

## STEEL PLATE AND METHOD OF PRODUCING SAME

### TECHNICAL FIELD

5 [0001] The present disclosure relates to a steel plate having particularly excellent mid-thickness part property and suitable for structural steel used in very-low-temperature environments such as liquefied gas storage tanks, and a method of producing the same.

### BACKGROUND

10 [0002] Operating environments of structures such as liquefied gas storage tanks reach very low temperatures, and thus hot-rolled steel plates used for such structures are required to have excellent toughness at very low temperatures as well as excellent strength. For example, a hot-rolled steel plate used for a liquefied natural gas storage needs to have excellent  
15 toughness in a temperature range lower than -164 °C which is the boiling point of liquefied natural gas. If the low-temperature toughness of the steel plate used for the very-low-temperature storage structure is insufficient, the safety of the very-low-temperature storage structure is likely to be undermined. There is thus strong need to improve the low-temperature  
20 toughness of the steel plate used.

[0003] In response to this need, austenitic stainless steel plates having austenite microstructure which is not embrittled at very low temperatures, 9 % Ni steel plates, and 5000 series aluminum alloys have been conventionally used. However, due to high alloy costs or production costs of these metal  
25 materials, there has been demand for a steel plate that is inexpensive and has excellent very-low-temperature toughness. In view of this, studies have been conducted to use, as a new steel plate to replace conventional steels for very low temperature use, high-Mn steel containing a large amount of Mn which is a relatively inexpensive austenite-stabilizing element and having austenite  
30 microstructure, as a structural steel plate in very-low-temperature environments.

[0004] For example, JP 2015-508452 A (PTL 1) discloses a steel material that contains Mn: 15 % to 35 %, Cu: 5 % or less, and appropriate amounts of C and Cr to improve the machinability by cutting and the Charpy impact property of

a heat-affected zone at -196 °C.

**[0005]** JP 2016-84529 A (PTL 2) discloses a high-Mn steel material that contains 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  
5 less than 8.0 % to improve the low-temperature toughness.

**[0006]** JP 2016-196703 A (PTL 3) discloses a high-Mn steel material that contains C: 0.001 % to 0.80 %, Mn: 15 % to 35 %, and elements such as Cr, Ti, Si, Al, Mg, Ca, and REM to improve the very-low-temperature toughness of base metal and welds.

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## CITATION LIST

### Patent Literature

**[0007]** PTL 1: JP 2015-508452 A

PTL 2: JP 2016-84529 A

15 PTL 3: JP 2016-196703 A

## SUMMARY

(Technical Problem)

**[0008]** High-Mn steel is high-alloy as compared with typical carbon steel, and  
20 accordingly has a low melting point. Moreover, its viscosity around the melting point is high. High-Mn steel is thus more susceptible to coarse casting defects than carbon steel. If casting defects remain in a product, in the case where tensile stress acts in the thickness direction of a steel plate of a cross joint or the like, the product may fracture, leading to a collapse of the  
25 structure.

**[0009]** However, regarding the respective steel materials described in PTL 1, PTL 2, and PTL 3, there is no mention of reduction-of-area property in a mid-thickness part which is important in terms of the production costs for achieving the strength and the low-temperature toughness and in terms of the  
30 safety of the structure using the foregoing austenite steel material, and thus there is still room to study.

**[0010]** It could therefore be helpful to provide a high-Mn steel plate having excellent reduction-of-area property in a mid-thickness part.

(Solution to Problem)

**[0011]** We conducted intensive studies on chemical compositions, production methods, etc. of steel plates for high-Mn steel, and discovered the following:

(i) By limiting the S content to 0.005 % or less in high-Mn steel as a  
5 base material, the amount of MnS generated can be reduced and the tensile property in the thickness direction can be improved.

(ii) In hot finish rolling, by performing rolling with a rolling reduction ratio of 3 or more, casting defects can be rendered harmless. Moreover, by setting the rolling reduction of each of at least two passes of final three passes  
10 to 10 % or more to homogenize the whole steel plate and prevent abnormal coarse grains from remaining, the tensile property in the thickness direction can be improved.

**[0012]** The present disclosure is based on these discoveries and further studies. We thus provide:

15 1. A steel plate comprising a chemical composition containing (consisting of), in mass%, C: 0.20 % or more and 0.70 % or less, Si: 0.05 % or more and 1.0 % or less, Mn: 15 % or more and 35 % or less, Al: 0.1 % or less, Cr: 8.0 % or less, N: 0.0010 % or more and 0.0500 % or less, P: 0.03 % or less, and S: 0.005 % or less, with a balance consisting of Fe and inevitable  
20 impurities, wherein tensile strength is 600 MPa or more, absorbed energy at -196 °C is 27 J or more, and reduction of area in a thickness direction of the steel plate is 30 % or more.

**[0013]** The reduction of area in the thickness direction can be measured in a test conforming to JIS Z 3199.

25 **[0014]** 2. The steel plate according to 1., wherein the chemical composition further contains, in mass%, one or more selected from Nb: 0.003 % or more and 0.030 % or less, V: 0.01 % or more and 0.10 % or less, Ti: 0.003 % or more and 0.040 % or less, and B: 0.0003 % or more and 0.0100 % or less.

**[0015]** 3. The steel plate according to 1. or 2., wherein the chemical  
30 composition further contains, in mass%, one or more selected from Cu: 0.01 % or more and 0.70 % or less, Ni: 0.01 % or more and 0.50 % or less, Sn: 0.01 % or more and 0.30 % or less, Sb: 0.01 % or more and 0.30 % or less, Mo: 0.05 % or more and 2.0 % or less, and W: 0.05 % or more and 2.0 % or less.

**[0016]** 4. The steel plate according to any one of 1. to 3., wherein the

chemical composition further contains, in mass%, one or more selected from Ca: 0.0005 % or more and 0.0050 % or less, Mg: 0.0005 % or more and 0.0100 % or less, and REM: 0.0010 % or more and 0.0200 % or less.

**[0017]** 5. A method of producing the steel plate according to any one of 1. to 4., the method comprising: heating a steel raw material to 1000 °C or more and 1300 °C or less; and thereafter subjecting the steel raw material to hot rolling with a rolling reduction ratio of 3 or more, wherein a rolling reduction of each of at least two passes of final three passes is 10 % or more.

(Advantageous Effect)

**[0018]** It is thus possible to provide a steel plate having excellent reduction-of-area property in a mid-thickness part. By using the presently disclosed steel plate for a steel structure used in a very-low-temperature environment such as a liquefied gas storage tank, the safety of the structure is greatly improved. This yields significantly advantageous effects in industrial terms. Moreover, the presently disclosed steel plate is less expensive than existing materials, and thus has excellent economic advantage.

#### DETAILED DESCRIPTION

**[0019]** A steel plate according to one of the disclosed embodiments will be described in detail below. The present disclosure is not limited to the embodiment described below.

[Chemical composition]

First, the chemical composition of the steel plate according to one of the disclosed embodiments and the reasons for limiting the chemical composition will be described below. Herein, “%” used with regard to the chemical composition denotes “mass%” unless otherwise specified.

**[0020]** C: 0.20 % or more and 0.70 % or less

C is effective in strengthening, and is an inexpensive austenite-stabilizing element that is important in obtaining austenite microstructure. To achieve the effects, the C content needs to be 0.20 % or more. If the C content is more than 0.70 %, C segregates to the mid-thickness part and facilitates excessive precipitation of Cr carbides and Nb-, V-, and Ti-based carbides, and consequently the low-temperature toughness decreases and the reduction of area decreases. The C content is

therefore 0.20 % or more and 0.70 % or less. The C content is preferably 0.25 % or more. The C content is preferably 0.60 % or less.

**[0021]** Si: 0.05 % or more and 1.0 % or less

Si acts as a deoxidizer, and not only is necessary for steelmaking but  
5 also has an effect of strengthening the steel plate through solid solution  
strengthening by dissolving in the steel. To achieve the effects, the Si  
content needs to be 0.05 % or more. If the Si content is more than 1.0 %, the  
weldability and the surface characteristics degrade. The Si content is  
therefore 0.05 % or more and 1.0 % or less. The Si content is preferably 0.07  
10 % or more. The Si content is preferably 0.5 % or less.

**[0022]** Mn: 15 % or more and 35 % or less

Mn is a relatively inexpensive austenite-stabilizing element. In the  
present disclosure, Mn is an important element for achieving both the strength  
and the very-low-temperature toughness. To achieve the effects, the Mn  
15 content needs to be 15 % or more. If the Mn content is more than 35 %, the  
effect of improving the very-low-temperature toughness is saturated, and the  
alloy costs increase. Moreover, the weldability and the cuttability degrade.  
Furthermore, segregation is facilitated, leading to lower very-low-temperature  
toughness, degraded tensile property in the thickness direction, and stress  
20 corrosion cracking. The Mn content is therefore 15 % or more and 35 % or  
less. The Mn content is preferably 18 % or more. The Mn content is  
preferably 28 % or less.

**[0023]** Al: 0.1 % or less

Al acts as a deoxidizer, and is most generally used in the molten steel  
25 deoxidation process for steel plates. Al also has an effect of suppressing a  
decrease in toughness due to solute N reduction by fixing solute N in the steel  
and forming AlN. To achieve the effects, the Al content needs to be 0.01 %  
or more. If the Al content is more than 0.1 %, Al diffuses into a weld metal  
portion during welding and decreases the toughness of the weld metal. The  
30 Al content is therefore 0.1 % or less. The Al content is preferably 0.07 % or  
less. The Al content is more preferably 0.02 % or more. The Al content is  
more preferably 0.06 % or less.

**[0024]** Cr: 8.0 % or less

Cr is an element necessary to improve the low-temperature toughness

and the corrosion resistance of high-Mn steel. Meanwhile, Cr may form nitrides, carbides, carbonitrides, or the like which precipitate during rolling. Such precipitates become a corrosion initiation point or a fracture origin to thus cause a decrease in low-temperature toughness. The upper limit of the

5 Cr content is therefore set to 8.0 %. The Cr content is preferably 1.0 % or more. The Cr content is preferably 6.0 % or less. The Cr content is more preferably 1.5 % or more. The Cr content is more preferably 5.5 % or less.

**[0025]** N: 0.0010 % or more and 0.0500 % or less

N is an austenite-stabilizing element, and is effective in improving the

10 very-low-temperature toughness. N also has an effect of combining with Nb, V, and Ti to form nitrides or carbonitrides which finely precipitate and suppress stress corrosion cracking as a diffusible hydrogen trapping site. To achieve the effects, the N content needs to be 0.0010 % or more. If the N content is more than 0.0500 %, excessive formation of nitrides or

15 carbonitrides is facilitated, as a result of which not only the amount of solute element decreases and the corrosion resistance decreases but also the toughness decreases. The N content is therefore 0.0010 % or more and 0.0500 % or less. The N content is preferably 0.0020 % or more. The N content is preferably 0.0200 % or less.

20 **[0026]** P: 0.03 % or less

If the P content is more than 0.03 %, P segregates to grain boundaries and decreases the grain boundary strength, and forms a fracture origin in some cases. It is therefore desirable to reduce the P content as much as possible, with its upper limit being set to 0.03 %. Thus, the P content is 0.03 % or less.

25 Since lower P content contributes to improved properties, the P content is preferably 0.025 % or less, and more preferably 0.020 % or less. Reducing the P content to less than 0.0005 % requires considerable steelmaking costs. Hence, the P content is preferably 0.0005 % or more from the viewpoint of economic efficiency.

30 **[0027]** S: 0.005 % or less

S forms MnS in the steel and significantly degrades the low-temperature toughness and the reduction of area during tension in the thickness direction. It is therefore desirable to reduce the S content as much as possible, with its upper limit being set to 0.005 %. The S content is

preferably 0.002 % or less. Reducing the S content to less than 0.0001 % requires considerable steelmaking costs. Hence, the S content is preferably 0.0001 % or more from the viewpoint of economic efficiency.

**[0028]** The balance other than the components described above consists of Fe and inevitable impurities. The inevitable impurities include Zr, As, and the like.

**[0029]** The chemical composition of the steel plate according to one of the disclosed embodiments may optionally contain the following elements in addition to the above-described essential elements, for the purpose of further improving the strength and the low-temperature toughness.

Nb: 0.003 % or more and 0.030 % or less

Nb is an element effective in improving the strength of the steel plate. To achieve the effect, the Nb content is preferably 0.003 % or more. If the Nb content is more than 0.030 %, coarse carbonitrides may precipitate and form a fracture origin, as a result of which the tensile property in the thickness direction degrades. In addition, precipitates may coarsen and cause a decrease in base metal toughness. Accordingly, in the case of containing Nb, the Nb content is preferably 0.003 % or more and 0.030 % or less. The Nb content is more preferably 0.005 % or more, and further preferably 0.007 % or more. The Nb content is more preferably 0.025 % or less, and further preferably 0.022 % or less.

**[0030]** V: 0.01 % or more and 0.10 % or less

V is an element effective in improving the strength of the steel plate. To achieve the effect, the V content is preferably 0.01 % or more. If the V content is more than 0.10 %, coarse carbonitrides may precipitate and form a fracture origin. In addition, precipitates may coarsen and cause a decrease in base metal toughness. Accordingly, in the case of containing V, the V content is preferably 0.01 % or more and 0.10 % or less. The V content is more preferably 0.02 % or more, and further preferably 0.03 % or more. The V content is more preferably 0.09 % or less, and further preferably 0.08 % or less.

**[0031]** Ti: 0.003 % or more and 0.040 % or less

Ti is an element that forms nitrides or carbonitrides which precipitate, and is effective in improving the strength of the steel plate. To achieve the

effect, the Ti content is preferably 0.003 % or more. If the Ti content is more than 0.040 %, precipitates may coarsen and cause a decrease in base metal toughness. In addition, coarse carbonitrides may precipitate and form a fracture origin. Accordingly, in the case of containing Ti, the Ti content is preferably 0.003 % or more and 0.040 % or less. The Ti content is more preferably 0.005 % or more, and further preferably 0.007 % or more. The Ti content is more preferably 0.035 % or less, and further preferably 0.032 % or less.

**[0032]** B: 0.0003 % or more and 0.0100 % or less

B is an element that enhances the austenite grain boundary strength and is effective in improving the very-low-temperature toughness. To achieve the effects, the B content is preferably 0.0003 % or more. If the B content is more than 0.0100 %, coarse B precipitates form, and the toughness decreases. The B content is therefore preferably 0.0100 % or less. The B content is more preferably 0.0030 % or less.

**[0033]** The chemical composition of the steel plate according to one of the disclosed embodiments may optionally further contain the following elements. One of more selected from Cu: 0.01 % or more and 0.70 % or less, Ni: 0.01 % or more and 0.50 % or less, Sn: 0.01 % or more and 0.30 % or less, Sb: 0.01 % or more and 0.30 % or less, Mo: 0.05 % or more and 2.0 % or less, and W: 0.05 % or more and 2.0 % or less

**[0034]** Cu, Ni, Sn, Sb, Mo, and W are each an element that, when added in combination with Cr, improves the corrosion resistance of the high-Mn steel.

The effect of each of these elements is realized in the case where the element is present together with Cr in the high-Mn steel, and is exhibited when the content of the element is not less than the foregoing upper limit. If the content of the element is more than the foregoing upper limit, the weldability and the toughness decrease, and a cost disadvantage ensues.

**[0035]** Accordingly, Cu, Ni, Sn, Sb, Mo, and W are each preferably added in the foregoing range. More preferably, the Cu content is 0.02 % or more and 0.50 % or less, the Ni content is 0.02 % or more and 0.40 % or less, the Sn content is 0.02 % or more and 0.25 % or less, the Sb content is 0.02 % or more and 0.25 % or less, the Mo content is 0.05 % or more and 1.50 % or less, and the W content is 0.05 % or more and 1.50 % or less.

**[0036]** The chemical composition of the steel plate according to one of the disclosed embodiments may optionally further contain the following elements. One or more selected from Ca: 0.0005 % or more and 0.0050 % or less, Mg: 0.0005 % or more and 0.0100 % or less, and REM: 0.0010 % or more and 0.0200 % or less

**[0037]** Ca, Mg, and REM are each an element useful for morphological control of inclusions such as MnS, and may be optionally contained. Morphological control of inclusions means turning elongated sulfide-based inclusions into granular inclusions. Through such morphological control of inclusions, the tensile property in the thickness direction, the toughness, and the sulfide stress corrosion cracking resistance can be improved. To achieve the effects, the Ca content and the Mg content are each preferably 0.0005 % or more, and the REM content is preferably 0.0010 % or more.

**[0038]** If the Ca content, the Mg content, and the REM content are each high, the amount of nonmetallic inclusions increases, which may decrease the property in the mid-thickness part. Accordingly, in the case of containing Ca, the Ca content is preferably 0.0050 % or less. In the case of containing Mg, the Mg content is preferably 0.0100 % or less. In the case of containing REM, the REM content is preferably 0.0200 % or less. More preferably, the Ca content is 0.0010 % or more and 0.0040 % or less, the Mg content is 0.0010 % or more and 0.0040 % or less, and the REM content is 0.0020 % or more and 0.0150 % or less.

**[0039]** It is important that the steel plate having the foregoing chemical composition has reduction of area in the thickness direction of 30 % or more. If the reduction of area in the thickness direction is less than 30 %, for example, a cross weld joint fractures and the soundness of the structure is significantly impaired.

**[0040]** The production conditions for the steel plate according to one of the disclosed embodiments will be described below. The steel plate according to one of the disclosed embodiments can be produced by: heating a steel raw material having the foregoing chemical composition to 1000 °C or more and 1300 °C or less; and thereafter subjecting the steel raw material to hot rolling with a rolling reduction ratio of 3 or more, wherein a rolling reduction of each of at least two passes of final three passes is 10 % or more.

In the following description, temperature “°C” denotes the temperature in the mid-thickness part.

**[0041]** [Heating temperature of steel raw material: 1000 °C or more and 1300 °C or less]

5           The steel raw material is heated to 1000 °C or more, in order to dissolve precipitates in the microstructure and homogenize the crystal grain size and the like. The heating temperature is 1000 °C or more and 1300 °C or less. If the heating temperature is less than 1000 °C, precipitates do not dissolve sufficiently, making it impossible to obtain desired properties. If  
10 the heating temperature is more than 1300 °C, the material properties degrade due to coarsening of crystal grains. Moreover, excessive energy is required, so that the productivity decreases. The upper limit of the heating temperature is therefore 1300 °C. The heating temperature is preferably 1050 °C or more. The heating temperature is preferably 1250 °C or less.  
15 The heating temperature is more preferably 1100 °C or more. The heating temperature is more preferably 1250 °C or less.

**[0042]** The steel raw material may be a raw material produced by a usual method such as a continuously-cast slab, an ingot-cast slab, or a bloom.

**[0043]** [Rolling reduction ratio in hot rolling: 3 or more]

20           If the rolling reduction ratio in the hot rolling is less than 3, it is difficult to suppress a decrease in tensile property in the thickness direction by pressure bonding of casting defects. Moreover, the promotion of recrystallization by the rolling to achieve homogenization is insufficient, and coarse austenite grains remain, as a result of which properties such as strength  
25 and toughness degrade. The rolling reduction ratio is therefore limited to 3 or more. The rolling reduction ratio is preferably 4 or more, and more preferably 5 or more. Although no upper limit is placed on the rolling reduction ratio, the rolling reduction ratio is preferably 50 or less. If the rolling reduction ratio is more than 50, the anisotropy of mechanical  
30 properties increases significantly.

**[0044]** Herein, the rolling reduction ratio in the hot rolling is defined as “(the thickness of the rolling raw material)/(the thickness of the steel plate after the rolling)”.

**[0045]** [Rolling reduction of each of at least two passes of final three passes:

10 % or more]

By setting the rolling reduction of each of at least two passes of final three passes that finally determine the material properties of the steel plate to 10 % or more, casting defects can be reliably rendered harmless, and the whole steel plate can be homogenized to prevent abnormal coarse grains from remaining. Consequently, the reduction of area in the tensile test in the thickness direction can be improved, and thus reduction of area of 30 % or more can be ensured.

**[0046]** That is, the rolling reduction of each of at least two passes of the final three passes is limited for reliable pressure bonding of casting defects. Hence, the rolling reduction of each of all final three passes is preferably 10 % or more. If the rolling reduction of each of at least two passes of the final three passes is less than 10 %, casting defects remain, and the reduction of area in the mid-thickness part decreases. Although no upper limit is placed on the rolling reduction, the upper limit is preferably 30 % in terms of production line constraints such as rolling load.

**[0047]** [Cooling after hot rolling]

To obtain necessary properties of the steel plate such as strength and low-temperature toughness, water cooling or the like may be performed after the hot rolling.

## EXAMPLES

**[0048]** Steels No. 1 to No. 26 in Table 1 prepared by steelmaking were melted to form slabs, and then steel plates with a thickness of 30 mm to 50 mm were produced under the production conditions indicated in Table 2. The obtained steel plates of samples No. 1 to No. 30 were then subjected to the following tensile test. The results of the tensile test are indicated in Table 2.

[0049]

[Table 1]

| Steel raw material | Chemical composition (mass%) |      |      |       |        |     |       |        |        |       |       |       |      |      |      |      |      |      |        |        |        | Remarks |
|--------------------|------------------------------|------|------|-------|--------|-----|-------|--------|--------|-------|-------|-------|------|------|------|------|------|------|--------|--------|--------|---------|
|                    | C                            | Si   | Mn   | P     | S      | Cr  | Al    | N      | B      | Ti    | V     | Nb    | Cu   | Ni   | Mo   | W    | Sn   | Sb   | Mg     | Ca     | REM    |         |
| 1                  | 0.43                         | 0.36 | 25.8 | 0.010 | 0.0022 | 7.1 | 0.088 | 0.0045 | 0.0010 | -     | -     | -     | -    | -    | -    | -    | -    | -    | -      | 0.0021 | -      |         |
| 2                  | 0.41                         | 0.29 | 26.3 | 0.009 | 0.0032 | 0.7 | 0.035 | 0.0036 | -      | -     | -     | -     | -    | -    | -    | -    | -    | -    | -      | -      | -      |         |
| 3                  | 0.47                         | 0.43 | 25.9 | 0.008 | 0.0018 | 5.0 | 0.037 | 0.0129 | 0.0003 | 0.009 | -     | -     | -    | -    | -    | -    | -    | -    | -      | 0.0008 | -      |         |
| 4                  | 0.38                         | 0.40 | 23.2 | 0.016 | 0.0022 | 7.8 | 0.032 | 0.0025 | 0.0058 | -     | -     | 0.011 | -    | -    | 1.15 | -    | 0.08 | -    | -      | -      | -      |         |
| 5                  | 0.49                         | 0.51 | 25.6 | 0.011 | 0.0036 | 4.5 | 0.038 | 0.0091 | -      | -     | -     | -     | -    | -    | -    | -    | -    | -    | -      | -      | -      |         |
| 6                  | 0.48                         | 0.47 | 25.8 | 0.009 | 0.0028 | 4.8 | 0.038 | 0.0105 | 0.0019 | 0.006 | 0.032 | -     | -    | -    | -    | -    | -    | -    | -      | 0.0016 | -      |         |
| 7                  | 0.33                         | 0.36 | 34.2 | 0.009 | 0.0016 | 4.6 | 0.036 | 0.0032 | -      | -     | -     | -     | 0.25 | -    | -    | -    | -    | -    | -      | 0.0014 | -      |         |
| 8                  | 0.69                         | 0.22 | 23.5 | 0.012 | 0.0033 | 4.8 | 0.032 | 0.0024 | 0.0022 | -     | -     | -     | -    | 0.23 | -    | -    | -    | -    | -      | 0.0019 | -      |         |
| 9                  | 0.41                         | 0.91 | 22.0 | 0.010 | 0.0013 | 4.5 | 0.032 | 0.0029 | 0.0038 | -     | -     | -     | -    | -    | -    | 1.38 | -    | 0.12 | -      | 0.0024 | -      |         |
| 10                 | 0.53                         | 0.07 | 24.8 | 0.008 | 0.0016 | 5.3 | 0.028 | 0.0025 | -      | -     | -     | -     | -    | -    | -    | 0.45 | -    | -    | -      | 0.0025 | -      |         |
| 11                 | 0.62                         | 0.10 | 17.5 | 0.011 | 0.0014 | 5.1 | 0.016 | 0.0115 | 0.0021 | -     | -     | -     | 0.48 | -    | -    | -    | -    | -    | -      | 0.0006 | -      |         |
| 12                 | 0.46                         | 0.39 | 24.6 | 0.009 | 0.0013 | 4.8 | 0.032 | 0.0044 | -      | -     | -     | -     | -    | -    | -    | -    | -    | -    | 0.0063 | -      | -      |         |
| 13                 | 0.42                         | 0.33 | 25.1 | 0.008 | 0.0018 | 4.6 | 0.025 | 0.0041 | 0.0012 | -     | -     | -     | 0.67 | -    | -    | -    | -    | -    | -      | -      | -      |         |
| 14                 | 0.21                         | 0.68 | 25.4 | 0.023 | 0.0015 | 2.2 | 0.032 | 0.0033 | 0.0024 | -     | -     | -     | -    | -    | -    | -    | -    | -    | -      | -      | 0.0085 |         |
| 15                 | 0.13                         | 0.21 | 29.5 | 0.014 | 0.0016 | 3.2 | 0.028 | 0.0041 | -      | -     | -     | 0.012 | 0.05 | -    | 0.20 | -    | -    | -    | -      | -      | -      |         |
| 16                 | 1.33                         | 0.24 | 27.3 | 0.011 | 0.0022 | 3.6 | 0.032 | 0.0041 | -      | -     | -     | -     | -    | -    | -    | -    | -    | -    | -      | -      | -      |         |
| 17                 | 0.55                         | 1.32 | 24.6 | 0.023 | 0.0031 | 6.1 | 0.041 | 0.0043 | 0.0018 | -     | 0.05  | -     | -    | -    | -    | -    | 0.03 | -    | -      | -      | 0.0032 |         |
| 18                 | 0.61                         | 0.45 | 12.1 | 0.018 | 0.0020 | 4.5 | 0.032 | 0.0026 | 0.0045 | 0.012 | -     | -     | -    | -    | 0.21 | 0.11 | -    | -    | -      | -      | -      |         |
| 19                 | 0.52                         | 0.61 | 41.0 | 0.013 | 0.0029 | 2.2 | 0.039 | 0.0054 | -      | -     | -     | -     | -    | -    | -    | -    | -    | -    | -      | 0.0021 | -      |         |
| 20                 | 0.41                         | 0.51 | 27.1 | 0.039 | 0.0026 | 6.3 | 0.029 | 0.0041 | 0.0018 | -     | -     | 0.014 | -    | 0.52 | -    | -    | -    | -    | -      | -      | -      |         |
| 21                 | 0.39                         | 0.46 | 28.0 | 0.021 | 0.0065 | 3.8 | 0.041 | 0.0055 | 0.0013 | -     | -     | -     | -    | -    | -    | -    | -    | -    | -      | -      | -      |         |
| 22                 | 0.65                         | 0.39 | 28.1 | 0.010 | 0.0029 | 9.2 | 0.029 | 0.0033 | 0.0012 | -     | -     | -     | -    | -    | 0.18 | -    | -    | -    | -      | -      | 0.0055 |         |
| 23                 | 0.45                         | 0.01 | 22.8 | 0.012 | 0.0013 | 2.5 | 0.030 | 0.0023 | -      | 0.009 | -     | -     | -    | -    | -    | 0.09 | -    | -    | -      | 0.0018 | -      |         |
| 24                 | 0.55                         | 0.29 | 21.3 | 0.012 | 0.0048 | 4.8 | 0.023 | 0.0546 | -      | -     | -     | -     | -    | -    | -    | -    | 0.15 | -    | -      | -      | -      |         |
| 25                 | 0.65                         | 0.21 | 27.8 | 0.018 | 0.0035 | 7.8 | 0.14  | 0.0038 | 0.0014 | -     | -     | -     | -    | -    | 0.15 | -    | -    | -    | 0.0019 | -      | -      |         |
| 26                 | 0.75                         | 0.18 | 28.2 | 0.013 | 0.0025 | 7.7 | 0.025 | 0.0040 | 0.0012 | -     | -     | -     | -    | -    | 0.22 | -    | -    | -    | -      | -      | -      |         |

Underlines indicate outside range according to present disclosure.

[0050]

[Table 2]

| Sample No. | Steel raw material No. | Product thickness (mm) | Heating temperature (°C) | Rolling reduction ratio | Number of passes with rolling reduction $\geq 10\%$ among final three passes | Rolling reductions of final three passes (%) | Treatment after rolling | Reduction of area (%) | Tensile strength (MPa) | vE <sub>196</sub> °C | Remarks             |
|------------|------------------------|------------------------|--------------------------|-------------------------|------------------------------------------------------------------------------|----------------------------------------------|-------------------------|-----------------------|------------------------|----------------------|---------------------|
| 1          | 1                      | 30                     | 1200                     | 4                       | 2                                                                            | 13-9-12                                      | Water cooling           | 35                    | 886                    | 93                   | Example             |
| 2          | 2                      | 50                     | 1200                     | 4                       | 2                                                                            | 9-13-13                                      | Water cooling           | 40                    | 812                    | 102                  |                     |
| 3          | 3                      | 30                     | 1200                     | 4                       | 3                                                                            | 13-12-12                                     | Natural cooling         | 45                    | 853                    | 84                   |                     |
| 4          | 4                      | 30                     | 1250                     | 5                       | 2                                                                            | 12-9-10                                      | Water cooling           | 50                    | 752                    | 115                  |                     |
| 5          | 5                      | 30                     | 1150                     | 5                       | 3                                                                            | 12-11-12                                     | Natural cooling         | 55                    | 829                    | 73                   |                     |
| 6          | 6                      | 30                     | 1200                     | 5                       | 3                                                                            | 15-12-12                                     | Natural cooling         | 55                    | 863                    | 83                   |                     |
| 7          | 7                      | 30                     | 1200                     | 4                       | 2                                                                            | 15-8-12                                      | Water cooling           | 35                    | 1012                   | 61                   |                     |
| 8          | 8                      | 50                     | 1280                     | 4                       | 2                                                                            | 18-6-12                                      | Water cooling           | 40                    | 815                    | 91                   |                     |
| 9          | 9                      | 30                     | 1050                     | 4                       | 3                                                                            | 12-10-11                                     | Natural cooling         | 50                    | 821                    | 86                   |                     |
| 10         | 10                     | 30                     | 1250                     | 4                       | 2                                                                            | 8-12-12                                      | Natural cooling         | 35                    | 869                    | 78                   |                     |
| 11         | 11                     | 30                     | 1150                     | 4                       | 2                                                                            | 12-7-13                                      | Water cooling           | 35                    | 683                    | 138                  |                     |
| 12         | 12                     | 50                     | 1200                     | 3                       | 2                                                                            | 11-8-14                                      | Water cooling           | 30                    | 903                    | 77                   |                     |
| 13         | 13                     | 30                     | 1150                     | 4                       | 2                                                                            | 8-10-12                                      | Water cooling           | 40                    | 925                    | 74                   |                     |
| 14         | 14                     | 30                     | 1150                     | 4                       | 3                                                                            | 10-11-10                                     | Natural cooling         | 40                    | 896                    | 95                   |                     |
| 15         | 15                     | 30                     | 1050                     | 4                       | 3                                                                            | 12-12-11                                     | Natural cooling         | 40                    | 512                    | 103                  | Comparative Example |
| 16         | 16                     | 30                     | 1200                     | 5                       | 2                                                                            | 7-12-10                                      | Natural cooling         | 35                    | 1241                   | 22                   |                     |
| 17         | 17                     | 30                     | 1150                     | 5                       | 2                                                                            | 12-8-10                                      | Natural cooling         | 40                    | 918                    | 18                   |                     |
| 18         | 18                     | 30                     | 1200                     | 5                       | 2                                                                            | 8-12-12                                      | Natural cooling         | 35                    | 529                    | 15                   |                     |
| 19         | 19                     | 50                     | 1280                     | 4                       | 2                                                                            | 8-10-10                                      | Water cooling           | 20                    | 1069                   | 106                  |                     |
| 20         | 20                     | 30                     | 1200                     | 5                       | 2                                                                            | 12-9-12                                      | Water cooling           | 15                    | 958                    | 8                    |                     |
| 21         | 21                     | 30                     | 1200                     | 5                       | 2                                                                            | 13-5-10                                      | Water cooling           | 15                    | 877                    | 10                   |                     |
| 22         | 22                     | 30                     | 1150                     | 5                       | 2                                                                            | 12-8-10                                      | Water cooling           | 25                    | 963                    | 45                   |                     |
| 23         | 23                     | 30                     | 1200                     | 5                       | 2                                                                            | 10-9-13                                      | Natural cooling         | 25                    | 748                    | 20                   |                     |
| 24         | 24                     | 30                     | 1100                     | 4                       | 2                                                                            | 12-6-10                                      | Water cooling           | 20                    | 1018                   | 14                   |                     |
| 25         | 25                     | 30                     | 1150                     | 5                       | 2                                                                            | 8-10-10                                      | Water cooling           | 25                    | 983                    | 10                   |                     |
| 26         | 26                     | 30                     | 1100                     | 5                       | 2                                                                            | 7-10-10                                      | Water cooling           | 25                    | 1160                   | 25                   |                     |
| 27         | 6                      | 30                     | 1350                     | 4                       | 2                                                                            | 10-7-10                                      | Water cooling           | 20                    | 825                    | 13                   |                     |
| 28         | 6                      | 30                     | 850                      | 4                       | 2                                                                            | 12-8-11                                      | Water cooling           | 20                    | 843                    | 69                   |                     |
| 29         | 6                      | 50                     | 1200                     | 2                       | 2                                                                            | 12-7-10                                      | Water cooling           | 15                    | 813                    | 48                   |                     |
| 30         | 6                      | 30                     | 1200                     | 4                       | 1                                                                            | 12-8-6                                       | Water cooling           | 20                    | 852                    | 30                   |                     |

Underlines indicate outside range according to present disclosure.

**[0051]** The reduction of area in the thickness direction in the tensile test was evaluated in accordance with JIS G 3199. The test piece shape used was a type A test piece. The tensile strength was evaluated using a round bar tensile test piece collected from a depth position of 1/4 (hereafter referred to as “1/4t part”) of the thickness from the steel plate surface. The Charpy absorbed energy at -196 °C was evaluated by taking the average of three Charpy test pieces collected from the 1/4t part.

**[0052]** Each Example (samples No. 1 to No. 14) according to the present disclosure satisfied reduction of area of 30 % or more. Each Comparative Example (samples No. 15 to No. 30) outside the range according to the present disclosure failed to satisfy the foregoing target performance in at least one of tensile strength, absorbed energy, and reduction of area.

## CLAIMS

1. A steel plate comprising  
a chemical composition containing, in mass%,  
5 C: 0.20 % or more and 0.70 % or less,  
Si: 0.05 % or more and 1.0 % or less,  
Mn: 15 % or more and 35 % or less,  
Al: 0.1 % or less,  
Cr: 0.70 % or more and 8.0 % or less,  
10 N: 0.0010 % or more and 0.0500 % or less,  
P: 0.03 % or less, and  
S: 0.005 % or less,  
with a balance consisting of Fe and inevitable impurities,  
wherein tensile strength is 600 MPa or more,  
15 absorbed energy at -196 °C is 27 J or more, and  
reduction of area in a thickness direction of the steel plate is 30 % or  
more.
2. The steel plate according to claim 1, wherein the chemical  
20 composition further contains, in mass%, one or more selected from  
Nb: 0.003 % or more and 0.030 % or less,  
V: 0.01 % or more and 0.10 % or less,  
Ti: 0.003 % or more and 0.040 % or less, and  
B: 0.0003 % or more and 0.0100 % or less.
- 25 3. The steel plate according to claim 1 or 2, wherein the chemical  
composition further contains, in mass%, one or more selected from  
Cu: 0.01 % or more and 0.70 % or less,  
Ni: 0.01 % or more and 0.50 % or less,  
30 Sn: 0.01 % or more and 0.30 % or less,  
Sb: 0.01 % or more and 0.30 % or less,  
Mo: 0.05 % or more and 2.0 % or less, and  
W: 0.05 % or more and 2.0 % or less.

4. The steel plate according to any one of claims 1 to 3, wherein the chemical composition further contains, in mass%, one or more selected from

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

5 Mg: 0.0005 % or more and 0.0100 % or less, and

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

5. A method of producing the steel plate according to any one of claims 1 to 4, the method comprising:

10 heating a steel raw material to 1000 °C or more and 1300 °C or less;  
and

thereafter subjecting the steel raw material to hot rolling with a rolling reduction ratio of 3 or more, wherein a rolling reduction of each of at least two passes of final three passes is 10 % or more.