



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

(43) Date of publication:  
**10.07.2013 Bulletin 2013/28**

(51) Int Cl.:  
**C22C 38/54 (2006.01) C21D 8/02 (2006.01)**

(21) Application number: **11838055.9**

(86) International application number:  
**PCT/JP2011/075286**

(22) Date of filing: **02.11.2011**

(87) International publication number:  
**WO 2012/060405 (10.05.2012 Gazette 2012/19)**

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

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(30) Priority: **05.11.2010 JP 2010248032**

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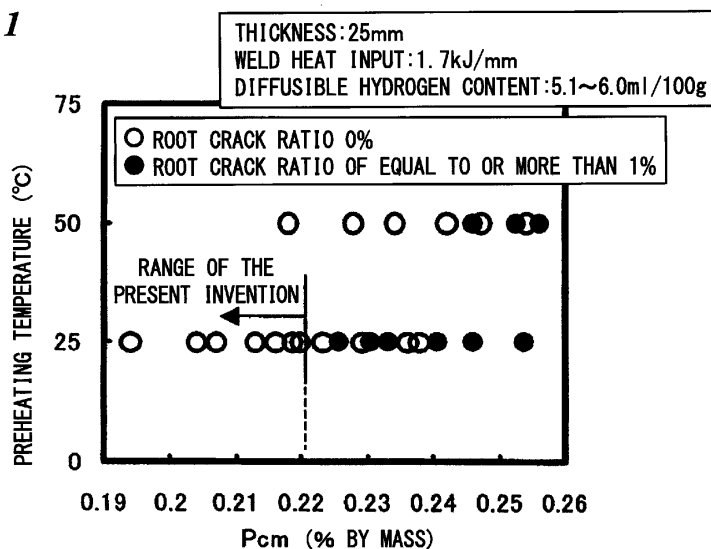
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(54) **HIGH-STRENGTH STEEL SHEET AND METHOD FOR PRODUCING SAME**

(57) A high-strength steel plate has a chemical composition containing, % by mass: C: 0.05% or more and less than 0.10%; Si: 0.20% or more and 0.50% or less; Mn: 0.20% or more and less than 1.20%; Cr: 0.20% or more and 1.20% or less; Mo: 0.20% or more and 0.60% or less; Nb: 0.010% or more and 0.050% or less; Ti: 0.005% or more and 0.030% or less; Al: 0.01% or more and 0.10% or less; B: 0.0003% or more and 0.0030% or less; V: 0% or more and 0.10% or less; Cu: 0% or more and 0.50% or less; and Ca: 0% or more and 0.0030% or less; and limited to: Ni: 0.1% or less; P: 0.012% or less;

S: 0.005% or less; and N: 0.0080% or less; and a balance consisting of Fe and inevitable impurities, wherein P<sub>cm</sub> is equal to or less than 0.22%, "A" is equal to or less than 2.0, the sum of a structural fraction of a lower bainite and a structural fraction of a martensite is equal to or more than 90%, the structural fraction of the lower bainite is equal to or more than 70%, an aspect ratio of a prior austenite grain is equal to or more than 2, a yield strength is equal to or more than 885 MPa, and a tensile strength is equal to or more than 950 MPa and equal to or less than 1130 MPa.

**FIG. 1**



**Description**

## Technical Field

5 **[0001]** The present invention relates to a high-strength steel plate having excellent weldability and a method of manufacturing the same. In particular, the present invention relates to a high-strength steel plate which is used as a structural member of a construction machine or an industrial machine, has a yield strength of equal to or more than 885 MPa, a tensile strength of equal to or more than 950 MPa and equal to or less than 1130 MPa, and generally has a thickness of equal to or more than 6 mm and equal to or less than 25 mm, and a method of manufacturing the same.

10 Priority is claimed on Japanese Patent Application No. 2010-248032, filed November 5, 2010, the content of which is incorporated herein by reference.

## Background Art

15 **[0002]** Recently, there is a tendency to increase the size of construction machines such as cranes and concrete pumping vehicles more and more with high-rise buildings. In order to suppress an increase in weight with the increase in size of the construction machine, needs for a lightweight structural member have been increased, and a demand for so-called 100-kg/mm<sup>2</sup> steel class high-strength steel (for example, yield strength of equal to or more than 885 MPa and tensile strength of equal to or more than 950 MPa) is tendency to further increase. On the other hand, since a large

20 additional amount of alloy elements is added to the high-strength steel, preheating is generally performed in order to avoid weld cracking at the time of performing a welding operation. However, there has been a demand for steel which does not require preheating to perform a more effective welding operation.

**[0003]** Since weld crack sensitivity is very largely influenced by diffusible hydrogen, it is preferable that the diffusible hydrogen content in weld metal be suppressed to be low. However, for example, in order to particularly suppress the diffusible hydrogen content in a carbon dioxide arc welding operation which is widely used for welding a structural member of a construction machine or an industrial machine, various management including a management of lubricant oil and a cleaning of a groove surface of a welding wire and the like, as well as a selection and a management of welding material, is necessary so that hydrogen is not mixed in at the time of performing the welding operation, and thereby a load in the operation is increased. Therefore, even when approximately 3.0 to 5.0 ml/100g of the diffusible hydrogen content in the carbon dioxide arc welding, which is thought to be mixed in when welding operation management is slightly

25 insufficient, is contained in the steel, it is preferable for steel to have a sufficiently low crack sensitivity in which cracking is not generated when welding is performed without preheating.

**[0004]** In a general strength standard of a 100-kg/mm<sup>2</sup> steel class steel plate, while yield strength is equal to or more than 885 MPa, and an upper limit of yield strength is not present, tensile strength is, for example, in a range of equal to or more than 950 MPa and equal to or less than 1130 MPa and an upper limit of tensile strength is present. A steel plate used for a construction machine or the like is usually bent and when the tensile strength of the steel plate exceeds a specified upper limit, a load which is necessary for bending work is increased. For this reason, it is necessary that the tensile strength of a steel plate not be excessively increased in consideration of a case where work is limited due to facility capacity.

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**[0005]** For example, with respect to the high-strength steel plate having a yield strength of 885 MPa-class, high tensile strength steel plates having a tensile strength of 950 MPa-class are disclosed in Patent Documents 1 and 2. However, these steel plates are relatively thick and used for a penstock. Due to this, a large amount of Ni is added to these steel plates as an essential element in order to secure toughness without particularly considering bending workability and thereby, the steel plates are not economical for use in a construction machine.

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**[0006]** In Patent Document 3, high tensile strength steel having excellent weldability and economic efficiency is disclosed. In the technology, a weld crack sensitivity index P<sub>cm</sub> is suppressed to be equal to or less than 0.29 so that weldability is secured. However, the lowest crack stopping preheating temperature is 100°C in a y-groove weld cracking test, and it is thought that weldability cannot be secured in welding without preheating.

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**[0007]** In Patent Document 4, a technology relating to high tensile strength steel having excellent weldability and arrestability is disclosed. In the technology, it is necessary to add Ni in order to secure toughness, and the steel plate is not economical for use in a construction. In addition, while cracking is not generated in a y-groove weld cracking test even without preheating, the diffusible hydrogen content is 1.2 ml/100g under the test conditions. Due to this, in this case, it is estimated that a load is increased at the time of performing a welding operation to manage the diffusible hydrogen content of weld metal.

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**[0008]** In Patent Document 5, a technology relating to high tensile strength steel having excellent weldability and HIC resistance is disclosed. In the technology, it is necessary to add Ni and 0.6% or more of Mo in order to secure toughness, and the steel plate is not economical for use in a construction machine. In addition, while cracking is not generated in a y-groove weld cracking test even without preheating, the diffusible hydrogen content is limited to 1.5 ml/100g under

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the test conditions. Due to this, in this case, it is estimated that a load is increased at the time of performing a welding operation to manage the diffusible hydrogen content in weld metal.

**[0009]** In Patent Document 6, a method in which a steel plate having a tensile strength exceeding 980 MPa is manufactured in a non-thermal refining manner is disclosed. In the method, it is necessary to add a large amount of alloy elements such as 1.5% or more of Mn in the steel in order to secure the tensile strength exceeding 980 MPa with a very small amount of C which is equal to or less than 0.025%, and particularly, when the amount of Mn is large, there is concern that the cracking sensitivity of a segregation portion is degraded. However, there is no estimated value of weldability and excellent weldability cannot be expected.

**[0010]** In Patent Document 7, a hot rolled steel sheet having a tensile strength of 950 MPa or more in which bending workability and weldability are considered is disclosed. Since it is necessary to add a large amount of Ti in the hot rolled steel sheet, it is thought that weldability is degraded. In addition, since it is necessary to add Ni in order to compensate for a decrease in toughness due to the addition of the large amount of Ti, there is a problem in economic efficiency.

**[0011]** In Patent Document 8, a method of manufacturing a steel plate which is mainly used for a line pipe and has a tensile strength of 950 MPa or more and excellent toughness and weldability is disclosed. Since it is necessary that the amount of Mn is equal to or more than 1.8%, there is concern that the cracking sensitivity of a segregation portion is degraded, and since low temperature rolling is necessary in a ferrite-austenite two-phase region, productivity is low.

#### Citation List

Patent Document

#### **[0012]**

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. H10-265893

[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. H08-269542

[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. H06-158160

[Patent Document 4] Japanese Unexamined Patent Application, First Publication No. H11-36042

[Patent Document 5] Japanese Unexamined Patent Application, First Publication No. H11-172365

[Patent Document 6] Japanese Unexamined Patent Application, First Publication No. 2004-84019

[Patent Document 7] Japanese Unexamined Patent Application, First Publication No. H05-230529

[Patent Document 8] Japanese Unexamined Patent Application, First Publication No. H08-269546

#### Summary of Invention

Technical Problem

**[0013]** An object of the present invention is to economically provide a high-strength steel plate having excellent weldability which is used as a structural member of a construction machine or an industrial machine, has a yield strength of equal to or more than 885 MPa, a tensile strength of equal to or more than 950 MPa and equal to or less than 1130 MPa, and generally has a thickness of equal to or more than 6 mm and equal to or less than 25 mm, and a method of manufacturing the same.

Solution to Problem

**[0014]** The summary of the present invention is described as follows:

(1) A high-strength steel plate according to an aspect of the present invention has a chemical composition containing, % by mass: C: 0.05% or more and less than 0.10%; Si: 0.20% or more and 0.50% or less; Mn: 0.20% or more and less than 1.20%; Cr: 0.20% or more and 1.20% or less; Mo: 0.20% or more and 0.60% or less; Nb: 0.010% or more and 0.050% or less; Ti: 0.005% or more and 0.030% or less; Al: 0.01 % or more and 0.10% or less; B: 0.0003% or more and 0.0030% or less; V: 0% or more and 0.10% or less; Cu: 0% or more and 0.50% or less; and Ca: 0% or more and 0.0030% or less; and limited to: Ni: 0.1% or less; P: 0.012% or less; S: 0.005% or less; and N: 0.0080% or less; and a balance consisting of Fe and inevitable impurities, wherein P<sub>cm</sub> defined by a following (Formula 1) is equal to or less than 0.22%, A defined by a following (Formula 2) is equal to or less than 2.0, a sum of a structural fraction of lower bainite and a structural fraction of a martensite is equal to or more than 90%, the structural fraction of the lower bainite is equal to or more than 70%, an aspect ratio of a prior austenite grain is equal to or more than 2, a yield strength is equal to or more than 885 MPa, and a tensile strength is equal to or more than 950 MPa and equal to or less than 1130 MPa.

$$P_{cm}=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B]$$

... (Formula 1)

$$A=([Mn]+1.5\times[Ni])/([Mo]+1.2\times[V]) \dots \text{(Formula 2)}$$

where [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] are % by mass of C, Si, Mn, Cu, Ni, Cr, Mo, V, and B in a chemical composition, respectively.

(2) In the high-strength steel plate according to (1), a number density of a cementite which is equal to or more than 50 nm may be equal to or less than 20 pieces/ $\mu\text{m}^3$ .

(3) In the high-strength steel plate according to (1) or (2), a thickness may be equal to or more than 6 mm and equal to or less than 25 mm.

(4) A method of manufacturing a high-strength steel plate according to an aspect of the present invention includes heating a steel whose chemical composition contains, % by mass: C: 0.05% or more and less than 0.10%; Si: 0.20% or more and 0.50% or less; Mn: 0.20% or more and less than 1.20%; Cr: 0.20% or more and 1.20% or less; Mo: 0.20% or more and 0.60% or less; Nb: 0.010% or more and 0.050% or less; Ti: 0.005% or more and 0.030% or less; Al: 0.01% or more and 0.10% or less; B: 0.0003% or more and 0.0030% or less; V: 0% or more and 0.10% or less; Cu: 0% or more and 0.50% or less; and Ca: 0% or more and 0.0030% or less, and limited to: Ni: 0.1% or less; P: 0.012% or less; S: 0.005% or less; and N: 0.0080% or less; and a balance consisting of Fe and inevitable impurities, in which  $P_{cm}$  defined by a following (Formula 3) is equal to or less than 2.0, and A defined by a following (Formula 4) is equal to or less than 2.0, to 1100°C or greater; performing hot rolling on the steel so that a cumulative rolling reduction ratio in a non-recrystallization temperature region is equal to or more than 60%; and performing on-line accelerated cooling on the steel from a temperature of equal to or more than Ar3 to a temperature of equal to or less than 450°C and equal to or more than 300°C at a cooling rate of equal to or more than 10°C/s and performing air cooling after stopping the accelerated cooling.

$$P_{cm}=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B]$$

... (Formula 3)

$$A=([Mn]+1.5\times[Ni])/([Mo]+1.2\times[V]) \dots \text{(Formula 4)}$$

where [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] are % by mass of C, Si, Mn, Cu, Ni, Cr, Mo, V, and B in a chemical composition, respectively.

#### Advantageous Effects of Invention

**[0015]** According to the present invention, it is possible to economically provide a high-strength steel plate having excellent weldability which is used as a structural member of a construction machine or an industrial machine, has a yield strength of equal to or more than 885 MPa, and generally has a thickness of equal to or more than 6 mm and equal to or less than 25 mm.

#### Brief Description of Drawings

##### **[0016]**

FIG. 1 is a graph showing a relationship between  $P_{cm}$  and a crack stopping preheating temperature in a y-groove weld cracking test.

FIG. 2 is a graph showing a relationship between a structural fraction of lower bainite and a yield ratio.

FIG. 3 is a graph showing a relationship between an A value and a structural fraction of lower bainite.

FIG. 4 is a flowchart schematically showing a method of manufacturing a high-strength steel plate according to an

embodiment of the present invention.

#### Description of Embodiments

5 **[0017]** In order to decrease weld crack sensitivity, it is known that it is effective to decrease a weld crack sensitivity index  $P_{cm}$ . The inventors examined to what extent the  $P_{cm}$  needs to be reduced not to generate weld cracking without preheating even when approximately 3.0 to 5.0 ml/100g of the diffusible hydrogen content, which is thought to be mixed when welding operation management was insufficient in carbon dioxide arc welding, is contained in steel. A y-groove weld cracking test (a weld heat input of 1.7 kJ/mm) specified by JIS Z3158 (1993) was performed on steel materials having various chemical compositions with temperature and humidity being adjusted. All testing materials had a thickness of 25 mm, and the test was necessarily performed on two testing materials under the same condition. One of the two testing materials was used as a testing material for analyzing hydrogen content, and immediately after the weld cracking test, a sample was obtained from the testing material to measure a diffusible hydrogen content using gas chromatography. A cracking presence evaluation test was performed on the other testing material only when the diffusible hydrogen content exceeded 5.0 ml/100g as a result of the analysis. The relationship between  $P_{cm}$  and a cracking prevention preheating temperature of steel shown FIG. 1 was obtained from the obtained result. That is, influences of the  $P_{cm}$  and preheating temperature of the steel on the presence of cracking are shown in FIG. 1. From FIG. 1, it is found that when the  $P_{cm}$  is decreased to equal to or less than 0.22% and the diffusible hydrogen content is in a range of 5.1 to 6.0 ml/100g, cracking is not generated under the condition of non-preheating (test temperature of 25°C).

20 **[0018]** In the related art, a 100-kg/mm<sup>2</sup> steel class steel plate is manufactured by a quenching and tempering process, and generally contains tempered martensite as a main structure. However, it is not easy to obtain the strength of 100-kg/mm<sup>2</sup> class steel in a case where a main structure is tempered martensite in a component composition (chemical composition) that satisfies a low  $P_{cm}$  of equal to or less than 0.22%. A simple method for obtaining high strength with such low  $P_{cm}$  is that a martensite structure is not subjected to tempering, that is, a martensite structure in an as-quenching state is used. However, since the martensite structure in the as-quenching state has many mobile dislocations, a yield ratio (yield strength/tensile strength) is low, and when there is an attempt to secure the yield strength specified by the standard, the tensile strength is forced to increase by all means. In the standard values of the strength of 100-kg/mm<sup>2</sup> class steel according to the JIS standard, the yield strength is equal to or more than 885 MPa and the tensile strength is equal to or more than 950 MPa and equal to or less than 1130 MPa. When a target lower limit value of yield strength is set to 915 MPa, and a target upper limit value of tensile strength is set to 1100 MPa in consideration of dispersions in quality (strength) in manufacturing with respect to the above-described standard values, it is thought that the yield ratio (yield strength/tensile strength) of equal to or more than 83% is a necessary condition. It is difficult to obtain this yield ratio in the martensite structure in the as-quenching state. As a result of variously examining the relationship between the structure and strength, the inventors concluded that it is effective that, in order to obtain a high yield ratio in the as-quenching state, the structure in the as-quenching state is controlled to a structure which is mainly composed of lower bainite and the structural fraction of the martensite is lowered.

35 **[0019]** In addition, the inventors specifically investigated to the relationship among a structural fraction, strength and yield ratio of steel having various component compositions in which C content is equal to or more than 0.05% and less than 0.10%, and  $P_{cm}$  is equal to or less than 0.22%. As a result, first, in order to secure a yield strength of equal to or more than 885 MPa, it becomes apparent that it is necessary that the sum of the structural fraction of the lower bainite (lower bainite fraction) and the structural fraction of the martensite (martensite fraction) be equal to or more than 90% (structural fractions of upper bainite and ferrite are less than 10%). Furthermore, it was found that it is necessary for the steel plate structure to be a structure which is mainly composed of lower bainite (lower bainite single phase structure or a mixed structure of lower bainite and martensite) in order to satisfy a yield ratio of equal to or more than 83%, specifically, the structural fraction of the lower bainite included in the steel plate structure is equal to or more than 70% (FIG. 2). In addition, in FIGS. 2 and 3 described later, a steel plate having a thickness of 6 to 25 mm in which the sum of the fraction of lower bainite and the fraction of martensite is equal to or more than 90% is used and the structure is controlled by stopping water cooling at 300 to 450°C in the steel plate.

45 **[0020]** Next, the inventors examined a method of stably controlling the structure of the steel plate in a structure which is mainly composed of lower bainite. For example, although a cooling rate at the time of quenching is controlled to be in a predetermined range and lower bainite can be obtained, a range of cooling rates to obtain lower bainite is generally narrow and such controlling of the cooling rate is industrially inadvisable. As a manufacturing process of stably and simply obtaining a structure which is mainly composed of lower bainite, it is effective to stop water cooling at an appropriate temperature in the middle of cooling, and slow down the cooling rate by using air cooling thereafter, instead of accelerated cooling to room temperature during quenching. When a water cooling stopping temperature (steel plate temperature to transition from water cooling to air cooling) is lower than 300°C, the martensite fraction is excessively high. Contrarily, when the water cooling stopping temperature is higher than 450°C, upper bainite is easily formed. Therefore, it is desirable that the water cooling stopping temperature be equal to or more than 300°C and equal to or less than 450°C.

**[0021]** The inventors investigated in detail the relationship between the structural fraction and strength of the steel in which the sum of the structural fraction of martensite and the structural fraction of lower bainite is equal to or greater than 90% by manufacturing the steel plate having a thickness of 6 to 25 mm under the condition in which the water cooling stopping temperature is equal to or more than 300°C and equal to or less than 450°C with respect to steel grades of various component compositions in which C content is equal to or more than 0.05% and less than 0.10% and P<sub>cm</sub> is equal to or less than 0.22%.

As a result, since Mn and Ni have an effect of suppressing the lower bainite transformation, particularly in a process of stopping the water cooling in the middle of the cooling, it becomes apparent that Mn and Ni have a strong tendency to decrease the structural fraction of the lower bainite, to increase the structural fraction of the martensite when the water cooling stopping temperature is low, and to increase the structural fraction of the upper bainite (upper bainite fraction) when the water cooling stopping temperature is high. In addition, it is confirmed that Mo and V have a strong tendency to suppress the formation of ferrite and upper bainite and to increase the structural fraction of the lower bainite. Therefore, it is found that it is very effective to suppress the content of Mn and Ni and increase the content of Mo and V in order to stably obtain the structure which is mainly composed of lower bainite in the process of stopping the water cooling in the middle of the cooling. Specifically, when A (A value) defined by the following (Formula 6) is adjusted to be equal to or less than 2.0 in addition to the component composition conditions in which the C content is equal to or more than 0.05% and less than 0.10%, and P<sub>cm</sub> defined by the following (Formula 5) is equal to or less than 0.22%, and the sum of the structural fraction of the martensite and the structural fraction of the lower bainite is equal to or more than 90%, it is found that the structure having lower bainite fraction of equal to or more than 70% is reliably obtained (FIG. 3).

**[0022]** Since such a structure which is mainly composed of lower bainite is obtained and the yield ratio is equal to or more than 83%, it is possible to stably satisfy the lower limit of the yield strength (885 MPa) and the upper limit of the tensile strength (1130 MPa) in consideration of a certain degree of dispersions in strength.

$$P_{cm}=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B]$$

... (Formula 5)

$$A=([Mn]+1.5\times[Ni])/([Mo]+1.2\times[V]) \dots \text{(Formula 6)}$$

In the Formulas, [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] are respectively % by mass of C, Si, Mn, Cu, Ni, Cr, Mo, V, and B in the chemical composition.

**[0023]** Hereinafter, a high-strength steel plate according to an embodiment of the present invention will be described in detail.

First, the reason to limit a component in steel of the present embodiment is described. Hereinafter, "%" represents "% by mass".

C is an important element that has a significant effect on the strength of steel of the present embodiment which has a structure which is mainly composed of lower bainite. In order to obtain a yield strength of equal to or more than 885 MPa, it is necessary for the C content to be equal to or more than 0.05%, and preferably equal to or more than 0.055% or equal to or more than 0.060%. However, when the C content is equal to or more than 0.10%, the tensile strength is excessively high. Therefore, the C content is less than 0.10%, and desirably equal to or less than 0.095% and equal to or less than 0.090%.

**[0024]** Since Si suppresses cementite from coarsening during slow cooling after stopping water cooling in the process of stopping the water cooling in the middle of the cooling described later, it is advantageous that Si content is high to obtain high strength. For this reason, the Si content is equal to or more than 0.20% and desirably equal to or more than 0.25% or equal to or more than 0.30%. However, when Si is excessively added to steel, there is a concern that toughness thereof may be degraded, and the upper limit of the Si content is 0.50%, and desirably 0.45% or 0.40%.

**[0025]** Mn is an element which is effective in improving strength by improving hardenability. For this reason, Mn content is equal to or more than 0.20%, desirably equal to or more than 0.30% or equal to or more than 0.50%. However, Mn has an effect of suppressing lower bainite transformation, particularly in the process of stopping the water cooling in the middle of the cooling, it becomes apparent that Mn has a strong tendency to decrease the structural fraction of the lower bainite, to increase the structural fraction of the martensite when the water cooling stopping temperature is low, and to increase the upper bainite fraction when the water cooling stopping temperature is high. In particular, when the Mn content is equal to or more than 1.20%, it is difficult to obtain a yield ratio of equal to or more than 83%, and therefore the Mn content is less than 1.20% and desirably 1.00% or equal to or less than 0.90%.

**[0026]** Since Cr is effective in improving strength by improving hardenability, Cr content is equal to or more than 0.20% and desirably equal to or more than 0.25%, or equal to or more than 0.30%. However, when Cr is excessively added to steel, weldability is degraded and thereby, the Cr content is equal to or less than 1.20%, and desirably equal to or less than 1.10% or equal to or less than 1.00%.

**[0027]** Mo is effective for stably forming lower bainite in the process of stopping the water cooling in the middle of the cooling described later by suppressing the ferrite formation. For this reason, it is necessary that the Mo content be equal to or more than 0.20% and it is preferable to be equal to or more than 0.25% or equal to or more than 0.30%. However, when a large amount of Mo is added to steel, weldability is deteriorated and also, Mo is an expensive element. Therefore, the Mo content is equal to or less than 0.60%, and desirably equal to or less than 0.58% or equal to or less than 0.55%.

**[0028]** Since Ni has an effect of suppressing lower bainite transformation similar to Mn, particularly in the process of stopping the water cooling in the middle of the cooling, Ni has a strong tendency to decrease the structural fraction of the lower bainite and to increase the structural fraction of the martensite when the water cooling stopping temperature is low, and to increase the upper bainite fraction when the water cooling stopping temperature is high. For this reason, when Ni is added to steel, it is difficult to obtain a yield strength of equal to or more than 83%. Therefore, Ni is not intentionally added to steel, and Ni content is suppressed to be in a range in which Ni is inevitably contained in the steel. Specifically, the upper limit of the Ni content is 0.1%, and desirably 0.05% or 0.04%. The lower limit of the Ni content does not need to be particularly limited and is 0%. In addition, when Cu is added to steel as a selective element, Ni whose content is 0.5 times or more of Cu content may be added to steel while limiting the Ni content to less than the above-described Ni content.

**[0029]** Nb forms fine carbide during rolling and widens a non-recrystallization temperature region to enhance a controlled rolling effect so that Nb improves toughness by grain refining. Therefore, Nb content is equal to or more than 0.010% and desirably equal to or more than 0.015% or equal to or more than 0.020%. However, when Nb is excessively added to steel, weldability is deteriorate and thereby, the Nb content is equal to or less than 0.050%, and desirably equal to or less than 0.045% or equal to or less than 0.040%.

**[0030]** In the present embodiment, B is used in order to secure suitable hardenability to obtain the lower bainite structure. In order to obtain the suitable hardenability, it is necessary to secure free B at the time of direct quenching. Since N forms BN to decrease the free B, a suitable amount of Ti is added to steel to not form BN and N is fixed as TiN.

**[0031]** Ti is contained in steel to fix N as TiN. That is, Ti content in the steel is equal to or more than 0.005% and desirably 0.010% or equal to or more than 0.012%. However, since an excessive addition of Ti degrades weldability in some cases, the upper limit of the Ti content is 0.030%, and desirably 0.025% or 0.020%.

**[0032]** B has an effect for improving hardenability of steel, and it is necessary that B content is equal to or more than 0.0003% to exhibit the effect, and preferably equal to or more than 0.0005% or equal to or more than 0.0010%. However, when B whose content exceeds 0.0030% is added to steel, weldability and toughness are degraded. Therefore, the B content is equal to or less than 0.0030%, and desirably equal to or less than 0.0025% or equal to or less than 0.0020%.

**[0033]** When N is excessively contained in steel, BN is formed as described above so that the hardenability improvement effect of B is inhibited and toughness is degraded. Therefore, N content is suppressed to be equal to or less than 0.0080%, and desirably equal to or less than 0.0060% or equal to or less than 0.0050%. In addition, since N is inevitably contained in steel, the lower limit of the N content does not need to be particularly limited, and is 0%.

**[0034]** Al is added to steel as a deoxidizing material, and Al content in the steel is generally equal to or more than 0.01%. However, since an excessive addition of Al degrades toughness in some cases, the upper limit of the Al content is 0.10%, and desirably 0.08% or 0.05%.

**[0035]** P is a harmful element that degrades toughness. Therefore, P content is suppressed to be equal to or less than 0.012%, and desirably equal to or less than 0.010% or equal to or less than 0.008%. In addition, since P is an inevitable impurity, the lower limit of the P content does not need to be particularly limited and is 0%.

**[0036]** Since S is a harmful element that degrades bending workability by forming MnS, it is desirable to decrease the S content as much as possible. Therefore, the S content is suppressed to be equal to or less than 0.005%, and desirably equal to or less than 0.004% or equal to or less than 0.003%. In addition, since S is an inevitable impurity, the lower limit of the S content does not need to be particularly limited and is 0%.

**[0037]** The elements described above are basic components (basic elements) of the steel according to the present embodiment, and the chemical composition containing the basic elements and composed of a balance Fe and inevitable impurities is a basic composition of the present embodiment. However, in addition to the basic composition (instead of a part of the balance Fe), the following elements (selective elements) may be further contained in the present embodiment as needed. In addition, even when these selective elements are inevitably mixed, the effect of the present embodiment is not impaired.

**[0038]** In other word, one or more kinds selected from V, Cu, and Ca can be added to the steel as the selective element, in addition to the basic components.

Since V enhances a hardenability, has a precipitation strengthening effect of a tempered martensite structure or a tempered bainite structure and is effective in improving strength, V may be added as needed. However, since a large

amount of V is added to inhibit weldability in some cases, and V is an expensive element, a V content is equal to or less than 0.10%, and desirably equal to or less than 0.090% or equal to or less than 0.080%. In addition, in order to reduce the alloy cost, it is unnecessary to intentionally add V to the steel, and the lower limit of the V content is 0%.

Cu is an element that improves strength by solid-solution strengthening, and Cu may be added as needed. For example, Cu can be added to steel so that a Cu content is equal to or more than 0.05%. However, when a large amount of Cu is added, the effect of improving the strength by solid-solution strengthening reaches an upper limit. Due to this, the Cu content is equal to or less than 0.50%, and desirably equal to or less than 0.40% or equal to or less than 0.30%. Moreover, since Cu is an expensive element, it is unnecessary to intentionally add Cu to the steel, and the lower limit of the Cu content is 0% to reduce the alloy cost.

Ca has an effect of reducing a decrease in bending workability due to MnS by spheroidizing a sulfide of a steel plate, and Ca may be added to steel as needed. In addition, Ca is added to steel to achieve the object, and 0.0001% or more of Ca may be contained in the steel. However, since a large amount of Ca is added to degrade weldability in some cases, the upper limit of the Ca content is equal to or less than 0.0030%, and desirably equal to or less than 0.0020% or equal to or less than 0.0010%. Furthermore, it is unnecessary to intentionally add Ca to the steel, and the lower limit of the Ca content is 0% to reduce alloy cost.

**[0039]** As described above, the high-strength steel plate of the present embodiment contains the above-mentioned basic elements and has the chemical composition composed of the balance Fe and inevitable impurities, or contains the above-mentioned basic elements, one or more kinds selected from the above-mentioned selective element and has the chemical composition composed of the balance Fe and inevitable impurities.

**[0040]** In addition to the condition of the respective element content ranges, the component composition is adjusted so that the P<sub>cm</sub> defined in the above (Formula 5) is equal to or less than 0.22% in order to secure sufficient weldability as described above.

As described above, under the condition of P<sub>cm</sub> of equal to or less than 0.22%, the sum of the martensite fraction and the lower bainite fraction in the steel plate structure is equal to or more than 90%, and the lower bainite fraction needs to be equal to or more than 70% to satisfy a yield ratio of equal to or more than 83%. In order to stably and easily obtain the structure which is mainly composed of lower bainite, the component composition is adjusted so that A (A value) defined by the above (Formula 6) is equal to or less than 2.0.

Here, when V and Cu, which are selective elements, are not contained in the steel, P<sub>cm</sub> and "A" are respectively defined by the following (Formula 7) and (Formula 8). The (Formula 7) and (Formula 8) correspond to the above (Formula 5) and (Formula 6) respectively.

$$P_{cm}=[C]+[Si]/30+[Mn]/20+[Ni]/60+[Cr]/20+[Mo]/15+5\times[B] \dots \text{(Formula 7)}$$

$$A=([Mn]+1.5\times[Ni])/[Mo] \dots \text{(Formula 8)}$$

In the above (Formula 5) to (Formula 8), when each element (for example, V, Cu and Ni) corresponding to each variable in the formulas is not contained in the steel, the variable is substituted with 0.

A component composition satisfying the respective element content ranges and the conditions of P<sub>cm</sub> and A is the component composition of the present embodiment.

**[0041]** Next, the steel structure of the present embodiment will be described.

As described above, the sum of the martensite fraction and the lower bainite fraction is equal to or more than 90%, and the lower bainite fraction needs to be equal to or more than 70% to satisfy a yield ratio of equal to or more than 83% while weldability required for general welding operation management is secured.

Here, in the lower bainite, a large amount of fine cementite is present at interfaces between ferrite laths or inside ferrite lath. Since the fine cementite increases yield strength and, particularly, cementite having a diameter (equivalent circle diameter) of about 1 to 10 nm has a great yield strength improvement effect, it is desirable that a large amount of the fine cementite be present. However, it is not easy to accurately measure cementite with a size of several nm. Meanwhile, considering that a predetermined amount of cementite is formed in the steel according to the manufacturing conditions such as the C content, there is a tendency that the more fine cementite there is, the less coarse cementite there is. Here, as a result of the detailed investigation relating to the yield strength and the size and the number density of cementite, the inventors found that specifically, the fact that the number density of the relatively coarse cementite having a diameter (equivalent circle diameter) of equal to or more than 50 nm is equal to or less than 20 pieces/ $\mu\text{m}^3$  in the steel plate structure is a preferable condition to contain a large amount of the fine cementite and remarkably improve the yield strength. It is possible to easily achieve the yield ratio of equal to or more than 83% by containing a large amount of the fine cementite in the steel plate structure. In addition, the lower limit of the number density of the cementite is 0 pieces/ $\mu\text{m}^3$ .

In addition, a base material of a steel plate with a predetermined volume is eluted by electrolysis using an extraction replica method to prepare a sample which is obtained by extracting cementite, and the sample is observed by a transmission electron microscope (TEM) to obtain the number (number density) of the cementite having an equivalent circle diameter of equal to or more than 50 nm (cementite of equal to or more than 50 nm) per unit volume.

Furthermore, an aspect ratio of prior austenite (prior austenite grain) is equal to or more than 2 as described later. The aspect ratio of prior austenite is a ratio (axial ratio) of a long axis length to a short axis length of the prior austenite and an average value of each axial ratio of each prior austenite grain. Therefore, the lower limit of the aspect ratio is 1.

**[0042]** A method of manufacturing the high-strength steel plate according to an embodiment of the present invention will be described in detail. The high-strength steel plate was manufactured by the following method using a slab (steel) in which the component composition in the steel is adjusted by addition or the like so as to satisfy the component composition conditions of the present embodiment. FIG. 4 schematically shows an outline the method of manufacturing the high-strength steel plate according to the present embodiment.

In order to sufficiently solid-solute carbides or carbonitrides of alloy elements such as Nb which enhances a controlled rolling effect and Mo which contributes to hardenability in the steel, the slab is heated to a temperature (heating temperature) of equal to or more than 1100°C (S1). While the upper limit of the heating temperature is not particularly limited, it is preferable to be 1300 °C since productivity is decreased or the grain diameter of the austenite at the time of heating is extremely increased.

The heated slab is subjected to hot rolling to have a target thickness so that a cumulative rolling reduction ratio in the non-recrystallization temperature region is equal to or more than 60% (S2). The hot-rolled slab, that is, steel plate (steel) generally has a thickness of 6 to 25 mm, and the thickness is not necessarily limited thereto. Here, when the cumulative rolling reduction ratio in the non-recrystallization temperature region is equal to or more than 60%, it is possible to introduce sufficient working strain and to appropriately control strength properties of the steel plate. In addition, the non-recrystallization temperature region is a temperature region of equal to or more than Ar3 and equal to or less than 960°C, in which recrystallization (reduction of working strain) after rolling can be prevented. Moreover, the Ar3 (Ar3 transformation point) is a temperature in which the ferrite transformation is started at the time of cooling and can be measured by a hot working simulator manufactured by Fuji Electronic Industrial Co., Ltd (THERMECMASTOR-Z). In the Ar3 measurement, after the steel (sample) is heated up to 1200°C, retained for 10 minutes and cooled at 2.5°C/minute, a volume change at the time of cooling is measured to determine Ar3 on the basis of the volume change. The cumulative rolling reduction ratio in the non-recrystallization temperature region is less than 100%.

On-line accelerated cooling (water cooling) is performed on the steel plate (steel) obtained by the hot rolling after the hot rolling from the temperature of equal to or more than Ar3 (water cooling starting temperature). Hardenability can be increased by performing the on-line accelerated cooling, which is advantageous to decrease Pcm. The reason that the accelerated cooling starting temperature is set to the temperature of equal to or more than Ar3 is that ferrite or upper bainite is formed and the strength of the steel plate is significantly degraded when the accelerated cooling is started from the temperature of less than Ar3. After starting the accelerated cooling, the accelerated cooling is stopped at a temperature of equal to or more than 300°C and equal to or less than 450°C (water cooling stopping temperature), and air cooling is performed (S3). When the water cooling stopping temperature exceeds 450°C, upper bainite is easily formed and there is a tendency to decrease the yield strength and the tensile strength. In addition, when the water cooling stopping temperature is less than 300°C, the structural fraction of martensite is increased and the yield ratio is decreased so that it is difficult for the lower limit of the yield strength and the upper limit of the tensile strength to be compatible. Here, the accelerated cooling (water cooling) is cooling in which an average cooling rate in 1/4t parts of the steel plate is equal to or more than 10°C/s in a temperature region which is equal to or more than the cooling stopping temperature and equal to or less than Ar3, and the upper limit of the average cooling rate of the accelerated cooling is not particularly limited. In addition, the air cooling (retained in the atmosphere) is cooling in which an average cooling rate in 1/4t parts of the steel plate is equal to or less than 1°C/s in a temperature region which is equal to or more than the room temperature and less than the cooling stopping temperature, and the lower limit of the average cooling rate of the air cooling is not particularly limited. The 1/4t parts of the steel plate are a portion which is distant from a surface of the steel plate in a thickness center (depth) direction by a distance of 1/4 of the thickness, and the cooling rate of the 1/4t parts is obtained from temperature change obtained by performing a thermal analysis. By the air cooling after the accelerated cooling, 70% or more of lower bainite can be obtained and sufficiently fine cementite can be secured. In this case, the number density of relatively coarse cementite of equal to or more than 50 nm is equal to or less than 20 pieces/ $\mu\text{m}^3$  with respect to the most of the obtained steel plates.

In the steel plate manufactured by the present embodiment, the sum of the lower bainite fraction and the martensite fraction is equal to or more than 90%, the lower bainite fraction is equal to or more than 70%, and the aspect ratio of the prior austenite is equal to or more than 2 as a property the structure of the steel plate manufactured by the on-line accelerated cooling. In addition, it is possible to achieve the yield strength of equal to or more than 885 MPa and the tensile strength of equal to or more than 950 MPa and equal to or less than 1130 MPa without performing tempering in the present embodiment.

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On the other hand, when the steel plate is subjected to reheating and quenching after finishing cooling without performing the on-line accelerated cooling, the aspect ratio of the prior austenite in the steel plate is less than 2.0. In this case, since tempering is necessary to secure the yield ratio, the number of processes and process time are increased and industrially, cost is increased.

In addition, when the steel plate is wound after the accelerated cooling and left in a coil shape, the cooling rate in the time of air cooling is significantly decreased, and the number density of relatively coarse cementite of equal to or more than 50 nm exceeds 20 pieces/ $\mu\text{m}^2$ . For this reason, it is not desirable that the coil-shaped steel plate be subjected to air cooling after the accelerated cooling and it is desirable that the steel plates be left to be air-cooled without overlapping each other until the temperature of the steel plate is equal to or less than 250°C. That is, until the temperature of the steel plate is equal to or less than 250°C, it is desirable that the steel plates be not overlapped over each other (for example, so that the surfaces of the steel plates can be in contact with air) and be air-cooled. After the temperature of the steel plate reaches equal to or less than 250°C, the steel plates may be air-cooled in an overlapped manner. Moreover, after the hot rolling, when the steel plate obtained by performing the accelerated cooling is tempered at a high temperature, the cementite tends to be coarse so that it is difficult to secure the sufficiently fine cementite.

### Examples

**[0043]** Steel composition Nos. A to AP having component compositions shown in Tables 1 and 2 were smelted to obtain slabs and using the slabs, steel plates with numbers 1 to 55 having thickness of 6 to 25 mm were manufactured according to manufacturing conditions in Tables 3 and 4. In Tables 1 and 2, when Cu, Ni, V and Ca are not intentionally added to the steel, the amounts of these chemical components are provided with parentheses. In addition, In Tables 3 and 4, after the accelerated cooling (water cooling) was stopped, the steel plates were not wound and were air-cooled one by one, until the temperature of the steel plate is 250°C.

For the steel plates Nos. 1 to 55, the structural fractions of lower bainite and martensite, the number (number density) of cementite of equal to or more than 50 nm, the aspect ratio of prior austenite, the diffusible hydrogen content of weld metal in a y-groove weld cracking test, were measured by the following method, and the yield strength, tensile strength, weldability and toughness were evaluated. Tables 5 and 6 show structures and properties of the steel plates obtained from these measurements and evaluations.

**[0044]**

[Table 1]

5  
10  
15  
20  
25  
30  
35  
40  
45  
50  
55

Steel Composition No.	Component Element (% by mass)											Ceq* (% by mass)	Pcm** (% by mass)	A*** (-)	A13 (°C)					
	C	Si	Mn	Cr	Mo	Cu	Ni	Nb	Ti	Al	B					P	S	N	V	Ca
A	0.094	0.35	0.78	0.32	0.57	0.01	0.02	0.034	0.015	0.02	0.0009	0.003	0.002	0.0041	0.001	0.0001	0.446	0.204	1.42	739
B	0.088	0.37	0.47	0.87	0.48	0.02	0.03	0.021	0.014	0.03	0.0012	0.003	0.003	0.0031	0.002	0.0000	0.477	0.207	1.07	739
C	0.076	0.41	0.94	0.25	0.56	0.01	0.02	0.017	0.021	0.03	0.0012	0.004	0.001	0.0037	0.031	0.0001	0.442	0.196	1.62	743
D	0.081	0.38	0.29	1.15	0.39	0.03	0.01	0.022	0.011	0.02	0.0010	0.004	0.001	0.0031	0.001	0.0003	0.473	0.198	0.78	746
E	0.059	0.29	0.75	0.82	0.48	0.02	0.02	0.044	0.012	0.06	0.0012	0.003	0.001	0.0051	0.000	0.0001	0.481	0.187	1.62	747
F	0.090	0.24	0.58	0.97	0.28	0.01	0.04	0.015	0.012	0.03	0.0011	0.003	0.002	0.0034	0.092	0.0002	0.468	0.210	1.64	732
G	0.079	0.44	0.67	0.71	0.42	0.00	0.02	0.035	0.015	0.04	0.0009	0.002	0.001	0.0044	0.001	0.0012	0.457	0.196	1.66	744
H	0.068	0.30	0.81	0.68	0.43	0.02	0.01	0.016	0.009	0.02	0.0009	0.004	0.003	0.0052	0.047	0.0001	0.463	0.192	1.70	735
I	0.087	0.31	0.69	0.45	0.49	0.25	0.02	0.028	0.018	0.03	0.0011	0.008	0.001	0.0042	0.002	0.0001	0.428	0.206	1.46	740
J	0.081	0.42	1.02	0.27	0.58	0.01	0.01	0.027	0.012	0.02	0.0015	0.003	0.001	0.0036	0.001	0.0001	0.468	0.206	1.78	746
K	0.061	0.31	0.53	0.88	0.54	0.03	0.02	0.021	0.010	0.03	0.0010	0.004	0.001	0.0044	0.002	0.0002	0.474	0.185	1.03	745
L	0.072	0.39	0.69	0.89	0.31	0.02	0.03	0.021	0.012	0.04	0.0022	0.002	0.002	0.0048	0.062	0.0009	0.464	0.203	1.91	740
M	0.077	0.28	0.66	0.59	0.55	0.01	0.01	0.035	0.009	0.02	0.0019	0.001	0.003	0.0041	0.003	0.0001	0.455	0.196	1.22	737
N	0.034	0.31	0.92	1.05	0.51	0.02	0.01	0.021	0.012	0.03	0.0012	0.003	0.001	0.0036	0.001	0.0002	0.538	0.184	1.83	742
O	0.124	0.28	0.44	0.42	0.29	0.01	0.03	0.016	0.015	0.04	0.0011	0.005	0.002	0.0034	0.002	0.0001	0.366	0.202	1.66	727
P	0.077	0.13	0.76	0.65	0.52	0.01	0.02	0.012	0.015	0.03	0.0012	0.004	0.002	0.0048	0.001	0.0000	0.470	0.193	1.52	743
Q	0.085	0.91	0.57	0.29	0.37	0.00	0.01	0.015	0.012	0.03	0.0011	0.004	0.001	0.0035	0.003	0.0001	0.369	0.189	1.57	728
R	0.087	0.37	0.08	0.97	0.42	0.02	0.02	0.014	0.011	0.03	0.0014	0.003	0.001	0.0033	0.000	0.0002	0.415	0.188	0.26	750
S	0.065	0.36	1.44	0.34	0.55	0.03	0.04	0.020	0.012	0.04	0.0009	0.004	0.002	0.0046	0.001	0.0001	0.527	0.209	2.72	729
T	0.078	0.30	0.73	0.47	0.49	0.02	0.02	0.024	0.020	0.03	0.0021	0.018	0.001	0.0031	0.001	0.0002	0.429	0.193	1.55	741
U	0.080	0.31	0.82	0.41	0.48	0.01	0.01	0.022	0.011	0.03	0.0015	0.004	0.009	0.0034	0.002	0.0001	0.432	0.192	1.73	740

\*Ceq=[C]+[Si]/24+[Mn]/6+[Ni]/40+[Cr]/5+[Mo]/4+[V]/14  
 \*\*Pcm=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\*[B]  
 \*\*\*A=([Mn]+1.5\*[Ni])/([Mo]+1.2\*[V])

[0045]

[Table 2]

Steel Composition No.	Component Element (% by mass)													Ceq* (%by mass)	Pcm** (%by mass)	A*** (-)	At3 (°C)			
	C	Si	Mn	Cr	Mo	Cu	Ni	Nb	Ti	Al	B	P	S					N	V	Ca
V	0.080	0.28	0.78	0.42	0.48	0.01	0.41	0.027	0.016	0.03	0.0009	0.004	0.002	0.0041	(0.001)	(0.0001)	0.436	0.193	2.90	728
W	0.084	0.34	0.93	0.09	0.56	0.02	0.02	0.015	0.012	0.04	0.0012	0.005	0.001	0.0004	(0.001)	(0.0001)	0.412	0.191	1.71	737
X	0.079	0.31	0.64	1.55	0.35	0.01	0.01	0.021	0.013	0.03	0.0013	0.003	0.001	0.0040	(0.002)	(0.0002)	0.596	0.230	1.86	747
Y	0.086	0.33	0.74	0.92	0.11	0.01	0.01	0.015	0.015	0.04	0.0010	0.050	0.001	0.0033	(0.001)	(0.0000)	0.435	0.193	6.79	743
Z	0.071	0.29	0.62	0.23	0.89	0.03	0.02	0.015	0.021	0.05	0.0100	0.003	0.002	0.0051	(0.002)	(0.0001)	0.456	0.235	0.73	743
AA	0.069	0.27	0.96	0.74	0.55	0.01	0.04	0.030	0.013	0.00	0.0013	0.004	0.002	0.0043	(0.003)	(0.0002)	0.527	0.208	1.84	737
AB	0.089	0.31	0.79	0.32	0.52	0.02	0.03	0.024	0.013	0.16	0.0012	0.005	0.001	0.0033	(0.001)	(0.0001)	0.428	0.197	1.60	742
AC	0.079	0.32	0.92	0.25	0.53	0.00	0.03	0.001	0.015	0.04	0.0011	0.003	0.003	0.0033	(0.000)	(0.0001)	0.429	0.190	1.82	737
AD	0.084	0.31	0.81	0.27	0.48	0.01	0.03	0.080	0.014	0.03	0.0010	0.003	0.001	0.0040	(0.001)	(0.0002)	0.407	0.186	1.78	739
AE	0.088	0.31	0.85	0.51	0.54	0.02	0.02	0.015	0.001	0.02	0.0012	0.002	0.002	0.0038	(0.002)	(0.0002)	0.480	0.210	1.62	739
AF	0.080	0.31	0.64	0.75	0.39	0.01	0.02	0.013	0.055	0.03	0.0008	0.003	0.001	0.0050	(0.001)	(0.0001)	0.448	0.191	1.71	744
AG	0.090	0.33	0.76	0.45	0.46	0.01	0.01	0.012	0.011	0.03	0.0001	0.005	0.003	0.0044	(0.001)	(0.0001)	0.436	0.193	1.68	741
AH	0.078	0.30	0.83	0.39	0.51	0.02	0.01	0.018	0.014	0.02	0.0045	0.005	0.002	0.0038	(0.002)	(0.0001)	0.435	0.207	1.65	739
AI	0.091	0.30	0.61	0.24	0.47	0.01	0.02	0.022	0.013	0.04	0.0011	0.004	0.002	0.0102	(0.001)	(0.0001)	0.371	0.181	1.36	742
AJ	0.092	0.41	0.91	0.77	0.55	0.03	0.01	0.032	0.015	0.04	0.0011	0.003	0.003	0.0038	(0.002)	(0.0001)	0.553	0.234	1.67	741
AK	0.072	0.39	0.98	1.17	0.57	0.01	0.03	0.024	0.014	0.03	0.0012	0.005	0.001	0.0041	(0.001)	(0.0002)	0.629	0.238	1.79	741
AL	0.086	0.47	0.89	0.99	0.49	0.02	0.02	0.022	0.012	0.04	0.0009	0.003	0.001	0.0042	(0.002)	(0.0003)	0.575	0.234	1.87	743
AM	0.085	0.31	0.99	0.41	0.41	0.01	0.04	0.029	0.014	0.02	0.0011	0.005	0.001	0.0044	(0.002)	(0.0001)	0.449	0.200	2.55	735
AN	0.061	0.37	0.87	0.96	0.27	0.02	0.02	0.023	0.014	0.02	0.0011	0.005	0.001	0.0044	(0.001)	(0.0001)	0.481	0.190	3.32	742
AO	0.094	0.41	0.87	0.97	0.33	0.01	0.02	0.023	0.014	0.02	0.0011	0.005	0.001	0.0044	(0.001)	(0.0001)	0.533	0.228	2.72	741
AP	0.088	0.34	0.97	1.13	0.46	0.01	0.03	0.021	0.014	0.02	0.0011	0.005	0.001	0.0044	(0.003)	(0.0002)	0.606	0.242	2.03	739

Comparative Example Composition

\*Ceq=[C]+[Si]/24+[Mn]/6+[Ni]/40+[Cr]/5+[Mo]/4+[V]/14  
 \*\*Pcm=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5×[B]  
 \*\*\*A=(Mn)+1.5×(Ni)/(Mo)+1.2×(V)

[0046]

[Table 3]

Steel Sheet No.	Steel Composition No.	Hot Rolling and Accelerated Cooling					
		Rolling Heating Temperature (°C)	Thickness (mm)	Rolling Reduction in Non-Recrystallization Temperature Region (%)	Water Cooling Start Temperature (°C)	Water Cooling Stopping Temperature (°C)	Cooling Rate in Accelerated Cooling (°C/s)
1	A	1180	25	64	804	325	42
2	A	1170	6	70	761	420	105
3	B	1150	25	66	819	360	40
4	B	1175	9	62	750	425	71
5	C	1200	25	64	794	330	38
6	D	1165	25	63	820	370	40
7	D	1130	12	61	767	410	66
8	E	1150	25	64	809	335	41
9	E	1135	12	66	764	395	67
10	F	1160	25	66	798	405	40
11	G	1155	25	64	802	375	44
12	H	1135	25	70	799	360	37
13	I	1125	25	64	779	375	38
14	J	1180	25	65	794	410	37
15	K	1150	25	67	804	350	38
16	L	1160	25	66	787	320	41
17	M	1180	25	66	784	335	37
18	M	1145	16	69	765	365	58

Example

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(continued)

Hot Rolling and Accelerated Cooling							
Steel Sheet No.	Steel Composition No.	Rolling Heating Temperature (°C)	Thickness (mm)	Rolling Reduction in Non-Recrystallization Temperature Region (%)	Water Cooling Start Temperature (°C)	Water Cooling Stopping Temperature (°C)	Cooling Rate in Accelerated Cooling (°C/s)
Comparative Example	19	1170	25	67	820	350	43
	20	1175	25	68	782	360	40
	21	1150	25	64	820	380	40
	22	1150	25	66	816	370	37
	23	1150	25	66	810	375	42
	24	1165	25	65	789	315	38
	25	1165	25	68	792	435	43
	26	1160	25	67	804	345	39
27	1160	25	62	798	330	40	
28	1150	25	65	802	430	40	

[0047]

[Table 4]

Hot Rolling and Accelerated Cooling							
Steel Sheet No.	Steel Composition No.	Rolling Heating Temperature (°C)	Thickness (mm)	Rolling Reduction in Non-Recrystallization Temperature Region (%)	Water Cooling Start Temperature (°C)	Cooling Stopping Temperature (°C)	Cooling Rate in Accelerated Cooling (°C/s)
Comparative Example	V	1150	25	66	797	320	43
	W	1150	25	66	785	410	41
	X	1140	25	67	799	375	37
	Y	1155	25	66	805	370	42
	Z	1180	25	65	801	375	38
	AA	1175	25	66	798	350	40
	AB	1160	25	64	788	370	35
	AC	1165	25	66	813	380	43
	AD	1160	25	66	778	340	39
	AE	1160	25	68	800	375	41
	AF	1165	25	65	779	350	43
	AG	1160	25	67	804	360	41
	AH	1175	25	66	799	345	37
	AI	1165	25	64	802	350	39
	AJ	1145	25	66	789	355	40
	AK	1155	25	66	800	405	40
	AL	1125	25	65	785	380	37
	AM	1160	25	67	805	440	39
	AN	1160	25	66	799	325	38
	AO	1130	25	66	784	435	40

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(continued)

Hot Rolling and Accelerated Cooling							
Steel Sheet No.	Steel Composition No.	Rolling Heating Temperature (°C)	Thickness (mm)	Rolling Reduction in Non-Recrystallization Temperature Region (%)	Water Cooling Start Temperature (°C)	Cooling Stopping Temperature (°C)	Cooling Rate in Accelerated Cooling (°C/s)
49	AP	1130	25	67	769	330	38
50	D	<u>1050</u>	25	65	799	355	35
51	B	1170	25	63	<u>680</u>	360	30
52	A	1150	25	68	801	<u>495</u>	13
53	A	1140	25	64	798	<u>150</u>	41
54	A	1150	25	62	**	**	**
55	A	1170	25	64	802	333	7

After rolling and air cooling, steel sheets are reheated to 930°C and cooled from 810°C to 350°C at a cooling rate of 40°C/s.

[0048]

[Table 5]

Steel Sheet No.	Steel Sheet Structure				Steel Sheet Properties					Toughness vE-40 (J)
	Lower Bainite Fraction + Martensite Fraction (%)	Lower Bainite Fraction (%)	Number of Cementite of Equal to or More than 50 nm (pieces/ $\mu\text{m}^3$ )	Aspect Ratio of Prior Austenite (-)	Yield Strength (MPa)	Tensile Strength (MPa)	Diffusible Hydrogen Content in Weld Metal (ml/100g)	Weldability		
1	>95	84	0	3.4	934	1093	5.3	Pass	94	
2	92	84	1	4.8	917	1032	-	-	51*	
3	>95	>95	0	2.8	928	1047	5.7	Pass	91	
4	>95	>95	0	4.7	947	1072	-	-	39*	
5	>95	87	1	2.7	936	1089	5.5	Pass	87	
6	>95	>95	0	3.5	930	1052	5.8	Pass	96	
7	>95	92	7	3.8	920	1038	-	-	92	
8	>95	84	0	3.0	916	1052	5.6	Pass	74	
9	>95	90	1	3.4	957	1090	-	-	82	
10	>95	88	0	2.9	912	1060	5.2	Pass	92	
11	>95	>95	0	2.7	952	1077	5.1	Pass	86	
12	93	91	6	3.1	919	1044	5.4	Pass	85	
13	>95	>95	0	2.5	937	1068	5.3	Pass	72	
14	>95	73	1	2.9	895	1062	5.9	Pass	92	
15	92	86	3	3.5	895	1039	5.9	Pass	82	
16	>95	87	0	3.1	933	1092	5.6	Pass	72	
17	>95	>95	2	2.9	924	1020	5.6	Pass	98	
18	>95	92	0	3.7	946	1062	-	-	99	
19	68	67	24	1.8	852	987	5.5	Pass	140	
20	92	52	3	3.9	947	1168	5.8	Fail	41	
21	65	64	40	1.7	868	985	5.4	Pass	50	
22	92	88	1	3.2	935	1013	5.2	Pass	19	
23	84	73	5	3.1	872	997	5.4	Pass	66	
24	>95	49	1	2.8	927	1150	5.9	Pass	41	
25	75	72	15	2.2	810	933	5.8	Pass	56	
26	>95	87	1	2.7	941	1045	5.3	Pass	21	
27	>95	86	0	2.9	935	1018	5.4	Pass	19	
28	70	54	25	1.9	852	1045	5.6	Fail	42	

5 mm Subsize Charpy Specimen

Steel Sheet No.	Steel Sheet Structure			Steel Sheet Properties				Toughness VE-40 (J)	
	Lower Bainite Fraction + Martensite Fraction (%)	Lower Bainite Fraction (%)	Number of Cementite of Equal to or More than 50 nm <sup>3)</sup> (pieces/ $\mu\text{m}^3$ )	Aspect Ratio of Prior Austenite (-)	Yield Strength (MPa)	Tensile Strength (MPa)	Diffusible Hydrogen Content in Weld Metal (ml/100g)		Weldability
29	>95	51	0	3.5	922	1140	5.6	Fail	56
30	75	73	34	2.3	865	1040	5.1	Pass	56
31	>95	81	1	2.4	935	1121	5.2	Fail	33
32	72	54	18	1.7	978	1152	5.3	Pass	94
33	>95	>95	1	3.2	953	1049	5.1	Fail	44
34	91	80	4	3.8	927	1061	5.7	Pass	20
35	>95	90	2	2.4	942	1052	5.7	Pass	19
36	82	77	1	2.3	865	1012	5.3	Pass	57
37	>95	>95	0	3.2	935	1041	5.3	Pass	21
38	60	56	79	1.6	825	930	5.1	Pass	98
39	90	87	0	2.9	935	1044	5.2	Pass	20
40	33	28	175	1.2	840	937	5.3	Pass	130
41	>95	>95	2	2.8	912	1050	5.2	Pass	19
42	50	47	36	1.5	815	935	5.7	Pass	31
43	>95	>95	0	3.4	977	1095	5.4	Fail	61
44	92	87	0	3.3	938	1035	5.9	Fail	41
45	>95	92	1	2.9	971	1087	5.1	Fail	39
46	67	55	45	2.3	867	979	5.6	Pass	37
47	>95	15	1	3.1	855	1110	5.3	Pass	49
48	46	46	58	1.6	851	982	5.2	Fail	31
49	>95	21	0	3.5	904	1152	5.8	Fail	51
50	66	64	22	2.2	841	987	5.5	Pass	75
51	67	36	5	1.6	805	957	5.4	Pass	66
52	37	37	141	1.5	812	915	5.2	Pass	37
53	>95	24	0	3.5	907	1161	5.5	Pass	62
54	91	85	4	1.1	825	917	5.4	Pass	68
55	55	55	55	2.1	842	920	5.8	Pass	22

[Table 6]

[64001]

[0050] After a cross-section of the steel plate had been subjected to mirror polishing, the cross-section of the steel plate was subjected to nital corrosion and the vicinity of the 1/4t parts of the cross-section of the steel plate was observed with a scanning electron microscope (SEM). Here, a magnification was 3000 times and 15 fields of view in a range of 25 x 20  $\mu\text{m}$  were selected. Areas of lower bainite and martensite were measured from images obtained from the observation to calculate the respective structural fractions (area ratios). In addition, in the same manner as that of the images, the long axis length and the short axis length of the prior austenite were measured, and an aspect ratio was obtained by dividing the long axis length by the short axis length from an image obtained by observing a cross-section which is parallel to a rolling direction (longitudinal direction) of the steel plate in the vicinity of the 1/4t parts (L-shaped cross-section, a cross-section perpendicular to a thickness center direction). Moreover, a base material of a steel plate with a predetermined volume from the steel plates Nos. 1 to 55 was eluted by electrolysis using the extraction replica method to prepare a sample which was obtained by extracting cementite, and the sample was observed by a transmission electron microscope (TEM) to obtain the number density of the cementite having an equivalent circle diameter of equal to or more than 50 nm. In the number measurement, while precipitate other than the cementite was distinguished by EDX, precipitate of equal to or more than 50 nm, other than the cementite was rarely present in the steel plates Nos. 1 to 55. Moreover, Ar3 (Ar3 transformation point) was measured by a hot working simulator manufactured by Fuji Electronic Industrial Co., Ltd (THERMECMASTOR-Z), and in the Ar3 measurement, after the steel (sample) was heated up to 1200°C, retained for 10 minutes and cooled at 2.5°C/minute, a volume change at the time of cooling was measured to determine Ar3 on the basis of the volume change.

[0051] In addition, the yield strength and the tensile strength were measured by acquiring 1A-type specimens for a tensile test specified in JIS Z 2201 (1998) from the steel plates Nos. 1 to 55 according to a tensile test specified in JIS Z 2241 (1998). As a result of the tensile test, when the yield strength is equal to or more than 885 MPa, and the tensile strength is equal to or more than 950 MPa and equal to or less than 1130 MPa, the yield strength and the tensile strength of the steel plate were respectively evaluated as "Pass".

[0052] A y-groove weld cracking test specified by JIS Z 3158 (1993) was performed on the steel plates Nos. 1 to 55 to evaluate weldability. In the y-groove weld cracking test, temperature and humidity were adjusted to perform carbon dioxide arc welding at a heat input of 15 kJ/cm, and the steel plate provided for the evaluation had a thickness of 25 mm. As a result of the test, in a case that a root crack ratio was 0 without preheating (room temperature 25°C), the weldability of the steel plate was evaluated as "Pass". In addition, since it is considered that the steel plates Nos. 2, 4, 7, 9 and 18 having a thickness of 6 to 16 mm have the same weldability as that of the steel plates Nos. 1, 3, 6, 8 and 17 having similar components, the y-groove weld cracking test was omitted for the steel plates Nos. 2, 4, 7, 9 and 18. In addition, in the y-groove weld cracking test, each of two testing materials was subjected to welding in which the same conditions such as temperature, humidity and a heat input were set, and one of the two testing materials was sampled immediately after the welding so that the diffusible hydrogen content of the weld metal was measured using the gas chromatography method specified by JIS Z 3118 (2007). As a result of the analysis, only when the diffusible hydrogen content exceeded 5.0 ml/100g, the other testing material was subjected to the evaluation test of weldability (presence of cracking).

[0053] 4-type Charpy specimens specified in JIS Z 2201 (1998) were sampled at a right angle with respect to the rolling direction from the thickness center portion, and an absorbed energy of a Charpy impact test was measured at -40°C to evaluate toughness on the basis of an average value (vE-40) of the absorbed energies of 3 specimens so that 27 J was set to a target value of toughness. In addition, a 5 mm subsize Charpy specimen was sampled for the steel plate having a thickness of 6 mm and 9 mm, and an absorbed energy value of equal to or more than 27 J per 1 cm<sup>2</sup> was set to a target value of toughness.

[0054] In addition, chemical component amounts, Pcm values, and A values underlined in Tables 1 and 2 do not satisfy the conditions of the present invention. In the same manner, numerical values underlined in Tables 3 and 4 represent values that do not satisfy the manufacturing conditions of the present invention. Numerical values underlined in Tables 5 to 6 represent values that do not satisfy the steel plate structure of the present invention or have insufficient properties. In all the steel plates Nos. 1 to 18 in Table 2, the sum of the lower bainite fraction and the martensite fraction (lower bainite fraction + martensite fraction) is equal to or more than 90%, the lower bainite fraction is equal to or more than 70%, and the yield strength, tensile strength, yield ratio, weldability and toughness satisfied the target value. Here, in the y-groove weld cracking test which was performed to evaluate the weldability, since the diffusible hydrogen content in the weld metal was in a range of 5.1 to 6.0 ml/100g, it was confirmed that weld cracking was not generated in the range. Therefore, in the carbon dioxide arc welding, when the diffusible hydrogen content is 3.0 to 5.0 ml/100g which is thought to be mixed when the welding operation management was slightly insufficient, the diffusible hydrogen content is lower than the diffusible hydrogen content in the range so that it can be considered that the weld cracking is not generated. Here, when tempering was performed on the steel plates Nos. 1 to 18 at 500°C, the number density of the relatively coarse cementite of equal to or more than 50 nm was increased and the weld strength was degraded in comparison with a case where tempering was not performed. In addition, for example, in the manufacturing conditions

of the steel plate No. 7, when the cumulative rolling reduction ratio in the non-recrystallization temperature region was changed to less than 60%, any of the strength properties (for example, toughness) was degraded in comparison with the steel plate No. 7 because of not being capable of introducing sufficient working strain in the steel.

Contrarily, while the steel plates Nos. 19 to 42 in which each chemical component amount underlined in Tables 1 and 2 does not satisfy the conditions of the present invention satisfy the manufacturing conditions of the present invention, one or more of the yield strength, tensile strength, weldability, and toughness do not reach the target value.

**[0055]** In the steel plates Nos. 43 to 49, each chemical component amount satisfied the conditions of the present invention. However, in the steel plates Nos. 43 to 45 in which the Pcm value does not satisfy the conditions of the present invention, weldability was failed. In the same manner, in the steel plates Nos. 46 to 47 in which the A value does not satisfy the conditions of the present invention, the yield strength was failed. In addition, in the steel plates Nos. 48 and 49 in which any one of Pcm and A values does not satisfy the conditions of the present invention, the weldability and the yield strength were failed.

**[0056]** In the steel plates Nos. 50 to 55, each chemical component amount and values of Pcm and A satisfied the conditions of the present invention. However, in the steel plates Nos. 50 to 55, any one of manufacturing conditions did not satisfy the conditions of the present invention. For this reason, in the steel plates Nos. 50 to 55, the structure condition of the steel plate (one or more of lower bainite + martensite fractions and the lower bainite fractions) did not satisfy the conditions of the present invention and one or more of the yield strength, tensile strength and toughness were also failed. In addition, in the steel plate No. 54, after the slab was rolled to manufacture a steel plate and air cooling was performed on the steel plate, the steel plate was reheated to 930°C, and cooled in a temperature region which is from 810°C to 350°C at a cooling rate of 40°C/s. Therefore, for example, manufacturing cost was increased in the steel plate No. 54 in comparison with the steel plate No. 52.

#### Industrial Applicability

**[0057]** It is possible to economically provide a high-strength steel plate which has a yield strength of equal to or more than 885 MPa, and a tensile strength of equal to or more than 950 MPa and equal to or less than 1130 MPa, and a method of manufacturing the same.

#### Claims

1. A high-strength steel plate having a chemical composition comprising, % by mass:

C: 0.05% or more and less than 0.10%;  
 Si: 0.20% or more and 0.50% or less;  
 Mn: 0.20% or more and less than 1.20%;  
 Cr: 0.20% or more and 1.20% or less;  
 Mo: 0.20% or more and 0.60% or less;  
 Nb: 0.010% or more and 0.050% or less;  
 Ti: 0.005% or more and 0.030% or less;  
 Al: 0.01% or more and 0.10% or less;  
 B: 0.0003% or more and 0.0030% or less;  
 V: 0% or more and 0.10% or less;  
 Cu: 0% or more and 0.50% or less; and  
 Ca: 0% or more and 0.0030% or less, and

limited to:

Ni: 0.1% or less;  
 P: 0.012% or less;  
 S: 0.005% or less; and  
 N: 0.0080% or less; and  
 a balance consisting of Fe and inevitable impurities,

wherein Pcm defined by a following (Formula 1) is equal to or less than 0.22%, "A" defined by a following (Formula 2) is equal to or less than 2.0, a sum of a structural fraction of a lower bainite and a structural fraction of a martensite is equal to or more than 90%, the structural fraction of the lower bainite is equal to or more than 70%, an aspect ratio of a prior austenite grain is equal to or more than 2, a yield strength is equal to or more than 885 MPa, and a

tensile strength is equal to or more than 950 MPa and equal to or less than 1130 MPa.

$$P_{cm}=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B]$$

... (Formula 1)

$$A=([Mn]+1.5\times[Ni])/([Mo]+1.2\times[V]) \dots \text{(Formula 2)}$$

where [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] are % by mass of C, Si, Mn, Cu, Ni, Cr, Mo, V, and B in a chemical composition, respectively.

2. The high-strength steel plate according to Claim 1, wherein a number density of a cementite which is equal to or more than 50 nm is equal to or less than 20 pieces/ $\mu\text{m}^3$ .
3. The high-strength steel plate according to Claim 1 or 2, wherein a thickness is equal to or more than 6 mm and equal to or less than 25 mm.
4. A method of manufacturing a high-strength steel plate, the method comprising:

heating a steel whose chemical composition comprises, % by mass:

C: 0.05% or more and less than 0.10%;  
 Si: 0.20% or more and 0.50% or less;  
 Mn: 0.20% or more and less than 1.20%;  
 Cr: 0.20% or more and 1.20% or less;  
 Mo: 0.20% or more and 0.60% or less;  
 Nb: 0.010% or more and 0.050% or less;  
 Ti: 0.005% or more and 0.030% or less;  
 Al: 0.01 % or more and 0.10% or less;  
 B: 0.0003% or more and 0.0030% or less;  
 V: 0% or more and 0.10% or less;  
 Cu: 0% or more and 0.50% or less; and  
 Ca: 0% or more and 0.0030% or less, and

limited to:

Ni: 0.1% or less;  
 P: 0.012% or less;  
 S: 0.005% or less; and  
 N: 0.0080% or less; and  
 a balance consisting of Fe and inevitable impurities,

in which  $P_{cm}$  defined by a following (Formula 3) is equal to or less than 0.22%, and A defined by a following (Formula 4) is equal to or less than 2.0, to 1100°C or greater;

performing hot rolling on the steel so that a cumulative rolling reduction ratio in a non-recrystallization temperature region is equal to or more than 60%; and

performing on-line accelerated cooling on the steel from a temperature of equal to or more than Ar3 to a temperature of equal to or less than 450°C and equal to or more than 300°C at a cooling rate of equal to or more than 10°C/s and performing air cooling after stopping the accelerated cooling.

$$P_{cm}=[C]+[Si]/30+[Mn]/20+[Cu]/20+[Ni]/60+[Cr]/20+[Mo]/15+[V]/10+5\times[B]$$

... (Formula 3)

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$$A=([Mn]+1.5\times[Ni])/([Mo]+1.2\times[V]) \dots \text{(Formula 4)}$$

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where [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [V], and [B] are % by mass of C, Si, Mn, Cu, Ni, Cr, Mo, V, and B in a chemical composition, respectively.

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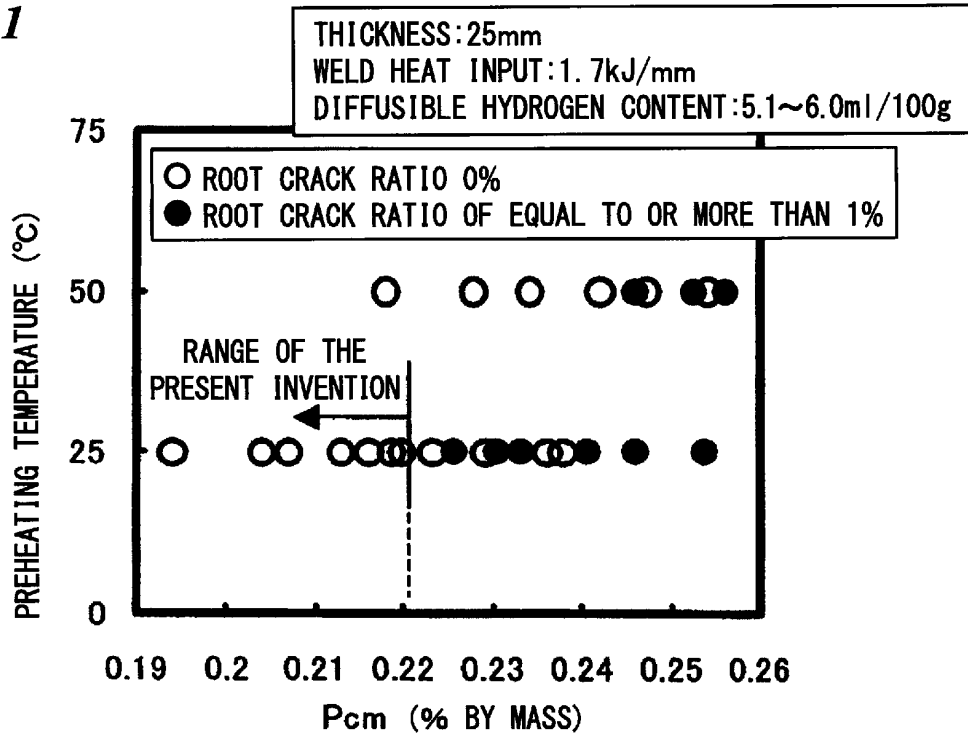
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**FIG. 1**



**FIG. 2**

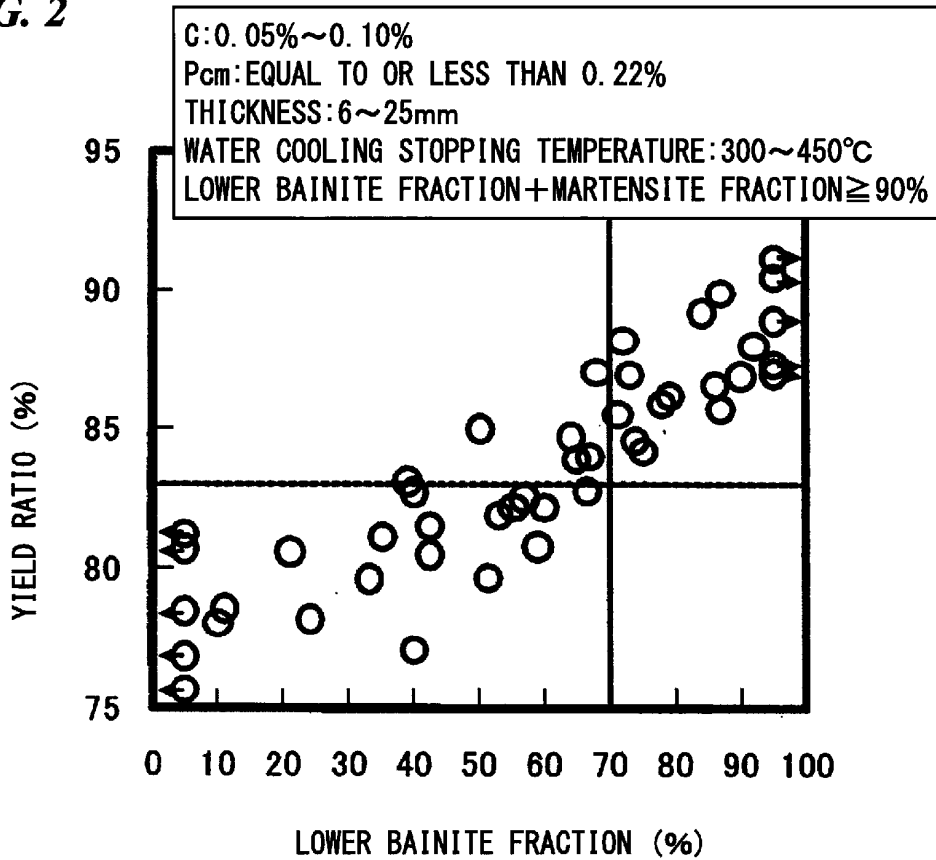


FIG. 3

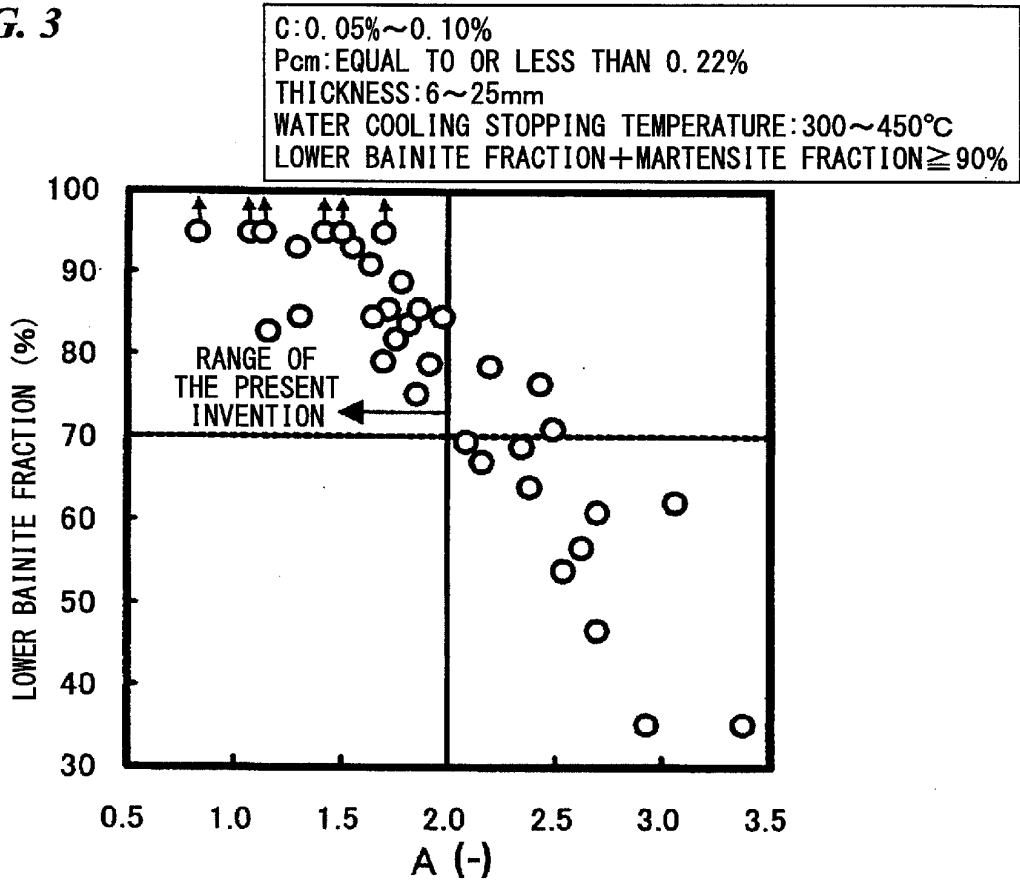
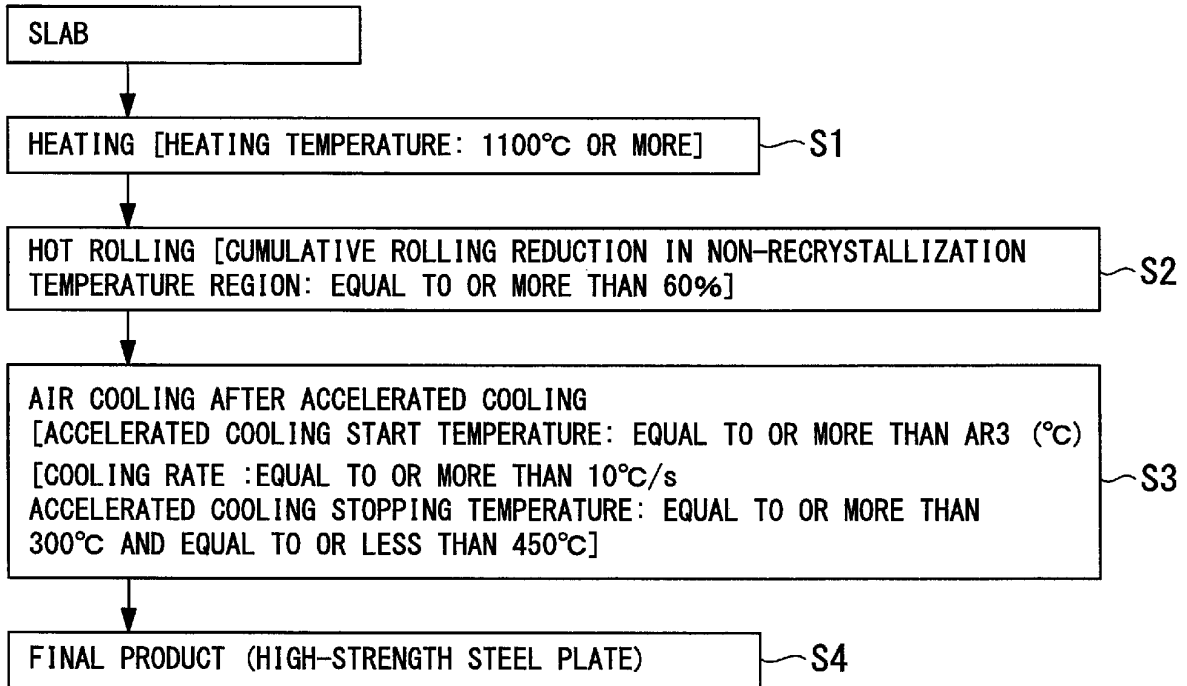


FIG. 4



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/075286

A. CLASSIFICATION OF SUBJECT MATTER C22C38/54(2006.01) i, C21D8/02(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) C22C38/00-38/60, C21D8/00-8/04		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2012 Kokai Jitsuyo Shinan Koho 1971-2012 Toroku Jitsuyo Shinan Koho 1994-2012		
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.
A	JP 11-229079 A (Sumitomo Metal Industries, Ltd.), 24 August 1999 (24.08.1999), claims; tables 1 to 4 (Family: none)	1-4
A	JP 2010-111936 A (Sumitomo Metal Industries, Ltd.), 20 May 2010 (20.05.2010), claims (Family: none)	1-4
A	JP 2-250941 A (Sumitomo Metal Industries, Ltd.), 08 October 1990 (08.10.1990), claims (Family: none)	1-4
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> 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	"I" 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 10 January, 2012 (10.01.12)	Date of mailing of the international search report 24 January, 2012 (24.01.12)	
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer	
Facsimile No.	Telephone No.	

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INTERNATIONAL SEARCH REPORT

International application No.  
PCT/JP2011/075286

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 2008-184638 A (Sumitomo Metal Industries, Ltd.), 14 August 2008 (14.08.2008), claims (Family: none)	1-4
A	JP 11-172365 A (Sumitomo Metal Industries, Ltd.), 29 June 1999 (29.06.1999), claims (Family: none)	1-4

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- JP 2004084019 A [0012]
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