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(54) **HIGH MN STEEL SHEET AND METHOD FOR PRODUCING SAME**

(57) A high-Mn steel plate and a manufacturing method therefor are provided. The high-Mn steel plate has a component composition containing, in mass%, C: 0.20 to 0.70%, Si: 0.05 to 1.0%, Mn: 15 to 30%, P: 0.028% or less, S: 0.02% or less, Al: 0.01 to 0.1%, Cr: 0.5 to 7.0%, Ni: 0.03 to 0.30%, N: 0.0010 to 0.0200%, and one or two or more of Nb: 0.003 to 0.030%, V: 0.03 to 0.10%, and

Ti: 0.003 to 0.040%, with the balance being Fe and incidental impurities, where: a microstructure 0.5 mm under a surface of the steel plate includes austenite as a base phase; and 25% or more of the austenite, in area ratio, has an equivalent circle diameter of 10 μm or more and an aspect ratio of a major axis to a minor axis of 3 or more.

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Description

Technical Field

[0001] The present invention relates to a high-Mn steel plate that is suitable for structural steel used in a cryogenic environment, such as a liquefied gas storage tank, in particular, to a high-Mn steel plate having excellent resistance to stress corrosion cracking in a salt water corrosive environment and to a manufacturing method therefor.

Background Art

[0002] When a hot-rolled steel plate is used for a liquefied gas storage structure, cryogenic temperatures are encountered in the usage environment. Thus, for cryogenic temperatures, the steel plate is required to have not only strength, but also toughness. When a hot-rolled steel plate is used for storage of liquefied natural gas, for example, excellent toughness at the boiling point of liquefied natural gas of -164°C or lower is required. When low-temperature toughness of a steel material is poor, there is a risk of failure in maintaining the safety of a cryogenic storage structure. Accordingly, there is a high demand for enhanced low-temperature toughness of a steel material to be employed. In response to such demand, 5000 series aluminum alloys, 9% Ni steel, or austenitic stainless steel including, as a steel plate micro-structure, austenite that does not exhibit brittleness at a cryogenic temperature have conventionally been used. However, since their alloying costs and/or manufacturing costs are high, there is a need for an inexpensive steel material having excellent cryogenic toughness. Accordingly, as a new steel material that can replace conventional cryogenic steel, the use of a high-Mn steel plate, to which a large amount of Mn that is a relatively inexpensive austenite stabilizing element is added, has been investigated as structural steel for a cryogenic environment.

[0003] Meanwhile, when austenitic steel is used in a corrosive environment, austenite grain boundaries are corroded and there is a problem in which stress corrosion cracking tends to arise under applied tensile stress. Especially, in a manufacturing stage for a liquefied gas storage structure and the like, a base iron surface of a steel plate is exposed in some cases. Upon contact of a steel material surface with oil, moisture, and/or water vapor containing a corrosive substance, such as salt, corrosion of the steel material arises. A high-Mn steel plate that has conventionally been investigated has, in some cases, corrosion resistance inferior to that of 9% Ni steel and common low alloy steel, not to mention austenitic stainless steel. In corrosion reactions on the surface of such a high Mn steel plate, oxides (rust) are formed by the anodic reaction of iron while hydrogen is generated by the cathodic reaction of moisture, thereby promoting stress corrosion cracking due to hydrogen embrittlement. Consequent stress corrosion cracking could result in breakage of a structure in the presence of stress applied in the usage environment or in the presence of residual stress through bending or welding during manufacture. Accordingly, in view of safety, it is important to have excellent resistance to stress corrosion cracking, not to mention strength and cryogenic toughness of a steel material to be used.

[0004] Patent Literature 1, for example, discloses a steel material having improved machinability and Charpy impact characteristics at -196°C in weld heat affected zones through addition of 15 to 35% of Mn, 5% or less of Cu, and appropriate amounts of C and Cr.

[0005] Moreover, Patent Literature 2 discloses a high-Mn steel material having improved low-temperature toughness through addition of C: 0.25 to 0.75%, Si: 0.05 to 1.0%, Mn: more than 20% and 35% or less, Ni: 0.1% or more and less than 7.0%, and Cr: 0.1% or more and less than 8.0%.

Citation List

Patent Literature

[0006]

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

PTL 2: Japanese Unexamined Patent Application Publication No. 2016-84529

Summary of Invention

Technical Problem

[0007] The high-Mn steel plates disclosed in Patent Literature 1 and 2, however, are intended to have strength and low-temperature toughness. The Charpy impact characteristics at -196°C in weld heat affected zones are 60 to 135 J (disclosed only in Patent Literature 1). However, the cryogenic toughness of the base metals is still unsatisfactory without achieving both cryogenic toughness and resistance to stress corrosion cracking.

[0008] In view of the above problem, an object of the present invention is to provide a high-Mn steel plate having excellent resistance to stress corrosion cracking and cryogenic toughness and to provide a manufacturing method therefor.

Solution to Problem

[0009] To achieve the above-mentioned object, the present inventors intensively studied, for high-Mn steel plates, various factors that determine the microstructure, a manufacturing method, and a component composition of a steel plate for ensuring excellent resistance to stress corrosion cracking, and found the following.

1. To achieve both cryogenic toughness and excellent resistance to stress corrosion cracking, it is effective to decrease the amount of hydrogen that penetrates a steel plate through corrosion reactions. Enhancing corrosion resistance of a steel plate surface in a salt water environment is essential. For this purpose, it is important to strictly control the component composition of a high-Mn steel plate as a base. Particularly, by adding Cr and Ni together and properly controlling the amounts, rust formed in the initial stage of corrosion reactions on a steel plate surface becomes fine. In addition, by retarding the subsequent corrosion reactions, the amount of hydrogen that penetrates steel can be decreased.

2. Moreover, it was found that strictly controlling the microstructure near a steel plate surface is also effective to improve resistance to stress corrosion cracking. In other words, to enhance resistance to stress corrosion cracking, it is important that 25% or more of austenite, in area ratio, has an equivalent circle diameter of 10 μm or more and an aspect ratio of a major axis to a minor axis of 3 or more. This is presumably because hydrogen that has penetrated a steel plate through corrosion reactions is trapped inside grains of non-recrystallized austenite, and consequently, the amount of hydrogen at austenite grain boundaries is decreased relatively, thereby lowering susceptibility of austenite grain boundaries to stress corrosion cracking.

3. In addition to the above-described 1 and 2, a carbide, a nitride, and a complex carbonitride of Nb, V, and/or Ti in a steel plate can further enhance resistance to stress corrosion cracking through proper control of their dispersed state. Such a carbide, nitride, and complex carbonitride of Nb, V, and/or Ti act as trapping sites of diffusible hydrogen in a steel plate. In other words, the carbide, nitride, and complex carbonitride act as trapping sites of diffusible hydrogen generated through corrosion reactions of a steel material and have an effect of suppressing stress corrosion cracking. The dispersed state of a carbide, a nitride, and a carbonitride of Nb, V, and/or Ti within austenite is affected, for example, by heating, rolling, and cooling conditions in a hot rolling step. Accordingly, it is important to control these manufacturing conditions.

4. Further, to effectively suppress intergranular fracture of austenite, measures to enhance grain boundary strength are effective. P is an element that tends to undergo cosegregation with Mn in a solidification process of ingots and lowers the strength of grain boundaries that cross microsegregation zones. Accordingly, it is required to decrease impurities, such as P.

[0010] The present invention was made on the basis of the above-described findings and further additional investigation and is summarized as follows.

[1] A high-Mn steel plate having a component composition containing, in mass%, C: 0.20 to 0.70%, Si: 0.05 to 1.0%, Mn: 15 to 30%, P: 0.028% or less, S: 0.02% or less, Al: 0.01 to 0.1%, Cr: 0.5 to 7.0%, Ni: 0.03 to 0.30%, N: 0.0010 to 0.0200%, and one or two or more of Nb: 0.003 to 0.030%, V: 0.03 to 0.10%, and Ti: 0.003 to 0.040%, with the balance being Fe and incidental impurities, where: a microstructure 0.5 mm under a surface of the steel plate includes austenite as a base phase; and 25% or more of the austenite, in area ratio, has an equivalent circle diameter of 10 μm or more and an aspect ratio of a major axis to a minor axis of 3 or more.

[2] The high-Mn steel plate according to [1], where the component composition further contains an element in at least one group selected from the following group A or B.

Group A: one or two, in mass%, selected from Mo: 0.05 to 2.0% and W: 0.05 to 2.0%

Group B: one or two or more, in mass%, selected from Ca: 0.0005 to 0.0050%, Mg: 0.0005 to 0.0050%, and REM: 0.0010 to 0.0200%

[3] The high-Mn steel plate according to [1] or [2], where the microstructure 0.5 mm under the surface of the steel plate further includes a total number of $2 \times 10^2/\text{mm}^2$ or more of a carbide, a nitride, and a carbonitride, the carbide, the nitride, and the carbonitride containing one or two or more of Nb, V, and Ti and having an equivalent circle diameter of 0.01 to 0.5 μm .

[4] A manufacturing method for a high-Mn steel plate, including: heating of steel having the component composition

according to any one of [1] to [3] to a temperature range of $(T_x - 50)^\circ\text{C}$ or higher and $(T_x + 200)^\circ\text{C}$ or lower as a surface temperature of the steel for any one or more of T_x ($^\circ\text{C}$) defined by any of formulae (1) to (3) when T_x ($x = \text{Nb}, \text{V}, \text{or Ti}$) is set to a temperature represented by any of the formulae (1) to (3); hot rolling at a finishing temperature of 750°C or higher and $1,000^\circ\text{C}$ or lower to yield a steel plate; and subsequently cooling at an average cooling rate of 1.0°C/s or more on the surface of the steel plate to 650°C from a lower temperature of either (finishing temperature $- 50^\circ\text{C}$) or a cooling start temperature.

$$T_{\text{Nb}} (^\circ\text{C}) = 7500 / [3.0 - \log_{10}([\% \text{Nb}] \times [\% \text{C}])] - 273 \quad (1)$$

$$T_{\text{V}} (^\circ\text{C}) = 10800 / [7.2 - \log_{10}([\% \text{V}] \times [\% \text{C}])] - 273 \quad (2)$$

$$T_{\text{Ti}} (^\circ\text{C}) = 7000 / [2.8 - \log_{10}([\% \text{Ti}] \times [\% \text{C}])] - 273 \quad (3)$$

where: $[\% \text{Nb}]$, $[\% \text{V}]$, $[\% \text{Ti}]$, and $[\% \text{C}]$ represent contents (mass%) of Nb, V, Ti, and C, respectively, in steel; and when an element is not contained, calculation is performed by setting the corresponding atomic symbol in the formulae to 0.

[0011] In the present invention, "high strength" means the strength of 400 MPa or higher in yield stress. Moreover, in the present invention, "cryogenic toughness" means low-temperature toughness, in other words, an absorbed energy vE_{-196} in a Charpy impact test at -196°C of 50 J or higher. Further, in the present invention, "excellent resistance to stress corrosion cracking" means a fracture stress of 500 MPa or higher when a test in accordance with a slow strain rate test method based on NACE Standard TM0111-2011 is performed by immersing in artificial seawater (chloride ion concentration of 18,000 ppm) at 23°C and performing a constant-rate tensile test at a strain rate of 4×10^{-7} inch/sec.

Advantageous Effects of Invention

[0012] According to the present invention, a high-Mn steel plate having excellent resistance to stress corrosion cracking and cryogenic toughness is obtained. A high-Mn steel plate of the present invention contributes greatly to enhanced safety and lifetime of steel structures used in a cryogenic environment, such as liquefied gas storage tanks, and exerts industrially remarkable effects. In addition, the high-Mn steel plate has excellent economic efficiency without causing lowered productivity or increased manufacturing costs.

Description of Embodiments

[0013] Hereinafter, embodiments of the present invention will be described. The present invention, however, is not limited to the following embodiments.

[Component Composition]

[0014] First, the component composition of a steel plate of the present invention and reasons for limiting the component composition will be described. In the present invention, to ensure excellent resistance to stress corrosion cracking, the component composition of a steel plate is specified as follows. Herein, the symbol % that represents the component composition means mass% unless otherwise indicated.

C: 0.20 to 0.70%

[0015] C is an inexpensive austenite stabilizing element and an important element for obtaining austenite. To achieve such an effect, C content of 0.20% or more is required. Meanwhile, when the content exceeds 0.70%, Cr carbide and a Nb-, V-, and/or Ti-based carbide are formed excessively, thereby impairing low-temperature toughness and resistance to stress corrosion cracking. Accordingly, C is set to 0.20 to 0.70%, preferably 0.25% or more and 0.60% or less, and more preferably 0.30% or more and 0.55% or less.

Si: 0.05 to 1.0%

[0016] Si is essential in steel making due to its action as a deoxidizing agent and further has an effect of increasing

strength of a steel plate by solid solution strengthening through dissolution in steel. To obtain such an effect, Si content of 0.05% or more is required. Meanwhile, when the content exceeds 1.0%, weldability deteriorates and SCC resistance is also affected. Accordingly, Si is set to 0.05 to 1.0%, preferably 0.07% or more and 0.50% or less, and more preferably 0.15% or more and 0.45% or less.

Mn: 15 to 30%

[0017] Mn is a relatively inexpensive austenite stabilizing element. In the present invention, Mn is an important element for achieving both strength and cryogenic toughness. To obtain such an effect, Mn content of 15% or more is required. Meanwhile, when the content exceeds 30%, an effect of improving cryogenic toughness levels off and increased alloying costs result. In addition, weldability and cutting properties deteriorate. Further, segregation is promoted, and the occurrence of stress corrosion cracking is thus promoted. Accordingly, Mn is set to 15 to 30%, preferably 18% or more and 28% or less, and more preferably 20% or more and 27% or less.

P: 0.028% or less

[0018] When P content exceeds 0.028%, P is segregated at grain boundaries and becomes initiation sites of stress corrosion cracking. Accordingly, the upper limit is set to 0.028% and P is desirably decreased as much as possible. P is thus set to 0.028% or less. Meanwhile, an excessive decrease in P results in soaring refining costs and economic disadvantages. Accordingly, P is desirably set to 0.002% or more. Preferably, P is set to 0.005% or more and 0.024% or less.

S: 0.02% or less

[0019] Since S impairs low-temperature toughness and ductility of a base metal, the upper limit is set to 0.02% and S is desirably decreased as much as possible. Accordingly, S is set to 0.02% or less. Meanwhile, an excessive decrease in S results in soaring refining costs and economic disadvantages. Accordingly, S is set to desirably 0.001% or more and preferably 0.002% or more. S is set to preferably 0.018% or less and more preferably 0.010% or less.

Al: 0.01 to 0.1%

[0020] Al acts as a deoxidizing agent and is most widely used in a deoxidation process of molten steel for steel plates. In addition, Al has an effect of suppressing coarsening of crystal grains by fixing N dissolved in steel to form AlN. Together with such an effect, Al also has an effect of suppressing deterioration in toughness due to a decrease in dissolved N. To obtain such effects, Al content of 0.01% or more is required. Meanwhile, when Al content exceeds 0.1%, Al is mixed into a weld metal portion during welding, thereby impairing toughness of the weld metal. Al is thus set to 0.1% or less. Accordingly, Al is set to 0.01 to 0.1% and preferably 0.02% or more and 0.07% or less.

Cr: 0.5 to 7.0%

[0021] Cr is an element effective for stabilizing austenite through its addition in an appropriate amount and for enhancing cryogenic toughness and base metal strength. Moreover, in the present invention, Cr is an important element that enhances resistance to stress corrosion cracking through a decreased amount of hydrogen that penetrates a steel plate through its effect of closely forming rust on a base metal surface in a salt water environment. To obtain such effects, Cr content of 0.5% or more is required. Meanwhile, when the content exceeds 7.0%, low-temperature toughness and resistance to stress corrosion cracking deteriorate due to formation of Cr carbide. Cr is thus set to 0.5 to 7.0%. Cr is set to preferably 1.0% or more, more preferably 1.2% or more, and further preferably 2.5% or more. Meanwhile, Cr is set to preferably 6.0% or less, more preferably 5.7% or less, and further preferably 5.5% or less.

Ni: 0.03 to 0.30%

[0022] Ni is a representative austenite stabilizing element and is an element effective for enhancing cryogenic toughness and base metal strength. Moreover, in the present invention, Ni is an important element that enhances resistance to stress corrosion cracking through a decreased amount of hydrogen that penetrates a steel plate through its effect of closely forming rust on a base metal surface in a salt water environment. To obtain such effects, Ni content of 0.03% or more is required. Meanwhile, when the content exceeds 0.30%, the alloying costs increase, and further, an effect of enhancing resistance to stress corrosion cracking levels off. Ni is thus set to 0.03 to 0.30%. Preferably, Ni is set to 0.25% or less and 0.04% or more. More preferably, Ni is set to 0.23% or less and 0.05% or more. Further preferably, Ni is set

to 0.21% or less.

N: 0.0010 to 0.0200%

[0023] N is an austenite stabilizing element and is an element effective for enhancing cryogenic toughness. Moreover, N has an effect of suppressing stress corrosion cracking as trapping sites of diffusible hydrogen through bonding with Nb, V, and/or Ti to precipitate as a nitride or a carbonitride. To obtain such effects, N content of 0.0010% or more is required. Meanwhile, when the content exceeds 0.0200%, such a nitride or a carbonitride coarsens, thereby impairing toughness. Accordingly, N is set to 0.0010 to 0.0200%. Preferably, N is set to 0.0020% or more and 0.0150% or less. More preferably, N is set to 0.0030% or more and 0.0170% or less.

One or two or More of Nb: 0.003 to 0.030%, V: 0.03 to 0.10%, and Ti: 0.003 to 0.040%

Nb: 0.003 to 0.030%

[0024] Nb is an element that has an effect of suppressing stress corrosion cracking through precipitation as a carbonitride (including a carbide), which is effective as trapping sites of diffusible hydrogen. To obtain such an effect, Nb content of 0.003% or more is required. Meanwhile, when Nb content exceeds 0.030%, a coarse carbonitride is precipitated and becomes the origin of breakage in some cases. Moreover, coarsened precipitates impair base metal toughness in some cases. Accordingly, if contained, Nb is set to 0.003 to 0.030%. Nb is set to preferably 0.005% or more and more preferably 0.007% or more. Meanwhile, Nb is set to preferably 0.025% or less and more preferably 0.022% or less.

V: 0.03 to 0.10%

[0025] V is an element that has an effect of suppressing stress corrosion cracking through precipitation as a carbonitride, which is effective as trapping sites of diffusible hydrogen. To obtain such an effect, V content of 0.03% or more is required. Meanwhile, when V content exceeds 0.10%, a coarse carbonitride is precipitated and becomes the origin of breakage in some cases. Moreover, coarsened precipitates impair base metal toughness in some cases. Accordingly, if contained, V is set to 0.03 to 0.10%. V is set to preferably 0.04% or more and more preferably 0.05% or more. Meanwhile, V is set to preferably 0.09% or less, more preferably 0.08% or less, and further preferably 0.07% or less.

Ti: 0.003 to 0.040%

[0026] Ti is an element that has an effect of suppressing stress corrosion cracking through precipitation as a nitride or a carbonitride, which is effective as trapping sites of diffusible hydrogen. To obtain such an effect, Ti content of 0.003% or more is required. Meanwhile, when Ti content exceeds 0.040%, a precipitate coarsens, thereby impairing base metal toughness in some cases. In addition, a coarse carbonitride is precipitated and becomes the origin of breakage in some cases. Accordingly, if contained, Ti is set to 0.003 to 0.040%. Ti is set to preferably 0.005% or more and more preferably 0.007% or more. Meanwhile, Ti is set to preferably 0.035% or less and more preferably 0.032% or less.

[0027] The balance is iron and incidental impurities. Examples of the incidental impurities include O and H, and the total of 0.01% or less is tolerable.

[0028] Further, in view of deterioration in low-temperature toughness, O and S are preferably specified as follows.

O: 0.0005 to 0.0070%

[0029] When O content exceeds 0.0070%, coarse inclusions are formed with Al, thereby impairing low-temperature toughness. Accordingly, the upper limit is set to 0.0070% and O is desirably decreased as much as possible. Preferably, O is set to 0.0060% or less. Meanwhile, an excessive decrease in O results in soaring refining costs and economic disadvantages. Accordingly, O is set to 0.0005% or more and preferably 0.0008% or more.

O/S < 1

[0030] The balance of O and S enhances resistance to stress corrosion cracking through formation of, together with Al, Ti, and Mn, an oxide, a sulfide, and a complex precipitate thereof, which effectively act as trapping sites of diffusible hydrogen. To obtain such an effect, O/S is set to less than 1. When O/S is 1 or more, there is a risk of formation of a coarse oxysulfide, thereby impairing low-temperature toughness. Accordingly, in the present invention, O/S is set to less than 1 to ensure low-temperature toughness.

[0031] The characteristics intended to achieve by the present invention can be obtained from the above-described

essential elements. In the present invention, to further enhance strength and low-temperature toughness, the following elements may be contained as necessary, in addition to the above-described essential elements.

One or two of Mo: 0.05 to 2.0% and W: 0.05 to 2.0%

Mo: 0.05 to 2.0%

[0032] Mo is a useful element for increasing strength of a base metal and may be contained as necessary. To obtain such an effect, Mo is preferably contained at 0.05% or more. Meanwhile, the content exceeding 2.0% adversely affects toughness and resistance to weld cracking in some cases. Mo is thus preferably set to 2.0% or less. Accordingly, if contained, Mo is set to 0.05 to 2.0%. More preferably, Mo is set to 0.07% or more and 1.7% or less.

W: 0.05 to 2.0%

[0033] W is a useful element for increasing strength of a base metal and may be contained as necessary. To obtain such an effect, W is preferably contained at 0.05% or more. Meanwhile, the content exceeding 2.0% adversely affects toughness and resistance to weld cracking in some cases. W is thus preferably set to 2.0% or less. Accordingly, if contained, W is set to 0.05 to 2.0%. More preferably, W is set to 0.07% or more and 1.5% or less.

One or two or More of Ca: 0.0005 to 0.0050%, Mg: 0.0005 to 0.0050%, and REM: 0.0010 to 0.0200%

Ca: 0.0005 to 0.0050%

[0034] Ca is a useful element for morphology control of an inclusion and may be contained as necessary. Morphology control of an inclusion herein means making an elongated sulfide inclusion into a granular inclusion. Through such morphology control of an inclusion, ductility, toughness, and resistance to sulfide stress corrosion cracking are enhanced. To obtain such an effect, Ca is preferably contained at 0.0005% or more. Meanwhile, when the content exceeds 0.0050%, the amount of nonmetal inclusions increases. Consequently, ductility, toughness, and resistance to sulfide stress corrosion cracking rather deteriorate in some cases. In addition, economic disadvantages result in some cases. Accordingly, if contained, Ca is set to 0.0005 to 0.0050%. More preferably, Ca is set to 0.0010% or more and 0.0040% or less.

Mg: 0.0005 to 0.0050%

[0035] Mg is useful as an element that contributes to improved resistance to sulfide stress corrosion cracking and may be contained as necessary. To obtain such an effect, Mg is preferably contained at 0.0005% or more. Meanwhile, when the content exceeds 0.0050%, the above-mentioned effect levels off and the effect commensurate with the content cannot be expected in some cases. In addition, economic disadvantages result in some cases. Accordingly, if contained, Mg is set to 0.0005 to 0.0050%. More preferably, Mg is set to 0.0010% or more and 0.0040% or less.

REM: 0.0010 to 0.0200%

[0036] REM is useful as an element that contributes to improved resistance to sulfide stress corrosion cracking and may be contained as necessary. To obtain such an effect, REM is preferably contained at 0.0010% or more. Meanwhile, when the content exceeds 0.0200%, the above-mentioned effect levels off and the effect commensurate with the content cannot be expected in some cases. Accordingly, if contained, REM is set to 0.0010 to 0.0200%. More preferably, REM is set to 0.0020% or more and 0.0150% or less.

[Microstructure]

[0037] Next, the microstructure near a steel plate surface, which is an important requirement for a steel plate of the present invention, will be described.

[0038] Microstructure 0.5 mm Under Steel Plate Surface Including Austenite as Base Phase, Where 25% or More of Austenite, in Area Ratio, Has Equivalent Circle Diameter of 10 μm or More and Aspect Ratio of Major Axis to Minor Axis of 3 or More

[0039] In the present invention, the base phase of the microstructure 0.5 mm under the steel plate surface is austenite. In the austenite, 25% or more, in area ratio, is austenite having an equivalent circle diameter of 10 μm or more and an aspect ratio of a major axis to a minor axis of 3 or more. Because of this, deformation bands inside crystal grains, in addition to grain boundaries near a steel plate surface layer, effectively act as trapping sites of diffusible hydrogen,

thereby effectively acting against stress corrosion cracking. Consequently, suppression of stress corrosion cracking can be enhanced remarkably. Moreover, yield stress is also enhanced. Preferably, the area ratio is set to 30% or more. Meanwhile, when the area ratio exceeds 95%, the strength of a steel material increases excessively, and base metal toughness deteriorates in some cases. Accordingly, the area ratio is set to preferably 95% or less, more preferably 94% or less, further preferably 90% or less, and still further preferably 85% or less.

[0040] When an equivalent circle diameter is less than 10 μm or an aspect ratio of a major axis to a minor axis is less than 3, a desirable yield stress cannot be achieved. In addition, deformation bands inside crystal grains that effectively act as trapping sites of diffusible hydrogen cannot be obtained, and resistance to stress corrosion cracking deteriorates. Consequently, the above-described effects cannot be obtained. The above-mentioned equivalent circle diameter, area ratio, and aspect ratio of austenite can be measured by the methods in the Examples section described hereinafter.

[0041] In the present invention, 0.5 mm under a steel plate surface means cross-sections parallel to the rolling direction at positions 0.5 mm from the front and rear surfaces of a steel plate in the thickness direction. Moreover, in the present invention, even when the above-described microstructure exists in a cross-section parallel to the rolling direction within a $\pm 5\%$ range of a position 0.5 mm under a steel plate surface, the above-described effects can similarly be obtained. Accordingly, in the present invention, 0.5 mm under a steel plate surface means that the above-described microstructure exists in a cross-section parallel to the rolling direction anywhere within a $\pm 5\%$ range of positions 0.5 mm from the front and rear surfaces of the steel plate in the thickness direction. The front and rear surfaces refer to not only intact surfaces of a finished product, but also steel plate surfaces that have been treated such that a cumulative degree of a crystal can be measured. For example, when the outermost surfaces of a steel plate are covered with scale, surfaces after scale have been removed are meant.

[0042] Microstructure 0.5 mm Under Steel Plate Surface Further Including, Within Microstructure, Total Number of $2 \times 10^2/\text{mm}^2$ or more of Carbide, Nitride, and Carbonitride That Contains one or two or More of Nb, V, and Ti and That Have Equivalent Circle Diameter of 0.01 to 0.5 μm

[0043] The state of existence of a carbide, a nitride, and a carbonitride (hereinafter, referred to as Nb-, V-, and/or Ti-based precipitates) containing one or two or more of Nb, V, and Ti in the microstructure 0.5 mm under a steel plate surface of the present invention will be described. Herein, a carbide, a nitride, and a carbonitride containing one or two or more of Nb, V, and Ti refer to: a carbide containing one or two or more of Nb, V, and Ti; a nitride containing one or two or more of Nb, V, and Ti; and a carbonitride containing one or two or more of Nb, V, and Ti.

[0044] The particle size of the Nb-, V-, and/or Ti-based precipitates is set to 0.01 to 0.5 μm in equivalent circle diameter. When the particle size is less than 0.01 μm , an effect of suppressing hydrogen embrittlement cracking as trapping sites of diffusible hydrogen levels off. Moreover, controlling the particle size to be less than 0.01 μm in actual manufacture results in excessively increased manufacturing load and increased manufacturing costs. Meanwhile, when the particle size exceeds 0.5 μm , low-temperature toughness deteriorates. Moreover, it is impossible to obtain an effect of suppressing hydrogen embrittlement cracking as trapping sites of diffusible hydrogen. Preferably, the particle size is set to 0.03 μm or more and 0.4 μm or less.

[0045] When the total number of Nb-, V-, and/or Ti-based precipitates having the above-described particle size is less than $2 \times 10^2/\text{mm}^2$ in the microstructure 0.5 mm under a steel plate surface, precipitates that act as trapping sites of diffusible hydrogen are insufficient. Consequently, an effect of suppressing hydrogen embrittlement cracking as trapping sites of diffusible hydrogen cannot be obtained. Accordingly, the total number is set to $2 \times 10^2/\text{mm}^2$ or more and preferably $5 \times 10^2/\text{mm}^2$ or more. The above-mentioned number density and equivalent circle diameter of the Nb-, V-, and/or Ti-based precipitates can be measured by the methods in the Examples section described hereinafter.

[0046] When martensite and other microstructures coexist with austenite in the microstructure 0.5 mm under a steel plate surface, low-temperature toughness deteriorates.

Accordingly, austenite is set to 90% or more. In view of deterioration in low-temperature toughness, the area ratio of martensite and other microstructures is preferably small. The above-mentioned martensite and other microstructures herein refer to martensite, bainite, ferrite, and pearlite. When martensite and other microstructures coexist with austenite, the total area ratio of each microstructure is desirably set to 10% or less based on the entire steel plate.

[Manufacturing Conditions]

[0047] Next, a manufacturing method for a steel plate of the present invention will be described. A steel plate according to the present invention is suitable for a high-Mn steel plate having a thickness of 4 mm or more.

[0048] A steel plate of the present invention is obtained through: heating of steel having the above-described component composition to a temperature range of $(T_x - 50)^\circ\text{C}$ or higher and $(T_x + 200)^\circ\text{C}$ or lower as a surface temperature of the steel for any one or more of T_x ($^\circ\text{C}$) defined by any of formulae (1) to (3) when T_x ($x = \text{Nb, V, or Ti}$) is set to a temperature represented by any of the formulae (1) to (3) described hereinafter; hot rolling at a finishing temperature of 750°C or higher and $1,000^\circ\text{C}$ or lower to yield a steel plate; and subsequently cooling at an average cooling rate of 1.0°C/s or more on the surface of the steel plate to 650°C from a lower temperature of either (finishing temperature - 50°C) or a

cooling start temperature.

[0049] Hereinafter, the details will be described. In the description, the symbol "°C" concerning a temperature refers to a temperature on a steel plate surface or a steel surface.

[0050] In a high-Mn steel plate according to the present invention, molten steel having the above-described component composition can be refined by a publicly known refining method, such as by using a converter or an electric furnace. Moreover, secondary refining may be performed in a vacuum degasser. Subsequently, steel, such as a slab of a pre-determined size, is preferably formed by a continuous casting method or a publicly known casting method, such as an ingot casting/slabbing method.

[0051] Slab After Casting: Heating of Obtained Steel, Without Cooling to Room Temperature or After Cooling to Room Temperature, to Temperature Range of $(T_x - 50)^\circ\text{C}$ or Higher and $(T_x + 200)^\circ\text{C}$ or Lower as Surface Temperature of Steel for any one or More of T_x ($^\circ\text{C}$) Defined by any of Formulae (1) to (3) When T_x ($x = \text{Nb}, \text{V}, \text{or Ti}$) is set to Temperature Represented by any of Formulae (1) to (3)

$$T_{\text{Nb}} (^\circ\text{C}) = 7500 / [3.0 - \log_{10}([\% \text{Nb}] \times [\% \text{C}])] - 273 \quad (1)$$

$$T_{\text{V}} (^\circ\text{C}) = 10800 / [7.2 - \log_{10}([\% \text{V}] \times [\% \text{C}])] - 273 \quad (2)$$

$$T_{\text{Ti}} (^\circ\text{C}) = 7000 / [2.8 - \log_{10}([\% \text{Ti}] \times [\% \text{C}])] - 273 \quad (3)$$

where: $[\% \text{Nb}]$, $[\% \text{V}]$, $[\% \text{Ti}]$, and $[\% \text{C}]$ represent contents (mass%) of Nb, V, Ti, and C, respectively, in steel; and when an element is not contained, calculation is performed by setting the corresponding atomic symbol in the formulae to 0.

[0052] When the heating temperature is lower than $(T_x - 50)^\circ\text{C}$, deformation resistance in hot rolling increases while decreasing reduction per pass. Consequently, an increased number of rolling passes results in low rolling efficiency. At the same time, casting defects within steel (slab) cannot be press-bonded in some cases. Moreover, Nb-, V-, and Ti-containing crystals that have been formed unevenly within steel in the refining stage remain within a steel plate even after the end of rolling. Accordingly, desirable Nb-, V-, and Ti-containing precipitates cannot be obtained and resistance to stress corrosion cracking deteriorates.

[0053] Meanwhile, when the heating temperature exceeds $(T_x + 200)^\circ\text{C}$, surface scratches readily arise due to scale formed during heating, thereby increasing a load of repair after rolling. Moreover, a steel surface is excessively decarburized, and a steel plate surface after rolling thus becomes martensite. Consequently, bendability and/or hydrogen embrittlement resistance deteriorate. Further, due to coarsening of austenite grains, the intended microstructure cannot be obtained.

[0054] Accordingly, the heating temperature of steel is set to $(T_x - 50)^\circ\text{C}$ or higher and $(T_x + 200)^\circ\text{C}$ or lower. Preferably, the heating temperature is set to $(T_x - 30)^\circ\text{C}$ or higher and $(T_x + 180)^\circ\text{C}$ or lower. In case of direct rolling, hot rolling is started while steel is at $(T_x - 50)^\circ\text{C}$ or higher and $(T_x + 200)^\circ\text{C}$ or lower.

[0055] Herein, the statement "heating to a temperature range of $(T_x - 50)^\circ\text{C}$ or higher and $(T_x + 200)^\circ\text{C}$ or lower as a surface temperature of the steel for any one or more of T_x ($^\circ\text{C}$) defined by any of formulae (1) to (3) when T_x ($x = \text{Nb}, \text{V}, \text{or Ti}$) is set to a temperature represented by any of the formulae (1) to (3)" of the present invention means that when the above-described component composition contains two elements of Nb and V, for example, the heating temperature may satisfy either one or more of $(T_{\text{Nb}} - 50)^\circ\text{C}$ or higher and $(T_{\text{Nb}} + 200)^\circ\text{C}$ or lower, or $(T_{\text{V}} - 50)^\circ\text{C}$ or higher and $(T_{\text{V}} + 200)^\circ\text{C}$ or lower. In other words, either of the heating temperatures may be selected.

Hot Rolling: Steel Plate Having Desirable Thickness is Obtained by Setting Finishing Temperature to 750°C or Higher and $1,000^\circ\text{C}$ or Lower in Finish Rolling After Roughening

[0056] When a finishing temperature in hot rolling exceeds $1,000^\circ\text{C}$, recrystallization of austenite near a steel plate surface readily progresses and the desirable microstructure cannot be obtained. Consequently, resistance to stress corrosion cracking deteriorates. Meanwhile, when a finishing temperature is set to lower than 750°C , hot deformation resistance increases excessively, thereby increasing a load on a rolling mill. In addition, low rolling efficiency and increased manufacturing costs result. Accordingly, a finishing temperature in hot rolling is set to 750°C or higher and $1,000^\circ\text{C}$ or lower, preferably 800°C or higher and 950°C or lower, and more preferably 940°C or lower.

Cumulative Reduction of 10% or More and 50% or Less in Temperature Range of 850°C or Higher and (Tx - 50)°C or Lower in Finish Rolling (Preferable Condition)

[0057] When a cumulative reduction is less than 10% in the temperature range of 850°C or higher and (Tx - 50)°C or lower, there is a risk of failure in obtaining the target microstructure. Meanwhile, when the cumulative reduction exceeds 50%, efficiency in rolling decreases. Moreover, there is a risk that the strength increases excessively and low-temperature toughness deteriorates. Here, the cumulative reduction is a total reduction obtained by adding up a reduction in each rolling pass in the temperature range of 850°C or higher and (Tx - 50)°C or lower in finish rolling.

Cumulative Reduction of 5% or More and 60% or Less in Non-recrystallization Region (960°C or Lower) in Finish Rolling (More Preferable Condition)

[0058] When a cumulative reduction is less than 5% in the non-recrystallization region, there is a risk of failure in achieving the target strength. Meanwhile, when a cumulative reduction exceeds 60%, there is a risk that the yield stress increases excessively and low-temperature toughness deteriorates. Here, the cumulative reduction is a total reduction obtained by adding up a reduction in each rolling pass in the non-recrystallization region in finish rolling.

After End of Finish Rolling, Cooling at Average Cooling Rate of 1.0°C/s or More on Steel Plate Surface to 650°C From Lower Temperature of Either (Finishing Temperature - 50°C) or Cooling Start Temperature

[0059] When an average cooling rate on a steel plate surface is less than 1.0°C/s, a carbide coarsens due to retention at a high temperature for a long time, thereby decreasing the strength. In addition, Cr carbide is formed, thereby impairing toughness and resistance to stress corrosion cracking. Accordingly, the average cooling rate is set to preferably 1.0°C/s or more and more preferably 2.0°C/s or more. Meanwhile, when the average cooling rate exceeds 150.0°C/s, it becomes difficult to retain the shape of a steel plate. Accordingly, the average cooling rate is set to preferably 150.0°C/s or less, more preferably 120.0°C/s or less, and further preferably 100.0°C/s or less. Here, the average cooling rate is an average cooling rate to 650° from a lower temperature of either (finishing temperature - 50°C) or a cooling start temperature after the end of finish rolling.

[0060] In the present invention, it was newly found that controlling an average cooling rate in cooling is effective for suppressing precipitation of Cr carbide during cooling and thereby enhancing resistance to stress corrosion cracking.

[0061] Here, an average cooling rate in the temperature range from a finishing temperature to (finishing temperature - 50°C) is not particularly specified, but is preferably 1.0°C/s or less since formation of Nb-, V-, and/or Ti-based precipitates can be promoted. Moreover, an average cooling rate at lower than 650°C is not particularly specified, but is set to preferably less than 100.0°C/s from a viewpoint of preventing strain of a steel plate and more preferably 80.0°C/s or less.

EXAMPLES

[0062] Hereinafter, the present invention will be described in further detail with the Examples. The present invention, however, is not limited to the following Examples.

[0063] Steel slabs (slab thickness: 250 to 300 mm) were prepared to have various component compositions shown in Table 1-1 and Table 1-2 by a converter/ladle refining/continuous casting method. The steel slabs were heated at (Tx - 50)°C or higher and (Tx + 200)°C or lower (x = Nb, V, or Ti), then hot-rolled under manufacturing conditions shown in Table 2-1 and Table 2-2, and cooled under the manufacturing conditions shown in Table 2-1 and Table 2-2. Here, (Tx - 50)°C and (Tx + 200)°C for Nb, V, or V are each shown in Table 1-1 and Table 1-2.

[0064] The obtained 12 mm to 80 mm-thick hot-rolled steel plates underwent microstructure examination, a base metal tensile test, a base metal toughness test, and a stress corrosion cracking test in the following manner.

(1) Microstructure

[0065] In microstructure examination, a specimen for microstructure observation was taken from each of the obtained steel plates on a cross-section parallel to the rolling direction at a position 0.5 mm under the surface in the thickness direction, etched with an aqueous solution of sodium pyrosulfite (10 g Na₂S₂O₅ + 95 mL water solution), and imaged for the optical microscopic structure in five fields of view at a magnification of 500×. Subsequently, an area ratio of austenite, an equivalent circle diameter, and an aspect ratio were obtained from each of the obtained microstructure images by using an image analyzer.

Area Ratio of Austenite

[0066] The area ratio of austenite was obtained as a ratio of the area of austenite of 10 μm or more to the total area of austenite by performing austenite etching, imaging the microstructure at a magnification of 500 $\times$, tracing austenite grain boundaries, and performing image analysis.

Equivalent Circle Diameter of Austenite

[0067] As for the grain size of austenite, in other words, the equivalent circle diameter of austenite, the individual areas of austenite were first determined through image analysis of the above-mentioned microstructure images. The equivalent circle diameter was then calculated from individual areas.

Aspect Ratio of Austenite Grains

[0068] The aspect ratio of austenite grains was calculated as a ratio of the longest diameter (major axis) to the largest width orthogonal to the major axis (minor axis) for each austenite grain through observation under an optical microscope of the microstructure in which austenite grain boundaries were exposed by the above-mentioned etching.

Equivalent Circle Diameter of Nb-, V-, and/or Ti-Based Precipitates

[0069] In examination of the equivalent circle diameter of Nb-, V-, and/or Ti-based precipitates, ten fields of view were imaged at a magnification of 50,000 $\times$ under a transmission electron microscope on a cross-section parallel to the rolling direction at a position 0.5 mm under the surface of each steel plate in the thickness direction, and the area of each Nb-, V-, and/or Ti-based precipitate was determined through image analysis of these microstructure images. The equivalent circle diameter of Nb-, V-, and/or Ti-based precipitates was calculated from each area.

Number Density of Nb-, V-, and/or Ti-based Precipitates

[0070] In examination of the number density of Nb-, V-, and/or Ti-based precipitates, ten fields of view were imaged under a transmission electron microscope at a magnification of 50,000 $\times$ on the cross-section parallel to the rolling direction at a position 0.5 mm under the surface of each steel plate in the thickness direction, the number of Nb-, V-, and/or Ti-based precipitates having an equivalent circle diameter of 0.01 to 0.5 μm was counted per 1 mm^2 , and a total number density of Nb-, V-, and/or Ti-based precipitates was obtained.

(2) Tensile Characteristics of Base metals

[0071] The tensile characteristics were examined by taking JIS No. 5 tensile specimens from each of the obtained steel plates and performing a tensile test in accordance with JIS Z 2241 (1998). In the present invention, a specimen having a yield stress of 400 MPa or higher is evaluated as excellent base metal tensile characteristics (within the scope of the present invention). Specimens having excellent base metal tensile characteristics of the present invention had a tensile strength of 800 MPa or higher and total elongation of 30% or more.

(3) Base metal Toughness

[0072] The base metal toughness was evaluated by: taking Charpy V-notch specimens in accordance with JIS Z 2202 (1998) in a direction perpendicular to the rolling direction at a position of 1/4 thickness for each steel plate having a thickness of more than 20 mm or at a position 1/2 thickness for each steel plate having a thickness of 20 mm or less; performing a Charpy impact test for three specimens for each steel plate in accordance with JIS Z 2242 (1998); and obtaining an absorbed energy at -196°C . In the present invention, a steel plate having an average absorbed energy (vE_{-196}) of three specimens of 50 J or higher is evaluated as excellent base metal toughness (within the scope of the present invention). More preferably, the average absorbed energy (vE_{-196}) is 100 J or higher.

(4) Stress Corrosion Cracking Property

[0073] A stress corrosion cracking test was performed in accordance with a slow strain rate test method based on NACE Standard TM0111-2011. A test piece having a shape of notched Type A round bar was used. The test piece was immersed in artificial seawater (chloride ion concentration of 18,000 ppm) at 23°C and subjected to a constant-rate tensile test at a strain rate of 4×10^{-7} inch/sec. In the present invention, a test piece having a fracture stress of 500

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MPa or higher is evaluated as excellent resistance to stress corrosion cracking (within the scope of the present invention).
More preferably, a fracture stress is 600 MPa or higher.

[0074] The results obtained as above are shown in Table 3-1 and Table 3-2.

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[Table 1-1]

Steel No.	Component composition (mass%)																	(°C)					
	C	Si	Mn	P	S	Al	Cr	Ni	Nb	V	Ti	Mo	W	N	Ca	Mg	REM	T _{Nb-50}	T _{Nb+200}	T _{V-50}	T _{V+200}	T _{Ti-50}	T _{Ti+200}
1	0.428	0.39	27.3	0.015	0.0036	0.033	3.20	0.06	0.012	-	-	-	-	0.0026	-	-	-	1094.9	1344.9	-	-	-	-
2	0.541	0.55	20.6	0.011	0.0020	0.018	5.19	0.09	-	0.07	-	-	-	0.0118	-	-	-	-	-	929.7	1179.7	-	-
3	0.476	0.45	24.4	0.008	0.0012	0.035	4.70	0.11	-	-	0.008	-	-	0.0048	-	-	-	-	-	-	-	1018.2	1268.2
4	0.365	0.29	26.1	0.022	0.0019	0.031	1.90	0.25	0.006	-	0.024	-	-	0.0031	-	-	-	1002.2	1252.2	-	-	1118.1	1368.1
5	0.262	0.83	28.2	0.024	0.0050	0.051	6.12	0.08	0.022	0.06	-	0.51	-	0.0028	0.0022	-	-	1108.5	1358.5	876.5	1126.5	-	-
6	0.603	0.43	18.1	0.005	0.0012	0.032	0.81	0.14	-	0.03	0.012	-	0.11	0.0151	-	0.0014	-	-	-	884.7	1134.7	1093.9	1343.9
7	0.325	0.82	27.6	0.021	0.0029	0.040	3.88	0.05	0.012	0.05	0.021	0.24	0.08	0.0030	-	-	0.0057	1063.6	1313.6	878.4	1128.4	1086.6	1336.6
8	0.503	0.40	25.2	0.012	0.0014	0.057	4.28	0.12	0.006	-	0.013	-	-	0.0022	0.0018	-	-	1035.6	1285.6	-	-	1081.4	1331.4
9	0.297	0.14	20.6	0.023	0.0041	0.021	6.41	0.27	-	-	0.016	0.40	-	0.0072	-	-	-	-	-	-	-	1043.4	1293.4
10	0.546	0.31	28.0	0.012	0.0047	0.081	1.02	0.22	0.014	0.04	0.006	-	0.13	0.0025	-	-	-	1142.8	1392.8	895.9	1145.9	1001.6	1251.6
11	0.512	0.31	30.0	0.014	0.0036	0.021	2.52	0.18	-	0.03	0.008	-	-	0.0048	-	-	-	-	-	875.2	1125.2	1026.4	1276.4
12	0.132	0.51	24.3	0.012	0.0018	0.029	2.76	0.18	0.018	-	-	-	-	0.0039	-	-	-	1010.5	1260.5	-	-	-	-
13	0.840	0.44	26.1	0.008	0.0023	0.030	4.11	0.11	0.021	0.05	-	-	0.10	0.0031	-	-	-	1254.8	1504.8	936.2	1186.2	-	-
14	0.391	1.21	21.8	0.024	0.0031	0.040	5.82	0.09	-	0.04	0.011	-	-	0.0048	-	-	0.0032	-	-	876.2	1126.2	1031.9	1281.9
15	0.491	0.47	13.2	0.021	0.0020	0.033	3.96	0.10	0.009	0.07	-	0.21	0.11	0.0025	-	-	-	1077.6	1327.6	923.6	1173.6	-	-
16	0.496	0.68	33.1	0.014	0.0028	0.038	2.12	0.14	-	-	0.011	-	-	0.0055	0.0023	-	-	-	-	-	-	1059.5	1309.5
17	0.431	0.51	24.8	0.029	0.0058	0.019	0.12	0.08	0.015	-	-	-	-	0.0029	-	-	-	1122.2	1372.2	-	-	-	-
18	0.521	0.37	27.3	0.011	0.0073	0.049	9.20	0.12	-	0.05	0.016	0.08	-	0.0031	-	-	0.0055	-	-	906.5	1156.5	1111.7	1361.7
19	0.448	0.62	22.8	0.012	0.0013	0.030	3.69	0.02	-	0.07	-	-	0.09	0.0023	0.0018	-	-	-	-	917.9	1167.9	-	-
20	0.571	0.32	21.8	0.016	0.0047	0.022	4.19	0.13	0.021	0.03	-	-	-	0.0236	-	-	-	1201.0	1451.0	881.5	1131.5	-	-
21	0.481	0.39	25.6	0.023	0.0055	0.018	6.11	0.08	0.001	0.005	0.001	0.13	-	0.0029	-	0.0019	-	864.1	1114.1	776.9	1026.9	821.2	1071.2
22	0.367	0.62	25.0	0.007	0.0021	0.051	3.18	0.11	0.067	-	-	-	-	0.0068	-	-	-	1304.2	1554.2	-	-	-	-
23	0.318	0.40	28.1	0.010	0.0015	0.032	5.26	0.15	-	0.15	-	0.39	-	0.0031	-	-	-	-	-	944.4	1194.4	-	-
24	0.497	0.61	23.7	0.008	0.0020	0.015	3.76	0.17	-	-	0.071	-	0.11	0.0060	0.0030	-	-	-	-	-	-	1323.1	1573.1

Note 1: underlines indicate the outside of the scope of the present invention

Note 2: $T_{Nb}(^{\circ}C) = 7500 / \{3 \cdot 0 \cdot \log 10 ([\%Nb] \times [\%C])\} - 273 \dots (1)$ $T_{V}(^{\circ}C) = 10800 / \{7 \cdot 2 \cdot \log 10 ([\%V] \times [\%C])\} - 273 \dots (2)$ $T_{Ti}(^{\circ}C) = 7000 / \{2 \cdot 8 \cdot \log 10 ([\%Ti] \times [\%C])\} - 273 \dots (3)$

where: [%Nb], [%V], [%Ti], and [%C] represent contents (mass%) of Nb, V, Ti, and C, respectively, in steel; and when an element is not contained, calculation is performed by setting the corresponding atomic symbol in the formulae to 0.

[Table 1-2]

Steel No.	Component composition (mass%)																		(°C)					
	C	Si	Mn	P	S	Al	Cr	Ni	Nb	V	Ti	Mo	W	N	O	Ca	Mg	REM	T _{Nb-50}	T _{Nb+200}	T _{V-50}	T _{V+200}	T _{Ti-50}	T _{Ti+200}
25	0.428	0.39	27.3	0.015	0.0036	0.033	3.20	0.06	0.012	-	-	-	-	0.0026	0.0025	-	-	-	1094.9	1344.9	-	-	-	-
26	0.541	0.55	20.6	0.011	0.0020	0.018	5.19	0.09	-	0.07	-	-	-	0.0118	0.0014	-	-	-	-	-	929.7	1179.7	-	-
27	0.476	0.45	24.4	0.008	0.0012	0.035	4.70	0.11	-	-	0.008	-	-	0.0048	0.0010	-	-	-	-	-	-	-	1018.2	1268.2
28	0.365	0.29	26.1	0.022	0.0019	0.031	1.90	0.25	0.006	-	0.024	-	-	0.0031	0.0015	-	-	-	1002.2	1252.2	-	-	1118.1	1368.1
29	0.262	0.83	28.2	0.024	0.0050	0.051	6.12	0.08	0.022	0.06	-	0.51	-	0.0028	0.0033	0.0022	-	-	1108.5	1358.5	876.5	1126.5	-	-
30	0.603	0.43	18.1	0.005	0.0012	0.032	0.81	0.14	-	0.03	0.012	-	0.11	0.0151	0.0011	-	0.0014	-	-	-	884.7	1134.7	1093.9	1343.9
31	0.325	0.82	27.6	0.021	0.0029	0.040	3.88	0.05	0.012	0.05	0.021	0.24	0.08	0.0030	0.0025	-	-	0.0057	1063.6	1313.6	878.4	1128.4	1086.6	1336.6
32	0.503	0.40	25.2	0.012	0.0014	0.057	4.28	0.12	0.006	-	0.013	-	-	0.0022	0.0012	0.0018	-	-	1035.6	1285.6	-	-	1081.4	1331.4
33	0.297	0.14	20.6	0.023	0.0041	0.021	6.41	0.27	-	-	0.016	0.40	-	0.0072	0.0030	-	-	-	-	-	-	-	1043.4	1293.4
34	0.546	0.31	28.0	0.012	0.0047	0.081	1.02	0.22	0.014	0.04	0.006	-	0.13	0.0025	0.0044	-	-	-	1142.8	1392.8	895.9	1145.9	1001.6	1251.6
35	0.512	0.31	30.0	0.014	0.0036	0.021	2.52	0.18	-	0.03	0.008	-	-	0.0048	0.0025	-	-	-	-	-	875.2	1125.2	1026.4	1276.4
36	0.132	0.51	24.3	0.012	0.0018	0.029	2.76	0.18	0.018	-	-	-	-	0.0039	0.0015	-	-	-	1010.5	1260.5	-	-	-	-
37	0.840	0.44	26.1	0.008	0.0023	0.030	4.11	0.11	0.021	0.05	-	-	0.10	0.0031	0.0020	-	-	-	1254.8	1504.8	936.2	1186.2	-	-
38	0.391	1.21	21.8	0.024	0.0031	0.040	5.82	0.09	-	0.04	0.011	-	-	0.0048	0.0020	-	-	0.0032	-	-	876.2	1126.2	1031.9	1281.9
39	0.491	0.47	13.2	0.021	0.0020	0.033	3.96	0.10	0.009	0.07	-	0.21	0.11	0.0025	0.0011	-	-	-	1077.6	1327.6	923.6	1173.6	-	-
40	0.496	0.68	33.1	0.014	0.0028	0.038	2.12	0.14	-	-	0.011	-	-	0.0055	0.0021	0.0023	-	-	-	-	-	-	1059.5	1309.5
41	0.431	0.51	24.8	0.029	0.0058	0.019	9.20	0.08	0.015	-	-	-	-	0.0029	0.0044	-	-	-	1122.2	1372.2	-	-	-	-
42	0.521	0.37	27.3	0.011	0.0073	0.049	9.20	0.12	-	0.05	0.016	0.08	-	0.0031	0.0036	-	-	0.0055	-	-	906.5	1156.5	1111.7	1361.7
43	0.448	0.62	22.8	0.012	0.0013	0.030	3.69	0.02	-	0.07	-	-	0.09	0.0023	0.0011	0.0018	-	-	-	-	-	917.9	1167.9	-
44	0.571	0.32	21.8	0.016	0.0047	0.022	4.19	0.13	0.021	0.03	-	-	-	0.0236	0.0028	-	-	-	1201.0	1451.0	881.5	1131.5	-	-
45	0.481	0.39	25.6	0.023	0.0055	0.018	6.11	0.08	0.001	0.005	0.001	0.13	-	0.0029	0.0033	-	0.0019	-	864.1	1114.1	776.9	1026.9	821.2	1071.2
46	0.367	0.62	25.0	0.007	0.0021	0.051	3.18	0.11	0.067	-	-	-	-	0.0068	0.0014	-	-	-	1304.2	1554.2	-	-	-	-
47	0.318	0.40	28.1	0.010	0.0015	0.032	5.26	0.15	-	0.15	-	0.39	-	0.0031	0.0013	-	-	-	-	-	944.4	1194.4	-	-
48	0.497	0.61	23.7	0.008	0.0020	0.015	3.76	0.17	-	-	0.071	-	0.11	0.0060	0.0017	0.0030	-	-	-	-	-	-	1323.1	1573.1
49	0.382	0.31	24.8	0.024	0.0045	0.029	1.84	0.09	-	-	0.009	-	-	0.0079	0.0075	-	-	-	-	-	-	-	1006.9	1256.9

Note 1: underlines indicate the outside of the scope of the present invention

Note 2: $T_{Nb}(^{\circ}C) = 7500 / \{3.0 - \log_{10}([\%Nb] \times [\%C])\} - 273 \dots (1)$ $T_V(^{\circ}C) = 10800 / \{7.2 - \log_{10}([\%V] \times [\%C])\} - 273 \dots (2)$ $T_{Ti}(^{\circ}C) = 7000 / \{2.8 - \log_{10}([\%Ti] \times [\%C])\} - 273 \dots (3)$

where: [%Nb], [%V], [%Ti], and [%C] represent contents (mass%) of Nb, V, Ti, and C in steel, respectively; and when an element is not contained, calculation is performed by setting the corresponding atomic symbol in the formulae to 0.

[Table 2-1]

Cooling										
Steel plate No.	Steel No.	Slab thickness (mm)	Plate thickness (mm)	Hot rolling			Cooling			
				Heating temperature (°C)	Finishing temperature (°C)	Cumulative reduction at 850°C or higher and (Tx - 50)°C or lower (%)	Accelerated cooling start temperature (°C)	Accelerated cooling end temperature (°C)	Average cooling rate to 650°C from lower temperature of either (finishing temperature - 50°C) or a cooling start temperature (°C/s)	Cooling method
1-1	1	250	25	1150	900	40	850	600	75.0	Water cooling
1-2	1	250	12	1150	850	40	-	-	2.5	Air cooling
1-3	1	250	12	1100	<u>720</u>	40	-	-	2.5	Air cooling
1-4	1	250	60	1250	950	40	900	600	15.0	Water cooling
1-5	1	250	60	1250	<u>1050</u>	40	1000	650	15.0	Water cooling
1-6	1	250	60	1250	950	40	-	-	<u>0.5</u>	Air cooling
1-7	1	250	12	<u>1050</u>	760	40	-	-	2.5	Air cooling
2-1	2	250	25	1150	900	40	850	600	75.0	Water cooling
2-2	2	250	25	<u>1280</u>	950	40	850	600	75.0	Water cooling
3	3	250	12	1150	780	40	700	500	5.0	Water cooling
4	4	300	80	1130	930	40	910	550	6.0	Water cooling
5	5	250	30	1150	880	40	800	400	10.0	Water cooling

(continued)

Steel plate No.	Steel No.	Slab thickness (mm)	Plate thickness (mm)	Hot rolling			Cooling			
				Heating temperature (°C)	Finishing temperature (°C)	Cumulative reduction at 850°C or higher and (Tx - 50)°C or lower (%)	Accelerated cooling start temperature (°C)	Accelerated cooling end temperature (°C)	Average cooling rate to 650°C from lower temperature of either (finishing temperature - 50°C) or a cooling start temperature (°C/s)	Cooling method
6	6	250	30	1150	900	40	850	600	75.0	Water cooling
7	7	250	25	1120	940	40	930	350	30.0	Water cooling
8	8	250	30	1200	900	40	850	600	75.0	Water cooling
9	9	250	12	1150	780	40	700	500	5.0	Water cooling
10	10	250	30	1150	900	40	850	600	40.0	Water cooling
11	11	250	30	1150	900	40	850	600	40.0	Water cooling
12	12	250	16	1150	880	40	840	300	75.0	Water cooling
13	13	250	25	1150	900	40	850	600	70.0	Water cooling
14	14	300	80	1100	930	40	910	550	6.0	Water cooling
15	15	250	25	1200	940	40	930	350	55.0	Water cooling
16	16	300	80	1150	930	40	910	550	6.0	Water cooling

(continued)

Steel plate No.	Steel No.	Slab thickness (mm)	Plate thickness (mm)	Hot rolling			Cooling			
				Heating temperature (°C)	Finishing temperature (°C)	Cumulative reduction at 850°C or higher and (Tx - 50)°C or lower (%)	Accelerated cooling start temperature (°C)	Accelerated cooling end temperature (°C)	Average cooling rate to 650°C from lower temperature of either (finishing temperature - 50°C) or a cooling start temperature (°C/s)	Cooling method
17	17	250	12	1150	780	40	700	500	5.0	Water cooling
18	18	250	12	1150	850	40	-	-	2.5	Air cooling
19	19	250	25	1100	960	40	930	350	55.0	Water cooling
20	20	250	25	1100	900	40	850	600	75.0	Water cooling
21	21	300	25	1100	940	40	880	450	40.0	Water cooling
22	22	250	16	<u>1150</u>	850	40	810	300	30.0	Water cooling
23	23	250	25	1150	900	40	850	600	70.0	Water cooling
24	24	250	12	<u>1150</u>	780	40	700	500	5.0	Water cooling
Note: underlines indicate the outside of the scope of the present invention										

[Table 2-2]

Cooling											
Hot rolling											
Steel plate No.	Steel No.	Slab thickness (mm)	Plate thickness (mm)	Heating temperature (°C)	Finish rolling temperature (°C)	Cumulative reduction at 850°C or higher and (Tx - 50)°C or lower) (%)	Cumulative reduction in non-recrystallization region (%)	Accelerated cooling start temperature (°C)	Accelerated cooling end temperature (°C)	Average cooling rate to 650°C from (finish rolling temperature - 50°C) (°C/s)	Cooling method
25-1	25	250	25	1150	900	20	35	850	600	75	Water cooling
25-2	25	250	12	1150	850	15	40	-	-	2.5	Air cooling
25-3	25	250	12	1100	720	50	55	-	-	2.5	Air cooling
25-4	25	250	60	1250	950	12	8	900	600	15	Water cooling
25-5	25	250	60	1250	1050	0	0	1000	650	15	Water cooling
25-6	25	250	60	1250	950	12	10	-	-	0.5	Air cooling
25-7	25	250	12	1050	760	30	55	-	-	2.5	Air cooling
25-8	25	250	60	1250	950	2	2	900	600	15	Water cooling
26-1	26	250	25	1150	900	50	50	850	600	75	Water cooling
26-2	26	250	25	1280	950	40	10	850	600	75	Water cooling
26-3	26	250	25	1150	900	70	20	850	600	75	Water cooling
27	27	250	12	1150	780	20	50	700	500	5	Water cooling

(continued)

Steel plate No.	Steel No.	Slab thickness (mm)	Plate thickness (mm)	Hot rolling				Cooling			
				Heating temperature (°C)	Finish rolling temperature (°C)	Cumulative reduction at 850°C or higher and (Tx - 50)°C or lower (%)	Cumulative reduction in non-recrystallization region (%)	Accelerated cooling start temperature (°C)	Accelerated cooling end temperature (°C)	Average cooling rate to 650°C from (finish rolling temperature - 50°C) (°C/s)	Cooling method
28	28	300	80	1130	930	15	15	910	550	6	Water cooling
29	29	250	30	1150	880	25	40	800	400	10	Water cooling
30	30	250	30	1150	900	40	20	850	600	75	Water cooling
31	31	250	25	1120	940	15	15	930	350	30	Water cooling
32	32	250	30	1200	900	30	35	850	600	75	Water cooling
33	33	250	12	1150	780	20	45	700	500	5	Water cooling
34	34	250	30	1150	900	25	25	850	600	40	Water cooling
35	35	250	30	1150	900	35	35	850	600	40.0	Water cooling
36	36	250	16	1150	880	30	25	840	300	75	Water cooling
37	37	250	25	1150	900	25	20	850	600	70	Water cooling
38	38	300	80	1100	930	15	10	910	550	6	Water cooling

(continued)

Steel plate No.	Steel No.	Slab thickness (mm)	Plate thickness (mm)	Hot rolling				Cooling			
				Heating temperature (°C)	Finish rolling temperature (°C)	Cumulative reduction at 850°C or higher and (Tx - 50)°C or lower (%)	Cumulative reduction in non-recrystallization region (%)	Accelerated cooling start temperature (°C)	Accelerated cooling end temperature (°C)	Average cooling rate to 650°C from (finish rolling temperature - 50°C) (°C/s)	Cooling method
39	39	250	25	1200	940	12	6	930	350	55	Water cooling
40	40	300	80	1150	930	30	25	910	550	6	Water cooling
41	41	250	12	1150	780	20	35	700	500	5	Water cooling
42	42	250	12	1150	850	30	30	-	-	2.5	Air cooling
43	43	250	25	1100	960	0	0	930	350	55	Water cooling
44	44	250	25	1100	900	40	20	850	600	75	Water cooling
45	45	300	25	1100	940	25	15	880	450	40	Water cooling
46	46	250	16	<u>1150</u>	850	30	30	810	300	30	Water cooling
47	47	250	25	1150	900	10	10	850	600	70	Water cooling
48	48	250	12	<u>1150</u>	780	25	40	700	500	5	Water cooling
49	49	300	80	1130	930	15	38	910	550	6	Water cooling

(continued)

Steel plate No.	Steel No.	Slab thickness (mm)	Plate thickness (mm)	Hot rolling				Cooling			Cooling method
				Heating temperature (°C)	Finish rolling temperature (°C)	Cumulative reduction at 850°C or higher and (Tx - 50)°C or lower (%)	Cumulative reduction in non-recrystallization region (%)	Accelerated cooling start temperature (°C)	Accelerated cooling end temperature (°C)	Average cooling rate to 650°C from (finish rolling temperature - 50°C) (°C/s)	
27-2	50	250	12	1150	760	20	40	700	500	5	Water cooling
Note: underlines indicate the outside of the scope of the present invention											

[Table 3-1]

Steel plate No.	Steel No.	Microstructure 0.5 mm under steel plate surface		Base metal characteristics			Base metal toughness	Stress corrosion cracking property	Note
		Area ratio of austenite with equivalent circle diameter of 10 μm or more and aspect ratio of major to minor axis of 3 or more (%)	Total number per 1 mm ² of Nb, V, and/or Ti carbide, nitride, and carbonitride having equivalent circle diameter of 0.01 to 0.5 μm (/mm ²)	Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)	Absorbed energy at -196°C (vE _{-196°C}) (J)	Fracture stress (MPa)	
1-1	1	42	880	431	884	52	143	765	Example
1-2	1	64	1260	418	880	39	109	803	Example
1-3	1	89	162	592	942	28	44	477	Comparative Example
1-4	1	29	980	429	888	48	135	773	Example
1-5	1	6	421	408	872	45	112	457	Comparative Example
1-6	1	18	3380	362	802	50	54	512	Comparative Example
1-7	1	88	167	563	927	35	43	411	Comparative Example
2-1	2	28	352	452	906	54	150	627	Example
2-2	2	4	396	512	995	41	78	386	Comparative Example
3	3	87	1690	481	865	48	148	659	Example
4	4	30	925	402	901	41	101	839	Example
5	5	52	2785	433	825	55	170	719	Example
6	6	41	572	420	913	43	112	688	Example
7	7	33	366	485	853	50	160	640	Example
8	8	49	2154	435	861	52	144	701	Example

(continued)

Steel plate No.	Steel No.	Microstructure 0.5 mm under steel plate surface		Base metal characteristics			Base metal toughness	Stress corrosion cracking property	Note
		Area ratio of austenite with equivalent circle diameter of 10 μm or more and aspect ratio of major to minor axis of 3 or more (%)	Total number per 1 mm ² of Nb, V, and/or Ti carbide, nitride, and carbonitride having equivalent circle diameter of 0.01 to 0.5 μm (/mm ²)	Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)	Absorbed energy at -196°C (vE _{-196°C}) (J)	Fracture stress (MPa)	
9	9	73	377	410	882	36	107	635	Example
10	10	66	1964	459	873	49	136	723	Example
11	11	59	1264	443	859	55	129	799	Example
12	12	70	1278	572	935	24	15	530	Comparative Example
13	13	83	1644	489	826	37	52	291	Comparative Example
14	14	32	405	457	883	50	30	481	Comparative Example
15	15	29	721	482	1023	19	12	654	Comparative Example
16	16	48	204	478	914	54	46	556	Comparative Example
17	17	80	1029	324	813	44	33	452	Comparative Example
18	18	59	380	441	872	25	21	388	Comparative Example
19	19	28	225	412	857	51	106	472	Comparative Example
20	20	52	2068	489	876	55	10	413	Comparative Example

(continued)

Steel plate No.	Steel No.	Microstructure 0.5 mm under steel plate surface		Base metal characteristics			Base metal toughness	Stress corrosion cracking property	Note
		Area ratio of austenite with equivalent circle diameter of 10 μm or more and aspect ratio of major to minor axis of 3 or more (%)	Total number per 1 mm ² of Nb, V, and/or Ti carbide, nitride, and carbonitride having equivalent circle diameter of 0.01 to 0.5 μm (/mm ²)	Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)	Absorbed energy at -196°C (vE _{-196°C}) (J)	Fracture stress (MPa)	
21	21	15	14	426	844	44	116	435	Comparative Example
22	22	95	120	504	837	28	30	393	Comparative Example
23	23	90	90	476	879	35	41	426	Comparative Example
24	24	96	140	521	883	22	10	371	Comparative Example
Note: underlines indicate the outside of the scope of the present invention									

[Table 3-2]

Steel plate No.	Steel No.	Microstructure 0.5 mm under steel plate surface			Base metal characteristics			Base metal toughness	Stress corrosion cracking property	Note
		Area ratio of austenite with equivalent circle diameter of 10 μm or more and aspect ratio of major to minor axis of 3 or more (%)	Total number per 1 mm ² of Nb, V, and/or Ti carbide, nitride, and carbonitride (/mm ²)		Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)	Absorbed energy at -196°C (vE _{-196°C}) (J)	Fracture stress (MPa)	
25-1	25	42	880		431	884	52	143	765	Example
25-2	25	64	1260		418	880	39	109	803	Example
25-3	25	89	<u>162</u>		592	942	<u>28</u>	44	477	Comparative Example
25-4	25	29	980		429	888	48	135	773	Example
25-5	25	6	421		408	872	45	112	<u>457</u>	Comparative Example
25-6	25	<u>18</u>	3380		<u>362</u>	802	50	54	512	Comparative Example
25-7	25	88	<u>167</u>		563	927	35	43	<u>411</u>	Comparative Example
25-8	25	<u>19</u>	995		<u>372</u>	831	52	169	769	Comparative Example
26-1	26	28	352		452	906	54	150	627	Example
26-2	26	<u>4</u>	396		512	995	41	78	<u>386</u>	Comparative Example
26-3	26	93	352		785	1106	22	150	627	Comparative Example
27	27	87	1690		481	865	48	148	659	Example
28	28	30	925		402	901	41	101	839	Example
29	29	52	2785		433	825	55	170	719	Example

(continued)

Steel plate No.	Steel No.	Microstructure 0.5 mm under steel plate surface			Base metal characteristics			Base metal toughness	Stress corrosion cracking property	Note
		Area ratio of austenite with equivalent circle diameter of 10 μm or more and aspect ratio of major to minor axis of 3 or more (%)	Total number per 1 mm ² of Nb, V, and/or Ti carbide, nitride, and carbonitride (/mm ²)		Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)	Absorbed energy at -196°C (VE _{-196°C}) (J)	Fracture stress (MPa)	
30	30	41	572		420	913	43	112	688	Example
31	31	33	366		485	853	50	160	640	Example
32	32	49	2154		435	861	52	144	701	Example
33	33	73	377		410	882	36	107	635	Example
34	34	66	1964		459	873	49	136	723	Example
35	35	59	1264		443	859	55	129	799	Example
36	36	70	1278		572	935	24	15	530	Comparative Example
37	37	83	1644		489	826	37	52	291	Comparative Example
38	38	32	405		457	883	50	30	481	Comparative Example
39	39	29	721		482	1023	19	12	654	Comparative Example
40	40	48	204		478	914	54	46	556	Comparative Example
41	41	80	1029		324	813	44	33	452	Comparative Example
42	42	59	380		441	872	25	21	388	Comparative Example
43	43	28	225		412	857	51	106	472	Comparative Example

(continued)

Steel plate No.	Steel No.	Microstructure 0.5 mm under steel plate surface			Base metal characteristics			Base metal toughness	Stress corrosion cracking property	Note
		Area ratio of austenite with equivalent circle diameter of 10 μm or more and aspect ratio of major to minor axis of 3 or more (%)	Total number per 1 mm ² of Nb, V, and/or Ti carbide, nitride, and carbonitride (/mm ²)		Yield stress (MPa)	Tensile strength (MPa)	Total elongation (%)	Absorbed energy at -196°C (vE _{-196°C}) (J)	Fracture stress (MPa)	
44	44	52	2068		489	876	55	10	413	Comparative Example
45	45	15	14		426	844	44	116	435	Comparative Example
46	46	95	1024		504	837	28	30	393	Comparative Example
47	47	90	90		476	879	35	41	426	Comparative Example
48	48	96	140		521	883	22	10	371	Comparative Example
49	49	29	910		414	862	39	38	760	Comparative Example
27-2	50	94	1580		499	864	47	136	660	Example
Note: underlines indicate the outside of the scope of the present invention										

[0075] The Examples were confirmed to satisfy the above-mentioned target performance (base metal yield stress of 400 MPa or higher, low-temperature toughness of 50 J or higher as average absorbed energy (vE_{-196}), resistance to stress corrosion cracking of 500 MPa or higher as fracture stress). Meanwhile, Comparative Examples that fall outside the scope of the present invention could not satisfy the above-mentioned target performance in any one or more of base metal strength, low-temperature toughness, and resistance to stress corrosion cracking. In Table 3-1 and Table 3-2, steel plates No. 12 and 36 of Comparative Examples had, in area ratio, 70% of austenite that has an average equivalent circle diameter of 10 μm or more and an aspect ratio of a major axis to a minor axis of 3 or more. This is because stable austenite is scarce, but unstable austenite predominates since C in the component composition falls beyond the scope of the present invention.

Claims

1. A high-Mn steel plate having a component composition containing, in mass%,

C: 0.20 to 0.70%,

Si: 0.05 to 1.0%,

Mn: 15 to 30%,

P: 0.028% or less,

S: 0.02% or less,

Al: 0.01 to 0.1%,

Cr: 0.5 to 7.0%,

Ni: 0.03 to 0.30%,

N: 0.0010 to 0.0200%, and one or two or more of

Nb: 0.003 to 0.030%,

V: 0.03 to 0.10%, and

Ti: 0.003 to 0.040%,

with the balance being Fe and incidental impurities, wherein:

a microstructure 0.5 mm under a surface of the steel plate includes austenite as a base phase; and

25% or more of the austenite, in area ratio, has an equivalent circle diameter of 10 μm or more and an aspect ratio of a major axis to a minor axis of 3 or more.

2. The high-Mn steel plate according to Claim 1, wherein the component composition further contains an element in at least one group selected from the following group A or B.

Group A: one or two, in mass%, selected from Mo: 0.05 to 2.0% and

W: 0.05 to 2.0%

Group B: one or two or more, in mass%, selected from

Ca: 0.0005 to 0.0050%,

Mg: 0.0005 to 0.0050%, and

REM: 0.0010 to 0.0200%

3. The high-Mn steel plate according to Claim 1 or 2, wherein the microstructure 0.5 mm under the surface of the steel plate further includes a total number of $2 \times 10^2/\text{mm}^2$ or more of a carbide, a nitride, and a carbonitride, the carbide, the nitride, and the carbonitride containing one or two or more of Nb, V, and Ti and having an equivalent circle diameter of 0.01 to 0.5 μm .

4. A manufacturing method for a high-Mn steel plate, comprising:

heating of steel having the component composition according to any one of Claims 1 to 3 to a temperature range of $(T_x - 50)^\circ\text{C}$ or higher and $(T_x + 200)^\circ\text{C}$ or lower as a surface temperature of the steel for any one or more of T_x ($^\circ\text{C}$) defined by any of formulae (1) to (3) when T_x ($x = \text{Nb}, \text{V}, \text{or Ti}$) is set to a temperature represented by any of the formulae (1) to (3);

hot rolling at a finishing temperature of 750°C or higher and $1,000^\circ\text{C}$ or lower to yield a steel plate; and

subsequently cooling at an average cooling rate of 1.0°C/s or more on the surface of the steel plate to 650°C from a lower temperature of either (finishing temperature - 50°C) or a cooling start temperature.

$$T_{\text{Nb}} \text{ (}^\circ\text{C)} = 7500 / [3.0 - \log_{10}([\% \text{Nb}] \times [\% \text{C}])] - 273 \quad (1)$$

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$$T_V (^{\circ}\text{C}) = 10800/[7.2 - \log_{10}([\%V] \times [\%C])] - 273 \quad (2)$$

$$T_{Ti} (^{\circ}\text{C}) = 7000/[2.8 - \log_{10}([\%Ti] \times [\%C])] - 273 \quad (3)$$

wherein: [%Nb], [%V], [%Ti], and [%C] represent contents (mass%) of Nb, V, Ti, and C, respectively, in steel; and when an element is not contained, calculation is performed by setting the corresponding atomic symbol in the formulae to 0.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/043245

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. C22C38/00 (2006.01) i, C21D8/02 (2006.01) i, C22C38/58 (2006.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. C22C38/00-38/60, C21D8/00-8/10

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2016-196703 A (NIPPON STEEL & SUMITOMO METAL CORP.) 24 November 2016, steel no. 6, 101 (Family: none)	1-4
A	JP 1-43830 B2 (KOBE STEEL, LTD.) 22 September 1989, column 4, lines 20-21 & US 4481033 A & GB 2099456 A	1-4
A	醍醐市朗ら, 鉄鋼材における不純物元素濃度の日中間比較, 鉄と鋼, 31 May 2014, vol. 100 no. 6, pp. 756-760, (DAIGO, Ichiro et al., "Comparison of Tramp Elements Compositions in Steel Bars between Japan and China", Tetsu-to-Hagané)	1-4



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search
13 February 2018 (13.02.2018)Date of mailing of the international search report
27 February 2018 (27.02.2018)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/043245

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2016-84529 A (NIPPON STEEL & SUMITOMO METAL CORP.) 19 May 2016, no. 18, 29 (Family: none)	1-4
A	JP 61-45697 B2 (SUMITOMO METAL INDUSTRIES, LTD.) 09 October 1986, claims (Family: none)	1-4
A	JP 56-23259 A (SUMITOMO METAL INDUSTRIES, LTD.) 05 March 1981, claims (Family: none)	1-4
A	US 2016/0319407 A1 (POSCO) 03 November 2016, tables 1-3 & WO 2015/099363 A1 & EP 3088555 A1 & KR 10-2015-0075315 A & CN 105849302 A	1-4

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2015508452 W [0006]
- JP 2016084529 A [0006]