

HIGH-Mn STEEL AND PRODUCTION METHOD THEREFOR

TECHNICAL FIELD

5 [0001] The disclosure relates to high-Mn steel that is suitable for structural steel used in an extremely low-temperature environment such as a storage tank of liquefied gas, in particular, high-Mn steel excellent in toughness at low temperature, and a production method therefor.

BACKGROUND

10 [0002] To use a hot-rolled steel plate in a structure for a storage tank of liquefied gas, the steel plate needs to have high strength and excellent toughness at extremely low temperature because the structure is used at extremely low temperature. For example, when the hot-rolled steel plate is used for a storage tank of liquefied natural gas, excellent toughness needs to
15 be guaranteed at the boiling point of the liquefied natural gas, that is, -164 °C or lower. When a steel material has poor low-temperature toughness, the safety as a structure for an extremely low temperature storage tank may not be maintained. Thus, there is a growing demand for steel materials with improved low-temperature toughness that are applied to such a structure.

20 [0003] In view of the demand, austenitic stainless steel which has austenite as a structure of a steel plate, the austenite showing no brittleness at extremely low temperature, 9 % Ni steel, or five thousand series aluminum alloys have been conventionally used. However, the alloy cost and production cost are high, and thus there is a demand for steel materials which are inexpensive and
25 excellent in extremely low-temperature toughness.

[0004] As new steel materials replacing conventional steel for extremely low temperature, for example, JP 2016-196703 A (PTL 1) proposes using, as structural steel used in an extremely low temperature environment, high-Mn steel added with a large amount of Mn which is relatively inexpensive and an
30 austenite-stabilizing element.

[0005] PTL 1 proposes a technique of properly controlling the austenite grain size to prevent carbides generated in crystal grain boundaries from becoming an origin of fracture and a propagation path of cracks. The technique may provide high-Mn steel which exhibits excellent low-temperature toughness in

a base metal and a heat-affected zone after welding.

CITATION LIST

Patent Literature

- 5 **[0006]** PTL 1: JP 2016-196703 A

SUMMARY

(Technical Problem)

10 **[0007]** In an application such as the aforementioned structure for a storage tank of liquefied gas, it is important to guarantee ductility in addition to low-temperature toughness. Specifically, when such a structure is made, steel materials to be used in the structure need to have high workability. Additionally, excellent ductility is required in such an application. The technique of PTL 1, however, does not verify ductility. Further, the high-Mn
15 steel material of PTL 1 has a thickness of about 15 mm to 50 mm, but for example, in an application such as a longitudinal member, the thickness is required to be less than 15 mm, in particular 10 mm or less. When such a thin plate is produced, the technique exemplified in paragraph 0040 of PTL 1 in which hot rolling at 950 °C or more and subsequent accelerated cooling are
20 performed tends to cause deflection and strain in an obtained steel plate, which requires an extra process such as shape adjustment, thus deteriorating productivity.

25 **[0008]** It could thus be helpful to propose a method of further imparting excellent ductility to high-Mn steel exhibiting excellent low-temperature toughness of base metal and heat-affected zone. Further, it could be helpful to propose a method of producing a thin plate of such high-Mn steel without deflection or strain. As used herein, the "exhibiting excellent low-temperature toughness" means that the absorbed energy vE-196 °C in a Charpy impact test at -196 °C is 100 J or more.

30 (Solution to Problem)

[0009] To achieve the aforementioned objects, we conducted extensive study on high-Mn steel as to various factors determining the chemical composition of a steel plate and a production method therefor to discover the following:

- a. High-Mn austenite steel has no occurrence of brittle fracture at

extremely low temperature. Such fracture occurs from grain boundaries. This suggests that for improving low-temperature toughness of high-Mn steel, it is effective to coarsen crystal grains to thereby decrease grain boundaries which become an origin of fracture and a propagation path.

5 b. Further, we newly discovered that nonmetallic inclusions become an origin of fracture and a propagation path of cracks to thus adversely affect low-temperature toughness and ductility. Thus, by properly controlling the Cr content added to high-Mn steel, and limiting the contents of Ti and Nb that are inevitably mixed, the increase in crystal grain boundaries and the
10 formation of excessive nonmetallic inclusions that become an origin of fracture are avoid.

 c. On the other hand, simply coarsening of crystal grains deteriorates yield stress. Further, when a thin plate with a thickness of less than 15 mm is produced, an obtained steel plate tends to have deflection and strain.
15 Therefore, to sufficiently guarantee yield stress as structural steel and leave no deflection or strain in a steel plate, it is necessary to properly control hot rolling conditions in producing a steel plate.

[0010] This disclosure is based on these discoveries and further investigation conducted by the inventors. The primary features of this disclosure are as
20 follows.

1. High-Mn steel comprising:

 a chemical composition containing (consisting of), in mass%,
 C: 0.30 % or more and 0.90 % or less,
 Si: 0.05 % or more and 1.0 % or less,
25 Mn: 15 % or more and 30 % or less,
 P: 0.030 % or less,
 S: 0.0070 % or less,
 Al: 0.01 % or more and 0.07 % or less,
 Cr: 0.5 % or more and 7.0 % or less,
30 N: 0.0050 % or more and 0.0500 % or less, and
 O: 0.0050 % or less,
 Ti: less than 0.005 %, and
 Nb: less than 0.005 %, with the balance being Fe and inevitable impurities;

a microstructure containing austenite as a matrix phase and nonmetallic inclusions with an area fraction of less than 5.0 %; and

a yield stress of 400 MPa or more and an absorbed energy (vE-196) of 100 J or more.

5 The nonmetallic inclusions are nonmetallic inclusions in a structure test of JIS G0202, and specifically refer to A type inclusions, B type inclusions, and C type inclusions that are described in JIS G0202.

[0011] 2. The high-Mn steel according to 1., wherein the chemical composition further contains, in mass %, at least one selected from

10 Cu: 0.01 % or more and 1.00 % or less,

 Ni: 0.01 % or more and 1.00 % or less,

 Mo: 2.0 % or less,

 V: 2.0 % or less,

 W: 2.0 % or less,

15 Ca: 0.0005 % or more and 0.0050 % or less,

 Mg: 0.0005 % or more and 0.0050 % or less, and

 REM: 0.0010 % or more and 0.0200 % or less.

 3. A production method of high-Mn steel comprising: heating a steel material having the chemical composition according to 1. or 2. to a
20 temperature range of 1100 °C or more and 1300 °C or less; hot rolling the steel material with a rolling finish temperature of 800 °C or more and less than 950 °C to obtain a hot-rolled steel plate; and then subjecting the hot-rolled steel plate to cooling treatment at an average cooling rate of 1.0 °C/s or more from a temperature at or above (the rolling finish temperature -
25 100 °C) to a temperature range of 300 °C or more and 650 °C or less.

 Each temperature range is a surface temperature of the steel material or the steel plate.

[0012] 4. The production method of high-Mn steel according to 3. comprising: after the cooling treatment, heating the steel plate to a
30 temperature range of 300 °C or more and 650 °C or less and then cooling the steel plate.

(Advantageous Effect)

[0013] According to the present disclosure, it is possible to provide high-Mn steel excellent in low-temperature toughness and ductility. When the

high-Mn steel is welded, both a base metal and a heat-affected zone have excellent low-temperature toughness. Therefore, our high-Mn steel largely contributes to the improvement of the safety and the service life of a steel structure used in an extremely low temperature environment such as a tank for
5 a storage tank of liquefied gas, and has industrially significant effects. Further, our production method does not decrease productivity or increase the production cost, and thus is excellent in economic efficiency.

DETAILED DESCRIPTION

10 **[0014]** Our high-Mn steel will be described in detail below.

[0015] [Chemical Composition]

The chemical composition of our high-Mn steel and the reasons for the limitations thereof are described first. In the description of the chemical composition, “%” denotes “mass%” unless otherwise noted.

15 **[0016]** C: 0.30 % or more and 0.90 % or less

C is an inexpensive austenite-stabilizing element, and an important element to obtain austenite. To obtain this effect, the C content needs to be 0.30 % or more. On the other hand, a C content beyond 0.90 % generates excessive Cr carbides, deteriorating low-temperature toughness. Therefore,
20 the C content is set to 0.30 % or more and 0.90 % or less. In particular, from the perspective of stabilizing austenite, the lower limit of the C content is preferably 0.36 %, and more preferably 0.40 %. Further, from the perspective of preventing deterioration in low-temperature toughness, the upper limit of the C content is preferably 0.80 %, and more preferably 0.66 %.
25 For the preferable C content, the upper limits and the lower limits can be arbitrarily combined. Thus, for example, the C content is preferably set to 0.36 % or more and 0.80 % or less, and more preferably 0.40 % or more and 0.80 % or less.

[0017] Si: 0.05 % or more and 1.0 % or less

30 Si acts as a deoxidizer, is necessary for steelmaking, and is effective at increasing hardness of a steel plate by solid solution strengthening when dissolved in steel. To obtain such an effect, the Si content needs to be 0.05 % or more. On the other hand, a Si content beyond 1.0 % deteriorates weldability. Therefore, the Si content is set to 0.05 % or more and 1.0 % or

less. In particular, from the perspective of obtaining a steel plate with increased hardness, the lower limit of the Si content is preferably 0.07 %, more preferably 0.23 %, further preferably 0.26 %, and still further preferably 0.51 %. Further, from the perspective of preventing deterioration in weldability, the upper limit of the Si content is set to 0.8 %, more preferably 0.7 %, further preferably 0.6 %, and still further preferably 0.5 %. For the preferable Si content, the upper limit and the lower limit can be combined. Thus, for example, the Si content is preferably set to 0.07 % or more and 0.8 % or less, 0.23 % or more and 0.7 % or less, and more preferably 0.26 % or more and 0.6 % or less. Further, the Si content is preferably 0.07 % or more and 0.5 % or less.

[0018] Mn: 15.0 % or more and 30.0 % or less

Mn is a relatively inexpensive austenite-stabilizing element. In the disclosure, Mn is an important element for achieving both strength and extremely low-temperature toughness. To obtain such effects, the Mn content needs to be 15.0 % or more. On the other hand, a Mn content beyond 30.0 % does not increase the effect of improving extremely low-temperature toughness, but increases alloy cost. Further, such a high Mn content deteriorates weldability and cuttability, and further promotes segregation as well as the occurrence of stress corrosion cracking. Therefore, the Mn content is set to 15.0 % or more and 30.0 % or less. In particular, from the perspective of stabilizing austenite, the lower limit of the Mn content is preferably 16.0 %, more preferably 18.0 %, and further preferably 19.0 %. Further, from the perspective of preventing deterioration in the low-temperature toughness, the upper limit of the Mn content is preferably 29.0 %, and more preferably 28.0 %. For the preferable Mn content, the upper limits and the lower limits can be arbitrarily combined. Thus, for example, the Mn content is preferably set to 16.0 % or more and 29.0 % or less, and more preferably 18.0 % or more and 28.0 % or less.

[0019] P: 0.030 % or less

When a P content is beyond 0.030 %, P segregates to grain boundaries and becomes an origin of stress corrosion cracking. Therefore, the upper limit of the P content is 0.030 %, and desirably, the P content is kept as small as possible. Therefore, the P content is set to 0.030 % or less. Further,

from the perspective of decreasing the origin of stress corrosion cracking, the upper limit of the P content is preferably 0.028 % or less, and more preferably 0.024 % or less. Excessively reducing P, however, involves high refining cost and is economically disadvantageous. Therefore, the lower limit of the
5 P content is preferably set to 0.002 %, and more preferably 0.005 %.

[0020] S: 0.0070 % or less

S deteriorates base metal low-temperature toughness and ductility. Therefore, the upper limit of the S content is 0.0070 %, and desirably, the S content is kept as small as possible. Therefore, the S content is set to 0.0070
10 % or less. From the perspective of preventing deterioration in base metal low-temperature toughness and ductility, the upper limit of the S content is preferably 0.0060 % or less. Excessively reducing S, however, involves high refining cost and is economically disadvantageous. Therefore, the lower limit of the S content is preferably set to 0.001 % or more. The S content is
15 preferably set to 0.0020 % or more and 0.0060 % or less.

[0021] Al: 0.01 % or more and 0.07 % or less

Al acts as a deoxidizer and is used most commonly in molten steel deoxidizing processes to obtain a steel plate. To obtain such an effect, the Al content needs to be 0.01 % or more. On the other hand, when the Al content
20 is beyond 0.07 %, Al is mixed into a weld metal portion during welding, deteriorating toughness of the weld metal. Therefore, the Al content is set to 0.07 % or less. Therefore, the Al content is set to 0.01 % or more and 0.07 % or less. In particular, from the perspective of obtaining an effect as a deoxidizer, the lower limit of the Al content is preferably 0.02 %, more
25 preferably 0.046 %, and further preferably 0.052 %. Further, from the perspective of toughness of weld metal, the upper limit of the Al content is preferably set to 0.065 %, and more preferably 0.06 %. For the Al content, the upper limit and the lower limit can be combined. Thus, for example, the Al content is preferably set to 0.02 % or more and 0.06 % or less.

30 **[0022]** Cr: 0.5 % or more and 7.0 % or less

Cr is an element which stabilizes austenite with an appropriate amount of addition and is effective at improving extremely low-temperature toughness and base metal strength. To obtain such effects, the Cr content needs to be 0.5 % or more. On the other hand, a Cr content beyond 7.0 % generates Cr

carbides, deteriorating low-temperature toughness and stress corrosion cracking resistance. Therefore, the Cr content is set to 0.5 % or more and 7.0 % or less. In particular, from the perspective of improving extremely low-temperature toughness and base metal strength, the lower limit of the Cr content is preferably 1 % or more, more preferably 1.2 %, and further preferably 2.0 %. Further, from the perspective of low-temperature toughness and stress corrosion cracking resistance, the upper limit of the Cr content is preferably set to 6.7 % or less, more preferably 6.5 % or less, and further preferably 6.0 %. For the preferable Cr content, the upper limits and the lower limits can be arbitrarily combined. Thus, for example, the Cr content is preferably set to 1.0 % or more and 6.7 % or less, and more preferably 1.2 % or more and 6.5 % or less. To further improve stress corrosion cracking resistance, the Cr content is further preferably 2.0 % or more and 6.0 % or less.

15 **[0023]** N: 0.0050 % or more and 0.0500 % or less

N is an austenite-stabilizing element and an element which is effective at improving extremely low-temperature toughness. To obtain such an effect, the N content needs to be 0.0050 % or more. On the other hand, the N content beyond 0.0500 % coarsens nitrides or carbonitrides, deteriorating toughness. Therefore, the N content is set to 0.0050 % or more and 0.0500 % or less. In particular, from the perspective of improving extremely low-temperature toughness, the lower limit of the N content is preferably 0.0060 % or more, more preferably 0.0355 %, and further preferably 0.0810 %. Further, from the perspective of preventing deterioration in toughness, the upper limit of the N content is preferably set to 0.0450 % or less, and more preferably 0.0400 % or less. For the preferable N content, the upper limits and the lower limits of the N content can be arbitrarily combined. Thus, for example, the N content is preferably set to 0.0060 % or more and 0.0400 % or less.

25 **[0024]** O: 0.0050 % or less

O deteriorates extremely low-temperature toughness because of the formation of oxides. Therefore, the O content is set to 0.0050 % or less. From the perspective of preventing deterioration in toughness, the upper limit of the O content is preferably 0.0045 % or less. Further, the lower limit of

the O content is preferably 0.0023 % or more. For the preferable O content, the upper limits and the lower limits of the O content can be arbitrarily combined. Thus, for example, the O content is preferably set to 0.0023 % or more and 0.0050 % or less.

5 **[0025]** Ti: less than 0.005 %, and Nb: less than 0.005 %

Ti and Nb form carbonitrides with a high melting point in steel to prevent coarsening of crystal grains, then becoming an origin of fracture and a propagation path of cracks. In particular, in high-Mn steel, Ti and Nb hinder structure control for enhancing low-temperature toughness and improving ductility, and thus, need to be intentionally limited. Specifically, Ti and Nb are components which is inevitably mixed from raw materials into steel, and Ti of 0.005 % or more and 0.010 % or less and Nb of 0.005 % or more and 0.010 % or less are typically mixed. Thus, according to the method described below, it is necessary to avoid inevitable mixing of Ti and Nb and
10 limit the content of each Ti and Nb to less than 0.005 %. By limiting the content of each Ti and Nb to less than 0.005 % to eliminate the adverse effect of carbonitrides, excellent low-temperature toughness and ductility can be guaranteed. Therefore, from the perspective of excellent low-temperature toughness and ductility, the content of each Ti and Nb is preferably set to
15 0.004 % or less, and more preferably 0.003 % or less.

[0026] The balance other than the aforementioned components includes Fe and inevitable impurities. The inevitable impurities include H, and a total content of 0.01 % may be allowed.

[0027] [Structure]

25 Microstructure which has austenite as its matrix phase

When a steel material has a body centered cubic (bcc) crystal structure, the steel material may cause brittle fracture in a low temperature environment, and thus, is not suitable for use in a low temperature environment. When the steel material is assumed to be used in a low temperature environment, the steel material is required to have, as its matrix phase, an austenite structure which has a face centered cubic (fcc) crystal structure. As used herein, "have austenite as its matrix phase" means that area ratio of austenite phase is 90 % or more. When area ratio of austenite phase is 90 % or more, low-temperature toughness can be guaranteed. The balance other than
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austenite phase is ferrite or martensite phase. However, even a small amount of ϵ martensite deteriorates low-temperature toughness. Thus, as the microstructure which has austenite as a matrix phase according to the disclosure, a structure is preferable which substantially has no ϵ martensite phase. Specifically, to guarantee low-temperature toughness, volume fraction of ϵ martensite is preferably less than 1.0 %, more preferably less than 0.5 %, and further preferably less than 0.1 %.

[0028] Area ratio of nonmetallic inclusions: less than 5.0 %

As to nonmetallic inclusions, A type means sulfide inclusions, B type means cluster-type inclusions, and C type means granular oxide inclusions. When a large amount of these nonmetallic inclusions exist in steel, they become an origin of fracture, deteriorating extremely low-temperature toughness and ductility. Therefore, area fraction of the inclusions in total needs to be limited to 5 % or less, and preferably 4 % or less. Accordingly, the control of the chemical composition as stated above and the following production method need to be performed.

[0029] Further, when area ratio of austenite phase is 90 % or more and area fraction of nonmetallic inclusions is less than 5.0 %, steel exhibiting extremely low-temperature toughness and good ductility can be provided.

[0030] When the above requirements are satisfied, properties desired in the disclosure can be obtained. For example, when high-Mn steel is subjected to welding treatment, low-temperature toughness of a heat-affected zone is particularly a matter of concern. However, when high-Mn steel satisfying the aforementioned requirements is used, the microstructure of the heat-affected zone has austenite as its matrix phase, and the grain size of the austenite is an equivalent circular diameter of 50 μm or more. Thus, low-temperature toughness is guaranteed in the heat-affected zone.

[0031] Specifically, coarsening of crystal grains is effective at guaranteeing low-temperature toughness in austenite steel. The same applies to a heat-affected zone. For example, to obtain a value of 100 J or more as an absorbed energy of a Charpy impact test at $-196\text{ }^{\circ}\text{C}$, the biggest crystal grain size of the microstructure needs to be 50 μm or more, which is achieved by using high-Mn steel satisfying the aforementioned requirements.

[0032] In the disclosure, to further improve strength and low-temperature

toughness, in addition to the essential elements described above, the following elements can be contained as necessary.

At least one of Cu: 0.01 % or more and 1.00 % or less, Ni: 0.01 % or more and 1.00 % or less, Mo: 2.0 % or less, V: 2.0 % or less, W: 2.0 % or less, Ca:
5 0.0005 % or more and 0.0050 % or less, Mg: 0.0005 % or more and 0.0050 % or less, and REM: 0.0010 % or more and 0.0200 % or less.

[0033] Cu: 0.01 % or more and 1.00 % or less, Ni: 0.01 % or more and 1.00 % or less, Mo, V, and W: 2.0 % or less

Cu, Ni, Mo, V, and W stabilize austenite and improve base metal
10 strength. To obtain such an effect, Cu and Ni are each preferably contained in an amount of 0.01% or more, and Mo, V, and W are each preferably contained in an amount of 0.001 % or more. On the other hand, when the content of each Cu and Ni is beyond 1.00 %, or the content of each Mo, V, and W is beyond 2.0 %, coarse carbonitrides are generated, which may become an
15 origin of fracture, and additionally increase production cost. Therefore, when these alloying elements are contained, the content of each Cu and Ni is preferably 1.00 % or less, and the content of each Mo, V, and W is preferably 2.0 % or less. The content of each Cu and Ni is more preferably 0.05 % or more and 0.70 % or less. The content of each Mn, V, and W is more
20 preferably 0.003 % or more and 1.7 % or less.

[0034] Ca: 0.0005 % or more and 0.0050 % or less, Mg: 0.0005 % or more and 0.0050 % or less, REM: 0.0010 % or more and 0.0200 % or less

Ca, Mg, and REM are elements useful for morphological control of inclusions, and can be contained as necessary. The morphological control of
25 inclusions means granulating elongated sulfide-based inclusions. The morphological control of inclusions improves ductility, toughness, and sulfide stress corrosion cracking resistance. To obtain such effects, Ca and Mg are preferably contained in an amount of 0.0005 % or more and REM is preferably contained in an amount of 0.0010 % or more. On the other hand, when these
30 elements are contained in a large amount, not only the amount of nonmetallic inclusions may be increased, ending up deteriorating ductility, toughness, and sulfide stress corrosion cracking resistance, but also an economic disadvantage may be entailed.

[0035] Therefore, when Ca and Mg are contained, the content of each element

is set to 0.0005 % or more and 0.0050 % or less. When REM is contained, the content is set to 0.0010 % or more and 0.0200 % or less. Preferably, the Ca content is set to 0.0010 % or more and 0.0040 % or less, the Mg content is set to 0.0010 % or more and 0.0040 % or less, and the REM content is set to 0.0020 % or more and 0.0150 % or less.

[0036] Our high-Mn steel can be obtained from molten steel having the aforementioned chemical composition which is prepared by steelmaking using a publicly-known method such as using a converter and an electric heating furnace. In addition, the high-Mn steel may also be subjected to secondary refinement in a vacuum degassing furnace. During the secondary refinement, to limit the contents of Ti and Nb which hinder suitable structure control within the aforementioned range, it is necessary to prevent Ti and Nb from being inevitably mixed from raw materials or the like into steel and decrease the contents of Ti and Nb. For example, by decreasing the basicity of slag in the refining stage, these alloy elements are concentrated in the slag to be discharged, thus decreasing Ti and Nb concentrations in a final slab product. Further, a method may be used in which oxygen is injected for oxidation, floating and separating alloy of Ti and Nb during circulation. Subsequently, it is preferable to make the steel into a steel material such as a slab having a determined size by a publicly-known steel making method such as continuous casting or ingot casting and blooming.

[0037] Further, production conditions are defined to make the aforementioned steel material into a steel material exhibiting excellent low-temperature toughness.

[0038] Heating temperature of a steel material: 1100 °C or more and 1300 °C or less

To coarsen crystal grains of the microstructure of the steel material, the heating temperature before hot rolling is set to 1100 °C or more. Further, when the lower limit of the heating temperature of the steel material is less than 1100 °C, the amount of nonmetallic inclusions in steel is increased, thus deteriorating extremely low-temperature toughness and ductility. However, the heating temperature beyond 1300 °C may trigger local melting. Thus, the upper limit of the heating temperature is set to 1300 °C. The temperature is controlled based on surface temperature of the steel material.

[0039] Rolling finish temperature: 800 °C or more and less than 950 °C

A steel ingot or a billet is heated and subsequently subjected to hot rolling. To make coarse crystal grains, it is preferable to increase the cumulative rolling reduction at high temperature. However, the crystal
5 grains become excessively coarse in a temperature range of 950 °C or more, and thus desired yield stress cannot be obtained. Therefore, final finish rolling of at least one pass at less than 950 °C is necessary. On the other hand, hot rolling at low temperature refines the microstructure and excessively introduces working strain, thus deteriorating low-temperature
10 toughness. Therefore, the lower limit of the rolling finishing temperature is set to 800 °C.

[0040] Average cooling rate from a temperature at or above (rolling finish temperature - 100 °C) to a temperature range of 300 °C or more and 650 °C or less: 1.0 °C/s or more

15 After the hot rolling, cooling is immediately performed. Slowly cooling of the steel plate after the hot rolling promotes formation of precipitates, thus deteriorating low-temperature toughness. Cooling the steel plate at a cooling rate of 1 °C/s or more can prevent formation of these precipitates. Further, excessive cooling distorts the steel plate, deteriorating
20 productivity. Therefore, the upper limit of cooling start temperature is set to 900 °C. For the aforementioned reasons, in the cooling after the hot rolling, the average rate of cooling a surface of the steel plate from a temperature at or above (rolling finish temperature - 100 °C) to a temperature range of 300 °C or more and 650 °C or less is set to 1.0 °C/s or more. In the case of air
25 cooling a thick steel plate having a thickness of 10 mm or less, the cooling rate is 1 °C/s or more. By air cooling a steel plate having a thickness of 10 mm or less, the steel plate can be free from strain.

[0041] Further, after the cooling treatment, treatment of heating to a temperature range of 300 °C or more and 650 °C or less and then cooling can
30 be added as necessary. Specifically, tempering treatment may be performed to adjust strength of the steel plate.

EXAMPLES

[0042] The present disclosure will be described in further detail below by

way of Examples. Note that the present disclosure is not limited to the following Example.

[0043] Steel slabs having the chemical compositions listed in Table 1 were made by a process for refining with converter and ladle and continuous
5 casting. Next, the obtained steel slabs were charged into a heating furnace and heated to 1150 °C, and subsequently, hot rolled into steel plates having a thickness of 10 mm to 30 mm. Tensile properties and toughness of the steel plates were evaluated as described below.

[0044]

10 (1) Tensile test properties

JIS NO. 5 tensile test pieces were collected from each steel plate. Then, the test pieces were subjected to a tensile test in conformity with JIS Z 2241 (1998) to investigate tensile test properties. In the disclosure, when a test piece had a yield stress of 400 MPa or more and a tensile strength of 800
15 MPa or more, the corresponding steel plate was determined to have excellent tensile properties. Further, when a test piece had a total elongation of 30 % or more upon breakage, the corresponding steel plate was determined to have excellent ductility.

[0045]

20 (2) Low-temperature toughness

Charpy V-notch test pieces were collected from each steel plate having a plate thickness of more than 20 mm at a 1/4 position of the plate thickness or from each steel plate having a plate thickness of 20 mm or less at a 1/2 position of the plate thickness, in a direction orthogonal to the rolling
25 direction in conformity with JIS Z 2202 (1998). Then, the test pieces were subjected to Charpy impact test in conformity with JIS Z 2242 (1998), where three test pieces were used for each steel plate, to determine absorbed energy at -196 °C and evaluate base metal toughness. When the three test pieces had an average absorbed energy (vE_{-196}) of 100 J or more, the corresponding
30 steel plate was determined to have good base steel toughness.

[0046] The above-described evaluation results are listed in Table 2.

[0047]

Table 1

Steel No.	Chemical composition (mass%)																		Remarks	
	C	Si	Mn	P	S	Al	Cr	O	N	Nb	V	Ti	Cu	Ni	Mo	W	Ca	Mg		REM
1	0.600	0.45	27.3	0.028	0.0066	0.029	4.52	0.0028	0.0084	0.002	-	0.002	-	-	-	-	-	-	-	Disclosed Steel
2	0.369	0.32	21.8	0.015	0.0037	0.026	2.26	0.0036	0.0073	0.001	-	0.002	-	-	0.25	-	-	-	-	Disclosed Steel
3	0.552	0.38	21.0	0.023	0.0037	0.047	5.71	0.0027	0.0307	0.001	-	0.002	-	-	-	-	-	-	-	Disclosed Steel
4	0.554	0.07	24.7	0.019	0.0028	0.028	6.00	0.0018	0.0192	0.002	-	0.002	-	-	-	-	-	-	-	Disclosed Steel
5	0.374	0.65	19.5	0.011	0.0046	0.027	5.82	0.0020	0.0211	0.002	-	0.004	-	-	-	-	-	-	-	Disclosed Steel
6	0.481	0.42	26.6	0.006	0.0019	0.016	6.23	0.0033	0.0060	0.003	-	0.003	0.4	-	-	-	-	-	-	Disclosed Steel
7	0.454	0.51	24.5	0.020	0.0030	0.042	1.80	0.0022	0.0280	0.003	0.07	0.003	-	-	-	-	-	-	-	Disclosed Steel
8	0.633	0.43	24.2	0.016	0.0064	0.035	5.27	0.0035	0.0389	0.004	-	0.001	-	-	-	-	-	-	-	Disclosed Steel
9	0.753	0.45	29.0	0.015	0.0039	0.029	3.20	0.0034	0.0104	0.001	-	0.001	0.5	0.5	-	-	-	-	-	Disclosed Steel
10	0.545	0.50	22.1	0.010	0.0057	0.020	6.72	0.0030	0.0357	0.002	-	0.001	-	-	-	-	-	-	-	Disclosed Steel
11	0.412	0.38	24.4	0.016	0.0036	0.070	4.64	0.0015	0.0205	0.001	-	0.001	-	-	-	-	-	-	-	Disclosed Steel
12	0.799	0.38	27.7	0.014	0.0050	0.054	4.80	0.0029	0.0276	0.001	-	0.001	-	-	0.05	-	-	-	-	Disclosed Steel
13	0.435	0.48	18.9	0.027	0.0042	0.040	5.65	0.0027	0.0400	0.002	-	0.001	-	-	-	-	-	-	-	Disclosed Steel
14	0.686	0.47	20.1	0.026	0.0022	0.049	5.16	0.0021	0.0339	0.001	-	0.001	-	-	-	0.05	-	-	-	Disclosed Steel
15	0.669	0.38	28.5	0.022	0.0035	0.046	3.83	0.0029	0.0175	0.002	-	0.001	-	-	-	-	0.0021	-	-	Disclosed Steel
16	0.629	0.28	18.5	0.008	0.0041	0.060	2.83	0.0040	0.0225	0.002	-	0.001	-	-	-	-	-	0.0020	-	Disclosed Steel
17	0.356	0.39	27.3	0.011	0.0034	0.038	2.02	0.0026	0.0121	0.002	-	0.001	-	-	-	-	-	-	0.0015	Disclosed Steel

Note: Underlines are out of the scope of the disclosure.

Table 1 (cont'd)

Steel No.	Chemical composition (mass%)																			Remarks
	C	Si	Mn	P	S	Al	Cr	O	N	Nb	V	Ti	Cu	Ni	Mo	W	Ca	Mg	REM	
18	<u>0.924</u>	0.49	17.0	0.009	0.0065	0.033	3.92	0.0035	0.0326	0.002	-	0.001	0.2	-	0.10	-	-	-	-	Comparative Steel
19	<u>0.080</u>	0.54	27.8	0.015	0.0034	0.034	6.11	0.0038	0.0126	0.004	-	0.003	-	-	-	-	-	-	-	Comparative Steel
20	0.582	<u>1.20</u>	26.9	0.013	0.0057	0.040	1.80	0.0019	0.0291	0.002	0.005	0.001	-	-	-	-	-	-	0.0055	Comparative Steel
21	0.514	<u>0.01</u>	27.1	0.010	0.0028	0.070	5.34	0.0025	0.0144	0.003	-	0.003	-	-	-	-	-	-	-	Comparative Steel
22	0.488	0.45	<u>32.3</u>	0.015	0.0042	0.052	6.64	0.0032	0.0129	0.002	-	0.002	-	-	-	-	-	-	-	Comparative Steel
23	0.680	0.64	<u>14.5</u>	0.002	0.0036	0.049	6.83	0.0026	0.0123	0.001	-	0.001	-	-	0.21	0.12	-	-	-	Comparative Steel
24	0.479	0.47	15.8	<u>0.040</u>	0.0045	0.051	3.48	0.0024	0.0268	0.001	-	0.001	-	-	-	-	0.0020	-	-	Comparative Steel
25	<u>0.265</u>	0.31	18.5	0.017	<u>0.0085</u>	0.035	4.45	0.0024	0.0311	0.001	-	0.001	-	-	-	-	-	-	-	Comparative Steel
26	0.498	0.28	26.6	0.019	0.0044	<u>0.009</u>	5.32	<u>0.0072</u>	0.0189	0.002	-	0.002	-	-	-	-	-	-	-	Comparative Steel
27	0.621	0.42	26.8	0.014	0.0039	<u>0.080</u>	5.91	0.0029	0.0201	0.003	-	0.003	-	-	-	-	-	-	-	Comparative Steel
28	<u>0.270</u>	0.66	26.7	0.021	0.0046	0.034	4.16	<u>0.0065</u>	0.0202	0.001	-	0.001	-	-	0.08	-	-	-	0.0032	Comparative Steel
29	0.569	0.58	25.9	0.018	0.0051	0.045	<u>7.50</u>	0.0039	0.0162	0.002	-	0.003	-	-	-	-	-	-	-	Comparative Steel
30	0.612	0.48	18.2	0.008	0.0010	0.039	<u>0.30</u>	0.0034	0.0396	0.001	-	0.001	-	-	-	0.08	0.0018	-	-	Comparative Steel
31	0.556	0.45	21.6	0.025	0.0041	0.022	1.43	0.0021	<u>0.0523</u>	0.001	-	0.001	-	-	-	-	-	-	-	Comparative Steel
32	0.588	0.47	27.4	0.021	0.0038	0.047	5.53	0.0027	<u>0.0029</u>	0.003	-	0.002	-	-	-	-	-	-	-	Comparative Steel
33	0.318	0.49	20.4	0.013	0.0024	0.044	3.43	0.0029	<u>0.0090</u>	<u>0.010</u>	-	0.001	-	-	0.35	-	-	0.0025	-	Comparative Steel
34	0.518	0.53	25.5	0.017	0.0038	0.048	3.99	0.0037	0.0123	<u>0.005</u>	-	0.003	-	-	-	-	-	-	-	Comparative Steel
35	0.603	0.59	27.1	0.018	0.0044	0.037	5.18	0.0041	0.0089	0.002	-	<u>0.005</u>	-	-	-	-	-	-	-	Comparative Steel
36	0.432	0.71	21.8	0.023	0.0032	0.047	3.47	0.0022	0.0214	0.001	-	<u>0.010</u>	-	-	-	-	-	-	-	Comparative Steel

Note: Underlines are out of the scope of the disclosure.

[0048]

Table 2

Sample No.	Steel No.	Sheet thickness (mm)	Production method					Base metal properties					Base metal toughness	HAZ portion		Remarks
			Slab heating temperature (°C)	Rolling finish temperature (°C)	Cooling start temperature (°C)	Cooling rate (°C/s)	Re-heating temperature (°C)	Area ratio of inclusions (%)	Volume fraction of ϵ martensite (%)	Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)		Absorbed energy at -196 °C (vE _{-196°C}) (J)	Largest grain size (μm)	
1	1	10	1110	945	872	13	450	0.2	0.0	480	912	60	100	145	165	Example
2	2	15	1110	835	768	7	-	4.0	0.0	510	934	62	108	100	175	Example
3	3	20	1100	890	815	12	-	2.0	0.0	487	912	61	113	112	150	Example
4	4	25	1100	910	845	10	-	0.2	0.0	446	891	61	124	134	187	Example
5	5	10	1150	860	795	12	500	0.2	0.1	467	905	62	125	121	50	Example
6	6	15	1150	890	808	5	550	0.3	0.0	442	899	61	133	129	102	Example
7	7	20	1150	825	785	7	-	0.2	0.0	445	903	61	122	128	100	Example
8	8	5	1200	825	740	4	-	1.0	0.0	598	987	51	106	108	50	Example
9	9	10	1200	810	730	10	450	0.1	0.0	484	858	65	112	115	100	Example
10	10	15	1200	870	798	10	-	0.3	0.0	466	884	64	127	124	150	Example
11	11	15	1250	860	795	9	500	2.0	0.0	487	840	66	114	106	100	Example
12	12	20	1250	915	860	13	550	0.5	0.0	435	850	67	113	113	168	Example
13	13	25	1250	860	805	6	-	1.5	0.2	441	852	65	109	110	125	Example
14	14	30	1250	815	744	3	300	0.1	0.0	426	853	61	132	127	109	Example
15	15	10	1300	870	821	1	-	0.1	0.0	422	874	61	104	108	115	Example
16	16	15	1300	854	784	7	450	1.0	0.0	501	926	57	116	114	89	Example
17	17	20	1300	884	810	20	-	1.5	0.0	512	934	52	112	116	97	Example

Note: Underlines are out of the scope of the disclosure.

(*) an average cooling rate from a temperature at or above (rolling finish temperature - 100 °C) to a temperature range of 300 °C or more and 650 °C or less

Table 2 (cont'd)

Sample No.	Steel No.	Sheet thickness (mm)	Production method					Base metal properties					Base metal toughness Absorbed energy at -196 °C (vE _{-196°C}) (J)	HAZ portion		Remarks
			Slab heating temperature (°C)	Rolling finish temperature (°C)	Cooling start temperature (°C)	Cooling rate (*) (°C/s)	Re-heating temperature (°C)	Area ratio of inclusions (%)	Volume fraction of α martensite (%)	Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)		Absorbed energy at -196 °C (vE _{-196°C}) (J)	Largest grain size (μm)	
18	18	10	1150	895	810	5	-	2.0	0.0	512	922	58	56	61	125	Comparative Example
19	19	15	1150	815	735	15	-	0.1	1.0	471	879	57	121	61	95	Comparative Example
20	20	20	1150	862	805	5	-	0.5	0.0	361	701	51	45	44	80	Comparative Example
21	21	25	1150	871	820	13	-	0.1	0.0	425	871	61	24	26	80	Comparative Example
22	22	10	1150	900	815	10	-	4.0	0.0	497	922	34	46	48	105	Comparative Example
23	23	15	1150	850	815	5	-	0.2	0.5	455	906	60	51	53	65	Comparative Example
24	24	20	1200	840	770	11	-	0.2	0.0	375	716	61	78	65	60	Comparative Example
25	25	5	1200	920	850	10	-	5.5	0.0	467	900	30	42	41	126	Comparative Example
26	26	10	1200	875	805	5	-	4.5	0.0	525	927	54	67	68	78	Comparative Example
27	27	15	1200	855	790	12	-	0.3	0.0	511	916	58	65	41	65	Comparative Example
28	28	15	1150	896	853	5	-	3.5	0.0	456	897	29	70	66	100	Comparative Example
29	29	15	1150	916	848	4	-	0.5	0.0	432	875	25	43	46	125	Comparative Example
30	30	15	1150	898	805	9	-	0.1	0.0	465	912	60	60	58	110	Comparative Example
31	31	15	1150	908	821	11	-	0.2	0.0	448	905	35	47	51	105	Comparative Example
32	32	15	1150	850	785	4	-	0.1	0.0	487	932	55	79	68	75	Comparative Example
33	33	15	1150	806	726	6	-	0.2	0.2	512	936	45	59	61	35	Comparative Example
34	34	15	1150	827	768	4	-	0.2	0.0	487	909	45	78	76	40	Comparative Example
35	35	15	1150	878	804	3	-	0.1	0.0	439	887	51	69	69	40	Comparative Example
36	36	15	1150	851	776	7	-	0.1	0.0	466	889	43	51	51	35	Comparative Example
37	1	20	1050	815	724	8	-	5.5	0.0	560	1064	42	78	91	165	Comparative Example
38	2	25	1250	960	885	9	-	3.5	0.1	367	724	61	116	108	175	Comparative Example
39	3	30	1250	780	695	14	-	2.0	0.0	598	987	52	54	81	150	Comparative Example
40	4	10	1250	835	715	10	-	0.2	0.0	437	879	28	65	70	187	Comparative Example
41	5	10	1250	975	889	8	-	0.2	0.0	375	786	64	126	124	50	Comparative Example
42	6	15	1250	850	800	0.5	-	0.3	0.0	412	861	28	55	67	102	Comparative Example
43	7	20	1250	915	865	9	800	0.2	0.0	316	704	45	119	112	100	Comparative Example

Note: Underlines are out of the scope of the disclosure.

(*) an average cooling rate from a temperature at or above (rolling finish temperature - 100 °C) to a temperature range of 300 °C or more and 650 °C or less

High-Mn steel of the disclosure was confirmed to satisfy the aforementioned desired performance (a base metal yield stress of 400 MPa or more, a total elongation upon breakage of 30 % or more, an average of absorbed energy (vE-₋₁₉₆) of 100 J or more for low-temperature toughness).

5 On the other hand, comparative examples out of the scope of the disclosure did not satisfy the aforementioned desired performance in terms of any one or more of total elongation, yield stress, and low-temperature toughness.

[0049] Further, to evaluate impact absorbed properties of a welded portion, the steel materials were subjected to heat cycle treatment under conditions of
10 peak temperature of 1400 °C and a cooling rate of 10 °C/s. The results are listed in Table 2. As illustrated in Table 2, the steel materials according to the disclosure were excellent in welded portion toughness as well as in base metal toughness at low temperature. Specifically, in welding which gave input heat of 0.5 kJ/cm to 5 kJ/cm, the maximum crystal grain size was 50 μm
15 or more, and the absorbed energy in Charpy impact test at -196 °C was 100 J or more.

[0050] The present disclosure claims priority to JP 2017-087702 A filed on April 26, 2017, which is incorporated herein for reference in its entirety.

CLAIMS

1. High-Mn steel comprising:
a chemical composition containing, in mass%,
5 C: 0.30 % or more and 0.90 % or less,
Si: 0.05 % or more and 1.0 % or less,
Mn: 15 % or more and 30 % or less,
P: 0.030 % or less,
S: 0.0070 % or less,
10 Al: 0.01 % or more and 0.07 % or less,
Cr: 0.5 % or more and 7.0 % or less,
N: 0.0050 % or more and 0.0500 % or less, and
O: 0.0050 % or less,
Ti: less than 0.005 %, and
15 Nb: less than 0.005 %, with the balance being Fe and inevitable
impurities;
a microstructure containing austenite as a matrix phase and
nonmetallic inclusions with an area fraction of less than 5.0 %; and
a yield stress of 400 MPa or more and an absorbed energy (vE-196) of
20 100 J or more.
2. The high-Mn steel according to claim 1, wherein the chemical
composition further contains, in mass %, at least one selected from
Cu: 0.01 % or more and 1.00 % or less,
25 Ni: 0.01 % or more and 1.00 % or less,
Mo: 2.0 % or less,
V: 2.0 % or less,
W: 2.0 % or less,
Ca: 0.0005 % or more and 0.0050 % or less,
30 Mg: 0.0005 % or more and 0.0050 % or less, and
REM: 0.0010 % or more and 0.0200 % or less.
3. A production method of high-Mn steel comprising:
heating a steel material having the chemical composition according to

claim 1 or 2 to a temperature range of 1100 °C or more and 1300 °C or less;
hot rolling the steel material with a rolling finish temperature of 800
°C or more and less than 950 °C to obtain a hot-rolled steel plate; and
then subjecting the hot-rolled steel plate to cooling treatment at an
5 average cooling rate of 1.0 °C/s or more from a temperature at or above (the
rolling finish temperature - 100 °C) to a temperature range of 300 °C or more
and 650 °C or less.

4. The production method of high-Mn steel according to claim 3
10 comprising:

after the cooling treatment, heating the steel plate to a temperature
range of 300 °C or more and 650 °C or less, and then cooling the steel plate.