieve these effects, the Si content is preferably 0.05% or more. Meanwhile, at a Si content exceeding 1.00%, a thermal stress increases excessively, and the low-temperature toughness may be degraded. Thus, the Si content is preferably 0.05% or more and 1.00% or less. The Si content is more preferably 0.07% or more and more preferably 0.80% or less. The Si content is yet more preferably 0.10% or more and yet more preferably 0.60% or less.

Mn: 20.0% or more and 40.0% or less

[0051] Mn is a relatively inexpensive austenite-stabilizing element. In the present invention, Mn is a critical element for achieving both strength and low-temperature toughness. In order to achieve this effect, the Mn content is preferably

20.0% or more. Meanwhile, at a Mn content exceeding 40.0%, the low-temperature toughness may be degraded. Furthermore, weldability and cutting performance may be degraded. In addition, segregation and occurrence of stress corrosion cracking are accelerated. Thus, the Mn content is preferably 20.0% or more and 40.0% or less. The Mn content is more preferably 23.0% or more and yet more preferably 24.0% or more. The Mn content is more preferably 35.0% or less and yet more preferably 30.0% or less.

P: 0.030% or less

[0052] P excessively segregates in the grain boundaries when contained in an amount exceeding 0.030%, and thus degrades the low-temperature toughness. Accordingly, the upper limit is 0.030%, and the P content is preferably decreased as much as feasibly possible. Thus, the P content is 0.030% or less. Excessively decreasing the P content increases the refining cost and brings about economic disadvantages; thus, the P content is preferably 0.002% or more. The P content is more preferably 0.005% or more and yet more preferably 0.010% or more. The P content is more preferably 0.028% or less and yet more preferably 0.024% or less.

S: 0.0050% or less

[0053] Since S degrades the low-temperature toughness and ductility of the base material, 0.0050% is the upper limit of the S content, and the S content is preferably decreased as much as feasibly possible. Thus, the S content is 0.0050% or less. The S content is more preferably 0.0045% or less and yet more preferably 0.0040% or less. Excessively decreasing the S content increases the refining cost and brings about economic disadvantages; thus, the S content is preferably 0.0010% or more. More preferably, the S content is 0.0012% or more.

Al: 5.00% or less

[0054] Al acts as a deoxidizing agent, and is the most versatile element used in deoxidizing process of the steel making for plate material. Moreover, the yield strength and local elongation during the tensile test are improved. In order to achieve these effects, the Al content is preferably 0.01% or more. Meanwhile, at an Al content exceeding 5.00%, a large amount of inclusions are formed and degrade the low-temperature toughness; thus, the Al content is 5.00% or less. The Al content is more preferably 0.01% or more and yet more preferably 0.02% or more. The Al content is more preferably 4.00% or less and yet more preferably 3.50% or less.

Cr: 7.0% or less

[0055] Cr improves the grain boundary strength and is an element effective for improving the low-temperature toughness. In order to achieve this effect, the Cr content is preferably 0.5% or more. Meanwhile, at a Cr content exceeding 7.0%, Cr carbides are formed, and the low-temperature toughness and stress corrosion cracking resistance may be degraded. Thus, the Cr content is preferably 7.0% or less. The Cr content is preferably 0.5% or more, more preferably 1.0% or more, and yet more preferably 1.2% or more. The Cr content is more preferably 6.7% or less and yet more preferably 6.5% or less. In addition, in order to further improve stress corrosion cracking resistance, the Cr content is further more preferably 2.0% or more and 6.0% or less.

N: 0.0500% or less

[0056] N is an austenite-stabilizing element and is an element effective for improving the low-temperature toughness. In order to achieve this effect, the N content is preferably 0.0050% or more. Meanwhile, at a N content exceeding 0.0500%, nitrides or carbonitrides coarsen, and the toughness may be degraded. Thus, the N content is preferably 0.0500% or less. The N content is preferably 0.0050% or more, more preferably 0.0060% or more, and yet more preferably 0.0070% or more. The N content is more preferably 0.0400% or less and yet more preferably 0.0300% or less.

O: 0.0050% or less

[0057] O degrades the low-temperature toughness by forming oxides. Thus, the O content is in the range of 0.0050% or less. The O content is preferably 0.0045% or less, more preferably 0.0040% or less, and yet more preferably 0.0035% or less. Excessively decreasing the O content increases the refining cost and brings about economic disadvantages; thus, the O content is preferably 0.0010% or more. More preferably, the O content is 0.0012% or more.

Ti: less than 0.005%, Nb: less than 0.005%

[0058] Ti and Nb form high melting-point carbonitrides in the steel, and thus degrade the low-temperature toughness. Ti and Nb are incidental impurities mixed in the raw materials etc., and are usually mixed in amounts of Ti: 0.005% or more and 0.010% or less and Nb: 0.005% or more and 0.010% or less. Thus, incidental mixing of Ti and Nb must be avoided through the steel making technique described below, and the Ti and Nb contents must be suppressed to less than 0.005% respectively. By suppressing the Ti and Nb contents to less than 0.005% respectively, the aforementioned adverse effects of the carbonitrides can be eliminated, and excellent low-temperature toughness and ductility can be obtained. Preferably, the Ti and Nb contents are 0.003% or less respectively. Certainly, the Ti and Nb contents may be 0%. More preferably, the Ti and Nb contents are 0.001% or more respectively.

[0059] At least one selected from Ca: 0.0100% or less, Mg: 0.0100% or less, and REM: 0.0200% or less

[0060] Ca, Mg, and rare earth metals (REM) are elements useful in controlling the morphology of inclusions. Controlling the morphology of inclusions refers to changing elongated sulfide inclusions into spheroidized inclusions. The ductility, toughness, and sulfide stress corrosion cracking resistance are improved by controlling the morphology of the inclusions. In order to achieve this effect, the Ca and Mg contents are preferably 0.0005% or more respectively, and the REM content is preferably 0.0010% or more. Meanwhile, when any of these elements is contained in a large amount, the amount of non-metallic inclusions increases, and the ductility, toughness, and sulfide stress corrosion cracking resistance are degraded. This is also economically disadvantageous.

[0061] Thus, when Ca and Mg are to be contained, the amount thereof is preferably 0.0100% or less respectively, and when REM is to be contained, the amount thereof is preferably 0.0200% or less. Preferably, the Ca content is 0.0005% or more, the Mg content is 0.0005% or more, and the REM content is 0.0010% or more. More preferably, the Ca content is 0.0010% or more and 0.0080% or less, the Mg content is 0.0010% or more and 0.0080% or less, and the REM content is 0.0020% or more and 0.0150% or less. Still more preferably, the Ca content is 0.0050% or less and the Mg content is 0.0050% or less.

[0062] In the austenite steel material of the present invention, the balance other than the aforementioned composition is iron (Fe) and incidental impurities. Examples of the incidental impurities here include H and B, and such incidental impurities are acceptable as long as the total content thereof is 0.01% or less.

[0063] The basic chemical composition is preferably composed of the aforementioned elements. The properties targeted by the present invention can be obtained by this basic chemical composition. In the present invention, in order to further improve the strength and low-temperature toughness, following elements can be contained as necessary in addition to the aforementioned elements.

[0064] At least one selected from Cu: 1.0% or less, Ni: 1.0% or less, Mo: 2.0% or less, V: 2.0% or less, and W: 2.0% or less

Cu: 1.0% or less, Ni: 1.0% or less

[0065] Cu and Ni are elements that not only strengthen the steel material by solid-solution strengthening, but also improve dislocation mobility and low-temperature toughness. In order to achieve these effects, the Cu and Ni contents are preferably 0.01% or more respectively. Meanwhile, at a Cu content and a Ni content exceeding 1.0%, the surface quality is degraded upon rolling, and the production cost is boosted up. Thus, when these alloying elements are to be contained, the contents thereof are preferably 1.0% or less respectively. The contents are more preferably 0.03% or more and more preferably 0.7% or less. The contents are further preferably 0.5% or less.

Mo: 2.0% or less, V: 2.0% or less, W: 2.0% or less

[0066] Mo, V, and W contribute to stabilizing austenite and improving the base material strength. In order to achieve this effect, the Mo, V, and W contents are preferably 0.001% or more respectively. Meanwhile, at Mo, V, and W contents exceeding 2.0% respectively, coarse carbonitrides are formed, resulting fracture initiation points, and the production cost is boosted up. Thus, when these alloying elements are to be contained, the contents thereof are preferably 2.0% or less respectively. The contents are more preferably 0.003% or more and more preferably 1.7% or less. The contents are further preferably 1.5% or less.

[0067] In the present invention, the "steel material (austenite steel material)" refers to a steel plate having a plate thickness of 6 mm or more. From the view point of using the steel material for a structural steel plate to be used in an ultra-low temperature environment, the plate thickness is preferably more than 9 mm and more preferably 12 mm or more. The upper limit of the plate thickness is not particularly limited, and the thickness may be arbitrary but is preferably 40 mm or less.

[Method for producing steel material]

[0068] Next, a method for producing a steel material according to one embodiment of the present invention is described.

[0069] The steel material (austenite steel material) of the present invention can be made by a known steel making method that processes a molten metal having the aforementioned chemical composition in a converter, an electric furnace, or the like. Secondary refining may be performed in a vacuum degassing furnace.

[0070] During this process, in order to limit the contents of Ti and Nb, which obstruct microstructure control, to the aforementioned numerical ranges, measures must be taken to avoid incidental mixing of Ti and Nb from the raw material and the like and to decrease the contents of such elements. For example, by decreasing the basicity of the slag in the refining stage, these elements are allowed to concentrate in the slag and discharged so that the Ti and Nb concentrations in the final slab product are decreased. Alternatively, a method involving blowing oxygen to perform oxidation and allowing elements of Ti and Nb to flotation-separate during refluxing may be employed, for example.

[0071] Subsequently, a known casting method such as a continuous casting method or an ingot making and slabbing method may be performed to produce a steel material such as a slab of a particular size.

[0072] In the description below, processing conditions for rolling the aforementioned slab into a steel plate (austenite steel material) having excellent low-temperature toughness are described in detail.

[0073] In order to obtain the austenite steel material having the aforementioned features, it is critical that a steel slab be heated to a temperature range of 1100°C or higher and 1300°C or lower, subjected to particular cross rolling, and hot-rolled under conditions that the rolling reduction of the finish rolling final pass is 30% or less and the finish rolling delivery temperature is 750°C or higher. The temperature control here is on the basis of the surface temperature of the steel in process.

[0074] In the description of the production method below, the notation "°C" indicates the surface temperature of the steel slab or the steel plate unless otherwise noted. The surface temperature can be measured by, for example, a radiation thermometer. The temperature of the plate thickness center position of a slab or a steel plate can be determined by measurement by attaching a thermocouple to the plate thickness center of the steel plate, or by calculating the temperature distribution in the steel plate cross section by heat-transfer analysis and determining the result according to the surface temperature of the steel plate.

Steel slab heating temperature: 1100°C or higher and 1300°C or lower

[0075] In order to sufficiently diffuse Mn before hot rolling, the heating temperature of the steel slab for hot rolling is set to 1100°C or higher. By diffusing Mn, stability of austenite can be obtained even in a Mn negative segregation area. In this manner, the stability of austenite can be obtained even in a coarse grain heat affected zone caused by welding, and thus brittle fracture can be prevented. Meanwhile, at a heating temperature higher than 1300°C, there is a risk that the steel would start melting, and thus the upper limit of the heating temperature is 1300°C. Preferably, the heating temperature is 1130°C or higher and 1270°C or lower.

[0076] Cross rolling ratio calculated from formula (1): 20 or less

$$\text{Cross rolling ratio} = \text{reduction ratio in rolling direction}/\ \text{reduction ratio in direction perpendicular to rolling direction} \cdots (1)$$

Here, the " reduction ratio in rolling direction" refers to the reduction ratio in the rolling direction relative to the total rolling reduction. The " reduction ratio in direction perpendicular to rolling direction" refers to the reduction ratio in a direction perpendicular to the rolling direction relative to the total rolling reduction. Thus, here, " reduction ratio in rolling direction/ reduction ratio in direction perpendicular to rolling direction" refers to the reduction ratio in the rolling direction relative to the reduction ratio in a direction perpendicular to the rolling direction.

[0077] As mentioned above, when austenite steel is rolled, the (110) [001] texture is likely to develop. Thus, by inserting rolling in a different direction, the extent of the (110)[001] texture is decreased, and the strength of the (110) [001] texture can be decreased. In order to control the (110)[001] texture strength to less than 10.0, the cross rolling ratio calculated from formula (1) is to be 20 or less.

[0078] Furthermore, it is also effective to perform cross rolling in the C direction during hot rolling so that the cross rolling ratio is 20 or less so as to decrease the area fraction of the sulfide inclusions in the C direction. The cross rolling ratio is preferably 18 or less and more preferably 15 or less.

[0079] Since the (110)[001] texture develops by repeating rolling in the same direction, it is preferable for homogenization of the texture to alternate rolling in the rolling direction and rolling in a direction perpendicular to the rolling direction. Preferably, the rolling direction alternation is repeated twice or more. Preferably, the rolling direction alternation is performed three times or less.

Rolling reduction of finish rolling final pass: 30% or less, finish rolling delivery temperature: 750°C or higher

[0080] When the rolling reduction of the finish rolling final pass is larger than 30%, the dislocation density increases excessively, and the low-temperature toughness is degraded. When the finish rolling delivery temperature is lower than 750°C, the (110)[001] texture develops excessively, and the low-temperature toughness is degraded. Thus, the rolling reduction of the finish rolling final pass is 30% or less. The rolling reduction is preferably less than 25% and more preferably 20% or less. The finish rolling delivery temperature is 750°C or higher. The finish rolling delivery temperature is preferably 780°C or higher and more preferably 800°C or higher. The upper limit of the finish rolling delivery temperature is not particularly limited; however, from the viewpoint of securing the strength, the finish rolling delivery temperature is preferably 950°C or lower and more preferably 920°C or lower. Although the lower limit of the rolling reduction of the finish rolling final pass is not particularly limited, from the viewpoint of securing the strength, the rolling reduction of the finish rolling final pass is preferably 5% or more and more preferably 10% or more.

[0081] In the present invention, in order to further improve the strength and toughness, the conditions for cross rolling are preferably controlled as below.

Rolling start temperature (preferable condition)

[0082] The rolling start temperature is preferably 1100 to 1250°C. At a temperature lower than 1100°C, the rolling temperature decreases to lower than 780°C, and the texture may develop excessively. At a temperature higher than 1250°C, the texture may remain unchanged.

Rolling temperature (preferable condition)

[0083] The rolling temperature (temperature during rolling) is preferably 780 to 1250°C. At a temperature lower than 780°C, the texture may develop excessively. At a temperature higher than 1250°C, the texture may remain unchanged.

Rolling reduction amount (preferable condition)

[0084] The rolling reduction amount in the temperature range of 780 to 1250°C is preferably 60 to 98%. At a rolling reduction amount less than 60%, the texture may remain unchanged. At a rolling reduction amount exceeding 98%, the texture may develop excessively. The rolling reduction amount indicates the total rolling reduction in the temperature range of 780 to 1250°C.

Cooling

[0085] After hot rolling, cooling is performed. The cooling conditions are not particularly specified. Cooling is preferably performed from a temperature equal to or higher than (hot rolling delivery temperature - 100°C) to a temperature equal to or lower than 600°C at an average cooling rate of 1.0°C/s or more. In this manner, carbide formation and grain boundary segregation of P are suppressed, and the properties of the steel material are further improved. The "hot rolling delivery temperature" refers to the finish rolling delivery temperature.

Next, a tank of the present invention is described.

[0086] A tank of the present invention is constructed by welding the aforementioned steel material. As described in the finding d above, in the steel material of the present invention, the microstructure before welding is maintained even after welding. Thus, the chemical composition and microstructure of the base material of the tank of the present invention are the same as the aforementioned steel material (austenite steel material). A tank having a Charpy impact absorbed energy of 41 J or more at -196°C at the 1/2 plate thickness position of the base material can be obtained by specifying the chemical composition and microstructure of the base material (steel material) as described above. Moreover, in the coarse grain heat affected zone of the tank, the Charpy impact absorbed energy at -196°C can be controlled to 41 J or more. Furthermore, the Charpy impact absorbed energy at -196°C after strain aging can be controlled to 41 J or more.

[0087] Since the tank of the present invention has the aforementioned properties, the tank can be used as, for example, a liquefied gas storage tank to be used in an ultra-low temperature environment.

[0088] Next, a preferable example of a method for constructing the tank described above is described.

[0089] The tank of the present invention is constructed by welding the aforementioned steel material. The method for producing a steel material (austenite steel material) used is already described above, and thus the description therefor is skipped. Here, preferable welding conditions are described.

[Preferable welding conditions]

[0090] The type of welding is preferably gas metal arc welding.
[0091] The heat input range is preferably 3.0 kJ/mm or less. More preferably, the heat input range is 0.5 kJ/mm or more. When such a heat input range is satisfied, the aforementioned properties can be satisfied.
[0092] The average cooling rate in the temperature range of 500 to 800°C is preferably 10°C/s or more. When the average cooling rate in this temperature range is less than 10°C/s, carbides are formed, and the absorbed energy is decreased.
[0093] As described above, in the present invention, the Charpy impact absorbed energy can be equalized in all directions of the steel material, in particular, the L direction and the C direction, and thus the orientation dependence of the impact toughness of the steel material (base material) and weld zones can be decreased. As a result, the reliability of the material is improved.

EXAMPLES

[0094] The present invention will now be described in further detail through examples. The examples below are preferable examples of the present invention, and do not limit the present invention.
[0095] Steel slabs having chemical compositions shown Table 1 were prepared by a converter-ladle refining-continuous casting method. In Table 1, "-" means that the corresponding composition was not intentionally added, and includes the case where the content was zero (0%) and the case where the corresponding composition was incidentally contained. Next, each of the obtained steel slabs was hot-rolled under the conditions shown Table 2 and cooled to prepare a steel material (steel plate) having a plate thickness of 6 to 40 mm.
The cross rolling was appropriately controlled so that the temperature during rolling was 780 to 1250°C, the rolling reduction amount at 780 to 1250°C was 60 to 98%, and the cooling condition after the rolling was 1.0°C/s or more. The "cooling condition after the rolling" refers to the average cooling rate from a temperature equal to or higher than (hot rolling delivery temperature - 100°C) to a temperature equal to or lower than 600°C.
[0096] Test specimens for joints (size: 250 mm × 500 mm) were taken from the obtained steel plate, and welded joints were prepared by welding the L direction to the L direction and the C direction to the C direction. Here, the welding conditions were as follows: shape of the groove: single bevel groove, backing material: ceramic, shield gas: Ar-30% CO_2, and torch drag angle: 5 to 10°.
[0097] The tensile test properties, low-temperature toughness, and microstructure of the steel plates were evaluated, and low-temperature toughness of coarse grain heat affected zones of the welded joints was evaluated by the procedures described below.

(1) Tensile test properties

[0098] From each of the obtained steel plates, a tensile test specimen described below was taken from the 1/2 plate thickness position at the center position in the longitudinal direction and the width direction of the steel plate. From a steel plate having a plate thickness exceeding 15 mm, a JIS No. 4 tensile test specimen was taken, and from a steel plate having a plate thickness of 15 mm or less, a round bar tensile test specimen was taken. A tensile test in compliance with the provisions of JIS Z 2241 (2011) was performed on the tensile test specimens to evaluate the tensile strength (TS) and yield stress (YS). In Examples, samples which had a yield stress of 400 MPa or more were evaluated as having "excellent base material strength".

(2) Low-temperature toughness

[0099] The low-temperature toughness of the steel plate was evaluated as follows.
[0100] C-direction Charpy V-notch test specimens were taken in a direction perpendicular to the rolling direction from each of the obtained steel plates at the 1/2 plate thickness position from the surface of the steel plate. L-direction Charpy V-notch test specimens were taken in a direction parallel to the rolling direction from each of the obtained steel plates at the 1/2 plate thickness position from the surface of the steel plate. Tensile test specimens having a gauge length of 200 mm were taken in the L direction and the C direction at the 1/2 plate thickness position from the steel plate surface of the obtained steel plate, and were subjected to 5% tensile pre-strain and then to an aging treatment at 250°C for 1 hour. Then Charpy V-notch test specimens were taken in the L direction and the C direction from the resulted tensile

test specimens.

[0101] Next, according to the provisions of JIS Z 2242 (2005), the Charpy impact test was performed on three specimens of each steel plate to determine the absorbed energy at -196°C and evaluate the steel material (base material) toughness. As described above, a low toughness value is exhibited in the steel plate C direction. Thus, in these examples, the sample in which the average of the absorbed energy (vE_{-196}) values of the three test specimens was 41 J or more in the C direction was evaluated as having "excellent base material toughness".

[0102] For a steel plate having a plate thickness of 10 mm or less, a subsize (5 mm) Charpy V-notch test specimen was prepared in the C direction, and the Charpy impact test was performed on three specimens from each sample at -196°C. In Table 3, the samples with which subsize Charpy V-notch test specimens were used are indicated by "*1" under the absorbed energy column. For the subsize specimens, the sample in which the average of the absorbed energy (vE_{-196}) values of the three test specimens was 27 J or more in the C direction was evaluated as having "excellent base material toughness".

[0103] The low-temperature toughness of the welded joints was evaluated as follows.

[0104] From each of the welded joints having a plate thickness exceeding 10 mm, Charpy V-notch test specimens were taken in accordance with the provisions of JIS Z 2242 (2005), and the Charpy impact test was performed on three test specimens of each welded joint at -196°C. In Examples, the sample in which the average of the absorbed energy values of the three test specimens was 41 J or more was evaluated as having "excellent weld zone toughness".

[0105] Note that, for each of the welded joints having a plate thickness less than 10 mm, subsize 5 mm Charpy V-notch test specimens were taken in accordance with the provisions of JIS Z 2242 (2005), and the Charpy impact test was performed on three test specimens of each welded joint at -196°C. In Table 3, the samples with which subsize Charpy V-notch test specimens were used are indicated by "*1" under the absorbed energy column. For the subsize specimens, the sample in which the average of the absorbed energy values of the three test specimens was 27 J or more was evaluated as having "excellent weld zone toughness".

Here, as in the above, evaluation was performed by using the measured value in the steel plate C direction that generally exhibits the lowest value.

(3) Microstructure evaluation

[Observation of microstructure]

[0106] The area fraction of each phase of the microstructure was determined from the phase map of the EBSD analysis.

[0107] An EBSD analysis test specimen was taken from a cross section parallel to the rolling direction at the 1/2 plate thickness position of the obtained steel plate, EBSD analysis was performed in a 500 μm × 200 μm visual field at a measurement step of 0.3 μm, and the values indicated in the phase map were respectively assumed to be the area fraction of the austenite phase, the ferrite phase, and the martensite phase.

[0108] In Table 3, "Other phases" means the balance other than the austenite phase, namely, the total area fraction of the ferrite phase and/or martensite phase.

[Texture strength]

[0109] From each of the obtained steel plates, a measurement test specimen was taken from the 1/2 plate thickness position at the center position in the longitudinal direction and the width direction of the steel plate. The texture strength of the ND plane was measured by X-ray diffraction from each of the measurement test specimens. The maximum value of the texture strength was determined from the obtained orientation distribution function (ODF). Note that the ODF can be obtained from a pole figure ((110) [001], (100) [011], (100) [010], (110) [112], and (112)[111]) measured by X-ray diffraction (internally standardized) after removing residual stress on the specimen surface by chemical polishing.

[Hardness]

[0110] By using the obtained steel plates, the hardness HV10kg was measured at the 1/2 plate thickness position at 100 points at the center position of the steel plate in the longitudinal direction and the width direction of the steel plate. The maximum value was used as the maximum hardness value.

[Cleanliness for sulfide inclusions]

[0111] From each of the obtained steel plates, an optical microscope sample was cut out from a rolling-direction cross section at the 1/2 plate thickness position at the center position in the longitudinal direction and the width direction of the steel plate, and the cleanliness was calculated according to JIS G 0555, Annex 1, "Microscopic testing method for non-metallic inclusions by point counting method". Here, the cleanliness for sulfide inclusions in the C direction was calculated. The cleanliness (%) was calculated by the following formula after observing 60 visual fields at a microscope magnification of 400x.

$$d = (n/p \times f) \times 100 \cdots (2)$$

Here, in formula (2) above, p: the total number of grating points in a visual field, f: the number of visual fields, and n: the number of grating point centers occupied by inclusions in f visual fields.
Note that the cleanliness for MnS as the sulfide inclusion was calculated.

[0112] The results obtained therefrom are shown in Table 3.

[Table 1]

Steel No.	Chemical composition (mass%)																		
	C	Si	Mn	P	S	Al	Cr	N	O	Ti	Nb	Ca	Mg	REM	Cu	Ni	Mo	V	W
1	0.455	0.31	24.2	0.017	0.0023	0.03	3.6	0.0160	0.0020	0.002	0.002	0.0005	-	-	-	-	-	-	-
2	0.528	0.24	25.5	0.016	0.0020	0.11	3.1	0.0201	0.0019	0.001	0.002	-	0.0005	-	-	-	-	-	-
3	0.290	0.98	34.8	0.014	0.0050	0.05	5.2	0.0332	0.0017	0.002	0.001	-	-	0.0010	-	-	-	-	-
4	0.334	0.58	32.4	0.030	0.0018	0.04	4.6	0.0164	0.0016	0.001	0.002	0.0010	-	-	0.8	0.8 -	-	-	-
5	0.489	0.39	23.7	0.016	0.0018	0.57	6.0	0.0173	0.0015	0.002	0.003	-	0.0007	-	-	0.9	-	-	-
6	0.616	0.15	20.4	0.013	0.0019	3.30	0.9	0.0090	0.0015	0.003	0.002	-	-	0.0012	-	-	1.8	-	-
7	0.198	0.87	33.6	0.015	0.0020	0.07	5.8	0.0427	0.0016	0.002	0.002	0.0030	-	-	-	-	-	0.2	-
8	0.421	0.36	26.7	0.016	0.0018	0.04	2.7	0.0245	0.0018	0.002	0.001	-	0.0010	-	-	-	-	- 0.2	0.2
9	0.092	0.43	20.5	0.020	0.0025	0.04	1.8	0.0189	0.0017	0.002	0.001	0.0035	-	-	-	-	-	-	-
10	0.713	0.89	38.7	0.028	0.0041	1.06	0.7	0.0373	0.0034	0.003	0.002	-	0.0005	-	-	-	-	-	-
11	0.644	1.04	21.6	0.026	0.0031	0.05	6.0	0.0390	0.0035	0.002	0.002	-	-	0.0011	-	-	-	-	-
12	0.201	0.56	19.6	0.019	0.0019	0.03	1.3	0.0175	0.0026	0.002	0.003	0.0018	-	-	-	-	-	-	-
13	0.357	0.34	40.5	0.022	0.0027	0.04	0.6	0.0193	0.0020	0.002	0.001	-	0.0008	-	-	-	-	-	-
14	0.669	0.58	22.2	0.033	0.0018	0.71	6.8	0.0214	0.0041	0.002	0.002	-	-	0.0013	-	-	-	-	-
15	0.582	0.73	37.6	0.021	0.0054	2.47	1.0	0.0172	0.0018	0.001	0.003	0.0022	-	-	-	-	-	-	-
16	0.453	0.53	35.1	0.017	0.0021	5.05	3.7	0.0168	0.0032	0.002	0.001	-	0.0011	-	-	-	-	-	-
17	0.652	0.30	23.0	0.026	0.0034	0.08	7.4	0.0457	0.0028	0.001	0.001	0.0025	-	-	-	-	-	-	-
18	0.632	0.61	21.6	0.019	0.0022	3.50	5.7	0.0519	0.0043	0.002	0.002	-	-	0.0010	-	-	-	-	-
19	0.524	0.84	20.2	0.020	0.0032	4.71	2.1	0.0230	0.0053	0.003	0.001	0.0016	-	-	-	-	-	-	-
20	0.119	0.56	20.5	0.025	0.0025	0.05	0.6	0.0152	0.0038	0.006	0.002	-	0.0009	-	-	-	-	-	-
21	0.642	0.79	23.1	0.028	0.0037	0.06	6.6	0.0475	0.0035	0.002	0.006	-	-	0.0015	-	-	-	-	-

[Table 2]

Sample No.	Steel No.	Plate thickness	Steel material production method								Welding conditions
			Slab heating temperature	Rolling start temperature	Cross rolling ratio	Number of times rolling in rolling direction and rolling in direction perpendicular to rolling direction are alternated	Rolling reduction of finish rolling final pass	Rolling reduction amount at 780°C to 1250°C	Finish rolling delivery temperature	Cooling	Cooling rate in 500°C - 800°C range
		(mm)	(°C)	(°C)	(-)	(-)	(%)	(%)	(°C)	(°C/s)	(°C/s)
1	1	12	1250	1230	15	3	20	95	851	15.0	8
2	2	15	1230	1210	13	2	18	94	807	10.0	11
3	3	18	1200	1180	17	3	17	93	835	12.0	13
4	4	21	1180	1160	12	2	16	92	812	9.0	10
5	5	24	1160	1140	15	2	17	90	826	7.0	19
6	6	27	1140	1120	11	2	15	89	833	8.0	15
7	7	30	1120	1100	10	1	16	86	750	5.0	17
8	8	9	1270	1250	20	3	25	93	870	Air cooling	5
9	9	21	1180	1160	15	3	18	92	813	11.0	18
10	10	21	1180	1160	16	3	17	92	828	10.0	10
11	11	12	1230	1210	18	1	19	95	782	8.0	16
12	12	25	1150	1130	12	3	18	90	831	14.0	15
13	13	25	1150	1130	14	3	17	90	840	8.0	17
14	14	12	1230	1210	18	2	21	94	773	12.0	14
15	15	20	1200	1180	17	2	19	92	795	9.0	13
16	16	20	1200	1180	18	1	18	92	809	13.0	10
17	17	30	1100	1080	13	3	15	88	816	10.0	10
18	18	12	1200	1180	16	2	20	95	800	7.0	11
19	19	15	1200	1180	18	2	17	94	797	11.0	12

(continued)

Sample No.	Steel No.	Plate thickness	Steel material production method								Welding conditions
			Slab heating temperature	Rolling start temperature	Cross rolling ratio	Number of times rolling in rolling direction and rolling in direction perpendicular to rolling direction are alternated	Rolling reduction of finish rolling final pass	Rolling reduction amount at 780°C to 1250°C	Finish rolling delivery temperature	Cooling	Cooling rate in 500°C - 800°C range
		(mm)	(°C)	(°C)	(-)	(-)	(%)	(%)	(°C)	(°C/s)	(°C/s)
20	20	7	1260	1250	17	2	22	94	783	Air cooling	8
21	21	7	1260	1250	18	2	23	93	771	Air cooling	9
22	1	30	1090	1060	15	1	14	88	804	6.0	12
23	2	30	1100	1080	21	1	16	88	780	8.0	11
24	3	6	1180	1160	15	2	24	94	740	Air cooling	6
25	4	15	1120	1100	-	0	18	94	785	12.0	9
26	6	27	1140	1120	11	2	17	87	754	10.0	11
27	6	27	1140	1120	11	2	16	89	783	9.0	13
28	7	30	1120	1100	10	2	17	86	755	7.0	18
29	7	30	1120	1100	10	3	18	86	758	8.0	19
30	6	12	1200	1180	15	2	30	95	946	6.0	10
31	6	12	1200	1180	15	2	31	95	950	5.0	10
32	1	30	1100	1080	18	3	15	57	770	0.8	16

[Table 3]

Sample No.	Steel No.	Steel material microstructure				Properties of steel material							Properties of coarse grain heat affected zone		Remarks
		(110) [001] texture strength	Cleanliness for sulfide inclusions (C direction)	Austenite phase	Other phases	TS	YS	Hardness	Absorbed energy at -196°C (L direction)	Absorbed energy at -196°C (C direction)	Absorbed energy at -196°C (L direction after strain aging)	Absorbed energy at -196°C (C direction after strain aging)	Absorbed energy at -196°C (L direction in CGHAZ)	Absorbed energy at -196°C (C direction in CGHAZ)	
		(-)	(%)	(area%)	(area%)	(MPa)	(MPa)	(HV)	(J)	(J)	(J)	(J)	(J)	(J)	
1	1	4.0	0.4	100	0	950	560	253	83	55	73	48	71	49	Example
2	2	5.9	0.3	100	0	956	571	252	102	56	85	46	99	56	Example
3	3	4.8	0.6	100	0	856	484	242	92	62	89	60	87	63	Example
4	4	5.6	0.1	100	0	887	502	240	120	60	114	57	113	60	Example
5	5	5.2	0.3	100	0	920	555	243	131	66	117	59	138	74	Example
6	6	5.1	0.2	100	0	966	580	243	137	69	109	55	137	71	Example
7	7	9.9	0.1	100	0	862	458	221	142	57	143	58	146	62	Example
8	8	4.0	0.9	100	0	936	551	280	94*1	50*1	73*1	34*1	55*1	30*1	Example
9	9	5.5	0.2	85	15	963	398	235	47	31	50	33	53	36	Comparative Example
10	10	5.0	0.5	100	0	809	590	247	45	32	33	24	44	32	Comparative Example
11	11	6.6	0.7	100	0	948	578	257	87	36	68	27	89	39	Comparative Example
12	12	4.7	0.2	88	12	970	460	234	48	32	46	31	50	34	Comparative Example
13	13	4.3	0.4	100	0	800	511	234	50	33	47	31	55	37	Comparative Example
14	14	8.0	0.6	100	0	947	582	266	67	35	51	26	65	37	Comparative Example

(continued)

Sample No.	Steel No.	Steel material microstructure				Properties of steel material							Properties of coarse grain heat affected zone		Remarks
		(110) [001] texture strength	Cleanliness for sulfide inclusions (C direction)	Austenite phase	Other phases	TS	YS	Hardness	Absorbed energy at -196°C (L direction)	Absorbed energy at -196°C (C direction)	Absorbed energy at -196°C (L direction after strain aging)	Absorbed energy at -196°C (C direction after strain aging)	Absorbed energy at -196°C (L direction in CGHAZ)	Absorbed energy at -196°C (C direction in CGHAZ)	
		(-)	(%)	(area%)	(area%)	(MPa)	(MPa)	(HV)	(J)	(J)	(J)	(J)	(J)	(J)	
15	15	6.3	0.5	100	0	835	574	236	67	35	56	29	68	36	Comparative Example
16	16	5.9	0.6	100	0	851	562	236	85	35	76	31	82	35	Comparative Example
17	17	5.5	0.2	100	0	852	581	237	48	32	38	25	42	32	Comparative Example
18	18	5.9	0.5	100	0	960	586	261	67	35	52	27	62	35	Comparative Example
19	19	6.2	0.6	100	0	963	569	249	69	36	58	30	67	36	Comparative Example
20	20	8.2	0.6	90	10	955	408	255	37*1	26*1	38*1	27*1	32*1	23*1	Comparative Example
21	21	8.5	0.6	100	0	948	577	273	34*1	24*1	24*1	16*1	28*1	23*1	Comparative Example
22	1	6.0	0.4	100	0	960	573	234	99	40	89	36	87	40	Comparative Example
23	2	8.2	1.0	100	0	955	570	238	114	39	96	33	108	39	Comparative Example
24	3	10.1	0.4	100	0	870	445	260	42*1	26*1	37*1	22*1	32*1	24*1	Comparative Example
25	4	10.1	0.3	100	0	893	506	248	120	40	114	38	110	40	Comparative Example

(continued)

Sample No.	Steel No.	Steel material microstructure				Properties of steel material							Properties of coarse grain heat affected zone		Remarks
		(110) [001] texture strength	Cleanliness for sulfide inclusions (C direction)	Austenite phase	Other phases	TS	YS	Hardness	Absorbed energy at -196°C (L direction)	Absorbed energy at -196°C (C direction)	Absorbed energy at -196°C (L direction after strain aging)	Absorbed energy at -196°C (C direction after strain aging)	Absorbed energy at -196°C (L direction in CGHAZ)	Absorbed energy at -196°C (C direction in CGHAZ)	
		(-)	(%)	(area%)	(area%)	(MPa)	(MPa)	(HV)	(J)	(J)	(J)	(J)	(J)	(J)	
26	6	7.5	0.2	95	5	970	599	242	82	41	82	42	81	43	Example
27	6	6.9	0.2	97	3	968	594	240	90	45	89	46	91	48	Example
28	7	9.7	0.1	100	0	856	450	230	120	60	120	60	123	64	Example
29	7	9.5	0.1	100	0	850	441	233	93	62	90	60	99	67	Example
30	6	5.9	0.1	100	0	960	590	298	100	56	79	43	95	50	Example
31	6	6.1	0.1	100	0	964	595	300	95	50	77	40	84	45	Comparative Example
32	1	8.9	0.4	100	0	828	420	233	67	43	65	42	69	44	Example

*1. 5 mm subsize

[0113] As shown in Table 3, it was confirmed that the austenite steel materials of the present invention satisfied the aforementioned target performance ((110)[001]texture strength of less than 10.0, a hardness of less than 300 HV, and a Charpy impact absorbed energy (vE_{-196}) of 41 J or more at the 1/2 plate thickness position of the steel material). Moreover, it was confirmed that welded joints obtained by welding the austenite steel materials of the present invention satisfied the aforementioned target performance (a Charpy impact absorbed energy (vE_{-196}) of 41 J or more in the coarse grain heat affected zone). Furthermore, the aforementioned performance (a Charpy impact absorbed energy (vE_{-196}) of 41 J or more after strain aging) was satisfied even after the strain aging treatment.

[0114] In contrast, the austenite steel materials of Comparative Examples outside the ranges of the present invention could not satisfy the target performance. Moreover, the absorbed energy of the welded joints obtained therefrom could not satisfy the aforementioned target performance. It was confirmed that the aforementioned target performance was satisfied after the strain aging treatment.

Claims

1. A steel material wherein:

   FCC accounts for 95% or more of a microstructure in terms of area fraction,
   a (110)[001] texture strength at a 1/2 plate thickness position is less than 10.0,
   a hardness at the 1/2 plate thickness position is less than 300 HV, and
   a Charpy impact absorbed energy at the 1/2 plate thickness position in a C direction at -196°C is 41 J or more.

2. The steel material according to Claim 1, wherein the Charpy impact absorbed energy at the 1/2 plate thickness position in the C direction at -196°C is 41 J or more after strain aging.

3. The steel material according to Claim 1 or 2, wherein a Charpy impact absorbed energy in a coarse grain heat affected zone in the C direction at -196°C is 41 J or more.

4. The steel material according to any one of Claims 1 to 3, having a chemical composition comprising, in terms of mass%,

   C: 0.100% or more and 0.700% or less,
   Si: 0.05% or more and 1.00% or less,
   Mn: 20.0% or more and 40.0% or less,
   P: 0.030% or less,
   S: 0.0050% or less,
   Al: 5.00% or less,
   Cr: 7.0% or less,
   N: 0.0500% or less,
   O: 0.0050% or less,
   Ti: less than 0.005%,
   Nb: less than 0.005%,
   at least one selected from Ca: 0.0100% or less, Mg: 0.0100% or less, and REM: 0.0200% or less, and
   the balance being iron and incidental impurities,
   wherein, in the microstructure, a cleanliness for a sulfide inclusion is less than 1.0%.

5. The steel material according to Claim 4, wherein the chemical composition further comprises, in terms of mass%, at least one selected from:

   Cu: 1.0% or less,
   Ni: 1.0% or less,
   Mo: 2.0% or less,
   V: 2.0% or less, and
   W: 2.0% or less.

6. The steel material according to Claim 4 or 5, wherein the sulfide inclusion is MnS.

7. A production method for the steel material according to any one of Claims 1 to 6, the production method comprising:

heating a steel slab to a temperature range of 1100°C or higher and 1300°C or lower; hot-rolling the steel slab under such conditions that a cross rolling ratio calculated from formula (1) is 20 or less, a rolling reduction at a finish rolling final pass is 30% or less, and a finish rolling delivery temperature is 750°C or higher; and then performing cooling,

$$\text{cross rolling ratio} = \text{reduction ratio in rolling direction}/\text{reduction ratio in direction perpendicular to rolling direction} \cdots (1).$$

8. A tank constructed by welding the steel material according to any one of Claims 1 to 6, wherein a Charpy impact absorbed energy in a coarse grain heat affected zone in the C direction at -196°C is 41 J or more.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/006963

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C21D8/02(2006.01)i, C22C38/38(2006.01)i, C22C38/58(2006.01)i
FI: C22C38/00302B, C22C38/00302A, C22C38/38, C22C38/58, C21D8/02D
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, C21D8/02, C22C38/38, C22C38/58

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	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

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 2018/199145 A1 (JFE STEEL CORPORATION) 01 November 2018 (2018-11-01), paragraphs [0015]-[0035], [0038]-[0040], [0043]-[0048]	1-6, 8
A	JP 2016-196703 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 24 November 2016 (2016-11-24)	1-8
A	JP 2017-155300 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 07 September 2017 (2017-09-07)	1-8
A	WO 2013/047819 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 04 April 2013 (2013-04-04)	1-8
A	JP 2015-86403 A (JFE STEEL CORPORATION) 07 May 2015 (2015-05-07)	1-8
A	JP 10-251807 A (KOBE STEEL, LTD.) 22 September 1998 (1998-09-22)	1-8

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 March 2021	18 May 2021

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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

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Form PCT/ISA/210 (patent family annex) (January 2015)

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