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# (54) STEEL SHEET AND METHOD FOR PRODUCING SAME

(57) There is provided a steel sheet including a chemical composition consisting of, in mass%: C: 0.14 to 0.60%, Si + Al ≤ 3.00, P ≤ 0.030%, S ≤ 0.0050%, N ≤ 0.015%, B ≤ 0.0050%, C × Mn ≤ 0.80, Mn + Ni + Cu + 1.3Cr + 4(Mo + W) ≥ 0.80, 0.003 ≤ Ti + Zr + Hf + V + Nb + Ta + Sc + Y ≤ 0.20, Sn + As + Sb + Bi ≤ 0.020, Mg: 0 to 0.005%, Ca: 0 to 0.005%, REM: 0 to 0.005%, with the balance: Fe and impurities, and satisfying Ms = 546 × exp(-1.362 × C) - 11 × Si - 30 × Mn - 18 × Ni - 20 × Cu - 12 × Cr - 8(Mo + W) ≥ 200, wherein a steel micro-structure includes, in volume%: martensite ≥ 85%, retained austenite ≤ 15%, and the balance: bainite, an average block size of martensite and bainite ≤ 3.0 μm, an average axial ratio of martensite and bainite: 1.0004 to 1.0100, and a yield stress is 1000 MPa or more.

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## Description

### TECHNICAL FIELD

**[0001]** The present invention relates to a steel sheet and a method for producing the steel sheet.

### BACKGROUND ART

**[0002]** From the viewpoint of reducing a weight of an automobile body and ensuring collision safety, the application of a high-strength steel sheet as a steel sheet for an automobile has been sought. Members for an automobile include reinforcing members such as a bumper or a door guard bar as well as skeleton members such as a pillar, a sill, and a member. A high-strength steel sheet applied to these members is required to have such a collision resistance that can ensure safety of passengers at the time of collision (e.g., Patent Documents 1 to 3). Here, the collision resistance refers to properties having high reaction force properties and enabling absorbing energy at the time of crash deformation without causing a brittle fracture even when a member significantly deforms at the time of the crash deformation.

**[0003]** As a steel sheet excellent in energy absorption properties, a DP steel sheet having a duplex micro-structure of ferrite and martensite (e.g., Patent Document 4) or a TRIP steel sheet (transformation induced plasticity steel sheet) having a steel micro-structure of ferrite and bainite as well as retained $\gamma$ (e.g., Patent Document 5) is used. Further, steel sheets and members having a steel micro-structure made mainly of martensite and having high yield stresses are disclosed (e.g., Patent Documents 6 to 8).

### LIST OF PRIOR ART DOCUMENTS

### PATENT DOCUMENT

**[0004]**

Patent Document 1: JP2009-185355A
Patent Document 2: JP2011-111672A
Patent Document 3: JP2012-251239A
Patent Document 4: JP11-080878A
Patent Document 5: JP11-080879A
Patent Document 6: JP2010-174280A
Patent Document 7: JP2013-117068A
Patent Document 8: JP2015-175050A

### NON PATENT DOCUMENT

**[0005]**

Non-Patent Document 1: "Atlas for Bainitic Microstructures Vol. 1", 1992, The Iron and Steel Institute of Japan, p. 4
Non-Patent Document 2: Tadashi Maki, "Tekko no soshiki seigyo (in Japanese) (Microstructure control in steels)", 2015, Uchida Rokakuho
Non-Patent Document 3: Liu Xiao, et al., "Lattice-parameter variation with carbon content of martensite. I. X-ray-diffraction experimental study", Physical Review B, 52 (1995), pp. 9970-9978

### SUMMARY OF INVENTION

### TECHNICAL PROBLEM

**[0006]** However, the DP steel sheet or the TRIP steel sheet described in Patent Document 4 or 5 provides a low yield stress and insufficient reaction force properties, and additionally, a crack occurs in some cases at the time of crash deformation from its end face formed by shearing punching, failing to obtain a predetermined amount of energy absorption.

**[0007]** In addition, although the steel sheets described in Patent Documents 6 to 8 having a steel micro-structure made mainly of martensite provide a high yield stress, when the steel sheet is formed into a member, brittle cracking occurs in some cases at the time of crash deformation at a stress concentration such as a punching end face or a portion at which the sheet is bent, failing to absorb collision energy sufficiently.

**[0008]** The present invention has an objective to provide a steel sheet that exerts good reaction force properties when an impact load is applied to a shaped component from the steel sheet, is unlikely to cause a crack from an end face of the component or a region of the component bent at the time of the impact, and has a yield stress of 1000 MPa or more, and to provide a method for producing the steel sheet.

SOLUTION TO PROBLEM

**[0009]** The present inventors conducted intensive studies about a technique to solve the problems described above, and consequently came to obtain the following findings.

(a) By optimizing a crystal structure of martensite and further decreasing its block size to a certain value or less, it is possible to prevent or reduce the occurrence and the propagation of a crack from a stress concentration at the time of a fast and large deformation.
(b) By optimizing components and optimizing a martensitic transformation starting temperature Ms, it is possible to prevent or reduce the occurrence and the propagation of a crack from a stress concentration at the time of a fast deformation.
(c) By having a high yield stress in addition to preventing or reducing the occurrence of a crack, high reaction force properties and impact energy absorption ability can be obtained.

**[0010]** The present invention is made based on such findings and has a gist of the following steel sheet and the following method for producing the steel sheet.
**[0011]**

(1) A steel sheet having a chemical composition consisting of, in mass%:

C: 0.14 to 0.60%,
Si: more than 0% to less than 3.00%,
Al: more than 0% to less than 3.00%,
Mn: 5.00% or less,
P: 0.030% or less,
S: 0.0050% or less,
N: 0.015% or less,
B: 0 to 0.0050%,
Ni: 0 to 5.00%,
Cu: 0 to 5.00%,
Cr: 0 to 5.00%,
Mo: 0 to 1.00%,
W: 0 to 1.00%,
Ti: 0 to 0.20%,
Zr: 0 to 0.20%,
Hf: 0 to 0.20%,
V: 0 to 0.20%,
Nb: 0 to 0.20%,
Ta: 0 to 0.20%,
Sc: 0 to 0.20%,
Y: 0 to 0.20%,
Sn: 0 to 0.020%,
As: 0 to 0.020%,
Sb: 0 to 0.020%,
Bi: 0 to 0.020%,
Mg: 0 to 0.005%,
Ca: 0 to 0.005%, and
REM: 0 to 0.005%,
with the balance: Fe and impurities, and
satisfying following formulas (i) to (v), wherein
a value of Ms expressed by a following formula (vi) is 200 or more,
a steel micro-structure contains, in volume%:
martensite: 85% or more, and
retained austenite: 15% or less,

with the balance: bainite,
an average block size of martensite and bainite: 3.0 μm or less,
an average axial ratio of martensite and bainite: 1.0004 to 1.0100, and a yield stress is 1000 MPa or more:

$$Si + Al \leq 3.00 \quad (i)$$

$$C \times Mn \leq 0.80 \quad (ii)$$

$$Mn + Ni + Cu + 1.3Cr + 4(Mo + W) \geq 0.80 \quad (iii)$$

$$0.003 \leq Ti + Zr + Hf + V + Nb + Ta + Sc + Y \leq 0.20 \quad (iv)$$

$$Sn + As + Sb + Bi \leq 0.020 \quad (v)$$

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \quad (vi)$$

where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol.

(2) The steel sheet according to the above (1), wherein an average particle size of iron carbides included in the steel micro-structure is 0.005 to 0.20 μm.
(3) The steel sheet according to the above (1) or (2), wherein the steel sheet includes a plating layer on a surface of the steel sheet.
(4) A method for producing the steel sheet according to any one of the above (1) to (3), wherein

a cast piece having the chemical composition according to the above (1) is subjected to a hot-rolling step, a cold-rolling step, an annealing step, and a heat treatment step in this order,
in the hot-rolling step, the steel sheet is cooled to room temperature at an average cooling rate for a range from a rolling finish temperature to 650°C set at 8°C/s or more,
in the annealing step, the steel sheet is held within a temperature range from an $Ac_3$ point to ($Ac_3$ point + 100)°C for 3 to 90 s, and
an average cooling rate for a range from 700°C to (Ms point - 50)°C is set at 10°C/s or more, and
in the heat treatment step,
in a case where the Ms point is 250°C or more,
a holding time for a temperature range from (Ms point + 50) to 250°C is set at 100 to 10000 s, and
in a case where the Ms point is less than 250°C,
a holding time for a temperature range from (Ms point + 80) to 100°C is set at 100 to 50000 s:
where the Ms point (°C) and the $Ac_3$ point (°C) are expressed by following formulas, where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol.

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \quad (vi)$$

$$Ac_3 = 910 - 203 \times C^{0.5} + 44.7(Si + Al) - 30 \times Mn + 700 \times P - 15.2 \times Ni - 26 \times Cu - 11 \times Cr + 31.5 \times Mo \quad (vii)$$

(5) A method for producing the steel sheet according to any one of the above (1) to (3), wherein

a cast piece having the chemical composition according to the above (1) is subjected to a hot-rolling step, an annealing step, and a heat treatment step in this order,
in the hot-rolling step, the steel sheet is cooled to room temperature at an average cooling rate for a range from a rolling finish temperature to 650°C set at 8°C/s or more,
in the annealing step, the steel sheet is held within a temperature range from an $Ac_3$ to ($Ac_3$ + 100)°C for 3 to 90 s, and
an average cooling rate for a range from 700°C to (Ms - 50)°C is set at 10°C/s or more, and
in the heat treatment step,
in a case where the Ms point is 250°C or more,
a holding time for a temperature range from (Ms + 50) to 250°C is set at 100 to 10000 s, and
in a case where the Ms point is less than 250°C,
a holding time for a temperature range from (Ms + 80) to 100°C is set at 100 to 50000 s:
where the Ms point (°C) and the $Ac_3$ point (°C) are expressed by following formulas, where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol.

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \quad \text{(vi)}$$

$$Ac_3 = 910 - 203 \times C^{0.5} + 44.7(Si + Al) - 30 \times Mn + 700 \times P - 15.2 \times Ni - 26 \times Cu - 11 \times Cr + 31.5 \times Mo \quad \text{(vii)}$$

(6) A method for producing the steel sheet according to any one of the above (1) to (3), wherein

a cast piece having the chemical composition according to the above (1) is subjected to a hot-rolling step and a heat treatment step in this order,
in the hot-rolling step, a rolling finish temperature is set at a $Ar_3$ point or more, and
an average cooling rate for a range from a rolling finish temperature to (Ms - 50)°C is set at 10°C/s or more, and
in the heat treatment step,
in a case where the Ms point is 250°C or more,
a holding time for a temperature range from (Ms + 50) to 250°C is set at 100 to 10000 s, and
in a case where the Ms point is less than 250°C,
a holding time for a temperature range from (Ms + 80) to 100°C is set at 100 to 50000 s:
where the Ms point (°C) and the $Ar_3$ point (°C) are expressed by following formulas, where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol.

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \quad \text{(vi)}$$

$$Ar_3 = 910 - 310 \times C + 33 \times Si - 80 \times Mn - 55 \times Ni - 20 \times Cu - 15 \times Cr - 80 \times Mo \quad \text{(viii)}$$

ADVANTAGEOUS EFFECT OF INVENTION

**[0012]** According to the present invention, it is possible to obtain a high-strength steel sheet that exerts good reaction force properties when an impact load is applied to a shaped component from the steel sheet, is unlikely to cause a crack from an end face of the component or a region of the component bent at the time of the impact, and has a yield stress of 1000 MPa or more.

BRIEF DESCRIPTION OF DRAWING

**[0013]** [Figure 1] Figure 1 is a diagram for describing a shape of a test piece used for a collision test.

DESCRIPTION OF EMBODIMENT

**[0014]** Requirements of the present invention will be described below in detail.

(A) Chemical Composition

**[0015]** Reasons for limiting a content of each element are as follows. In the following description, a symbol "%" for each content means "mass%".

C: 0.14 to 0.60%

**[0016]** C (carbon) is an element that has effects of improving strength and refining a block size. In order to maintain a yield stress of 1000 MPa, a content of C is set at 0.14% or more. On the other hand, if the content of C is more than 0.60%, an Ms point decreases, and an average axial ratio to be described below tends to increase. As a result, at the time of crash deformation, a brittle fracture occurs at a stress concentration, decreasing impact energy absorption ability. The content of C is therefore set at 0.14 to 0.60%. The content of C is preferably 0.15% or more, more preferably 0.18% or more, and is preferably 0.50% or less.

**[0017]** Si: more than 0% to less than 3.00% and Al: more than 0% to less than 3.00%, and

$$\mathrm{Si} + \mathrm{Al} \leq 3.00 \qquad \text{(i)}$$

**[0018]** Si (silicon) and Al (aluminum) are elements useful in deoxidizing steel and has, in the present invention, an effect of increasing an average axial ratio of martensite, an effect of preventing or reducing the formation of iron carbide, and an effect of decreasing a block size of martensite, thereby preventing or reducing cracking in a member at the time of crash deformation to improve energy absorption ability. In order to obtain an effect of the deoxidation, Si and Al are to be contained at more than 0% each. Si and Al are preferably contained at 0.01% or more each.

**[0019]** However, if their total content is more than 3.00%, a tendency of a brittle fracture to occur at the time of crash deformation increases, thereby decreasing impact energy absorption ability. The total content of Si and Al is therefore set at 3.00% or less. The total content is preferably 2.50% or less. A lower limit of the total content is not limited to a particular value, but in order to obtain the effect of decreasing the block size reliably, the total content is preferably 0.10% or more.

Mn: 5.00% or less

**[0020]** Mn (manganese) is an element that has effects of preventing or reducing the formation of ferrite and improving yield stress and is additionally useful in controlling the average axial ratio. However, if a content of Mn is more than 5.00%, the Ms point decreases, and the average axial ratio to be described below tends to increase. As a result, at the time of crash deformation, a brittle fracture occurs at a stress concentration, decreasing impact energy absorption ability. The content of Mn is therefore set at 5.00% or less. The content of Mn is preferably 4.00% or less, 3.00% or less, or 2.00% or less. In order to obtain the effect reliably, Mn is preferably contained at 0.01% or more.

$$\mathrm{C} \times \mathrm{Mn} \leq 0.80 \qquad \text{(ii)}$$

**[0021]** The product of the contents of C and Mn is a parameter that correlates with a brittle fracture at a stress concentration at the time of crash deformation. If the value of C x Mn is more than 0.80, the brittle fracture tendency increases, and thus the value is set at 0.80 or less. This value is preferably 0.60 or less, more preferably 0.40 or less.

P: 0.030% or less

**[0022]** P (phosphorus) is an element that contributes to the improvement of strength. However, if a content of P is more than 0.030%, a grain boundary fracture tendency at the time of crash deformation increases, thereby decreasing impact energy absorption ability. The content of P is therefore set at 0.030% or less. From the viewpoint of resistance weldability, the content of P is preferably 0.020% or less. A lower limit of the content is not limited to a particular value, but reducing the content to less than 0.001% leads to an increase in a production cost, and thus 0.001 % is practically the lower limit.

S: 0.0050% or less

**[0023]** S (sulfur) is an impurity element, and if a content of S is more than 0.0050%, a fracture occurs from a punched portion or a bent portion at the time of a crash. The content of S is therefore set at 0.0050% or less. The content of S is preferably 0.0040% or less or 0.0030% or less. A lower limit of the content is not limited to a particular value, but reducing the content to less than 0.0002% leads to an increase in a production cost, and thus 0.0002% is practically the lower limit.

N: 0.015% or less

**[0024]** N (nitrogen) is an element available for controlling the average axial ratio. However, if a content of N is more than 0.015%, a toughness of the steel sheet decreases, resulting in a tendency of cracking to occur from a stress concentration at the time of a crash. The content of N is therefore set at 0.015% or less. The content of N is preferably 0.010% or less or 0.005% or less. A lower limit of the content is not limited to a particular value, but reducing the content to less than 0.001% leads to an increase in a production cost, and thus 0.001% is practically the lower limit.

B: 0 to 0.0050%

**[0025]** B (boron) is an element that has an effect of increasing a hardenability of the steel sheet and therefore may be contained when necessary. However, if a content of B is more than 0.0050%, cracking may occur at the time of crash deformation. The content of B is therefore set at 0.0050% or less. The content of B is preferably 0.0040% or less or 0.0030% or less. A lower limit of the content of B is not limited to a particular value and may be 0%, but when obtaining the effect described above is intended, the content of B is preferably 0.0003% or more.

**[0026]** Ni: 0 to 5.00%, Cu: 0 to 5.00%, Cr: 0 to 5.00%, Mo: 0 to 1.00%, and W: 0 to 1.00%, and

$$\mathrm{Mn} + \mathrm{Ni} + \mathrm{Cu} + 1.3\mathrm{Cr} + 4(\mathrm{Mo} + \mathrm{W}) \geq 0.80 \qquad \text{(iii)}$$

**[0027]** As with Mn, Ni (nickel), Cu (copper), Cr (chromium), Mo (molybdenum), and W (tungsten) are elements that have effects of preventing or reducing the formation of ferrite and improving yield stress and are additionally useful in controlling the average axial ratio. Thus, one or more elements selected from these elements may be contained. In order to obtain this effect, contents of these elements need to satisfy Formula (iii).

**[0028]** From the viewpoint of stably preventing or reducing the formation of ferrite and bainite, the left side value of Formula (iii) described above is preferably 1.00 or more. An upper limit of the left side value is not limited to a particular value, but if the left side value is more than 4.00, the Ms point decreases, and the average axial ratio to be described below tends to increase. As a result, at the time of crash deformation, a brittle fracture may occur at a stress concentration, decreasing impact energy absorption ability. The left side value of Formula (iii) described above is preferably 4.00 or less.

**[0029]** In addition, the contents of Ni and Cu are each preferably 4.00% or less, more preferably 3.00% or less, still more preferably 1.00% or less. The content of Cr is preferably 3.00% or less, more preferably 1.00% or less. The contents of Mo and W are each preferably 0.80% or less, more preferably 0.60% or less.

**[0030]** Ti: 0 to 0.20%, Zr: 0 to 0.20%, Hf: 0 to 0.20%, V: 0 to 0.20%, Nb: 0 to 0.20%, Ta: 0 to 0.20%, Sc: 0 to 0.20%, and Y: 0 to 0.20%, and

$$0.003 \leq \mathrm{Ti} + \mathrm{Zr} + \mathrm{Hf} + \mathrm{V} + \mathrm{Nb} + \mathrm{Ta} + \mathrm{Sc} + \mathrm{Y} \leq 0.20 \qquad \text{(iv)}$$

**[0031]** These elements have an effect of decreasing a block size of martensite and an effect of preventing or reducing the formation of iron carbide, thereby preventing or reducing the occurrence and the propagation of a crack from a stress concentration at the time of crash deformation. Thus, at least one or more of these elements are contained, and their total content is set at 0.003% or more. On the other hand, if the total content is more than 0.20%, alloy precipitate precipitates in a large quantity, and thus cracking tends to occur at the time of crash deformation; therefore, the total content is set at 0.20% or less. The total content is preferably 0.010% or more.

**[0032]** Sn: 0 to 0.020%, As: 0 to 0.020%, Sb: 0 to 0.020%, and Bi: 0 to 0.020%, and

$$Sn + As + Sb + Bi \leq 0.020 \qquad (v)$$

**[0033]** Sn (tin), As (arsenic), Sb (antimony), and Bi (bismuth) are elements each of which is used for obtaining a predetermined steel micro-structure, and therefore one or more elements selected from these elements may be contained when necessary. However, if their total content is more than 0.020%, a grain boundary fracture tendency at the time of crash deformation increases; therefore, an upper limit of the total content is set at 0.020%. A lower limit of the total content is not limited to a particular value, but reducing the total content to less than 0.00005% leads to an increase in a production cost, and thus 0.00005% is practically the lower limit.

Mg: 0 to 0.005%, Ca: 0 to 0.005%, and REM: 0 to 0.005%

**[0034]** Mg (magnesium), Ca (calcium), and REM (rare earth metal) are elements each of which has an action that controls morphology of oxides and sulfides, and therefore one or more elements selected from these elements may be contained when necessary. However, if a content of any one of the elements is more than 0.005%, the effect provided by the addition of the element levels off, and energy absorption ability at the time of crash deformation decreases; therefore, the content of any one of the elements is set at 0.005% or less. Any one of the contents of Mg, Ca, and REM is preferably 0.003% or less. When obtaining the effect described above is intended, one or more elements selected from Mg: 0.001% or more, Ca: 0.001% or more, and REM: 0.001% or more are preferably contained.

**[0035]** Here, in the present invention, REM refers lanthanoids, which are 15 elements, and the content of REM means a total content of the lanthanoids. In industrial practice, the lanthanoids are added in a form of misch metal.

Value of Ms: 200 or more

**[0036]** Ms means a martensitic transformation starting temperature (°C). If a Ms point of a steel sheet is less than 200°C, an axial ratio increases, and it becomes difficult for the configuration according to the present invention to prevent or reduce brittle fracture at the time of crash deformation. For that reason, a value of Ms is set at 200 or more. The value of Ms is preferably 220 or more.

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \qquad (vi)$$

**[0037]** In the chemical composition of the steel sheet according to the present invention, the balance is Fe and impurities. The term "impurities" as used herein means components that are mixed in the steel sheet in producing the steel sheet industrially due to raw materials such as ores and scraps, and various factors of a producing process and that are allowed to be mixed in the steel sheet within ranges in which the impurities have no adverse effect on the present invention.

(B) Steel Micro-Structure

**[0038]** A steel micro-structure of a steel sheet according to an embodiment of the present embodiment will be described. In the following description, the symbol "%" means "volume%".

Martensite: 85% or more

**[0039]** Making the steel micro-structure mainly of martensite is indispensable for ensuring a yield stress of 1000 MPa or more. If a volume ratio of martensite is less than 85%, it becomes difficult to ensure the yield stress: 1000 MPa or more. For that reason, the volume ratio of martensite is set at 85% or more. In order to ensure the yield stress stably, the volume ratio of martensite is preferably 90% or more. Note that the martensite should be construed as including tempered martensite, that is, a martensite with carbides formed therein. In addition, the morphology of martensite may be any one of lath, butterfly, twin, lamella, and the like.

Retained austenite: 15% or less

**[0040]** Retained austenite is a steel micro-structure that is useful in improving formability and improving impact energy absorption properties. However, if its volume ratio is more than 15%, there are a tendency of yield stress to decrease and a tendency of brittle cracking to occur at the time of crash deformation. For that reason, the volume ratio of retained austenite is set at 15% or less. The volume ratio of retained austenite is preferably 12% or less. A lower limit of the volume ratio is not limited to a particular value, but the volume ratio is preferably 0.1% or more.

**[0041]** The remainder of the steel micro-structure is bainite. Here, the bainite includes lower bainite and upper bainite, and additionally, bainitic ferrite ($\alpha$°B) described in Non Patent Document 1 is categorized as the bainite. Note that tempered martensite is difficult to subject to structure separation from bainite in some cases even with Reference Document 1. In such a case where the structure separation is difficult, the bainite is considered as martensite to calculate a structure separation fraction. Although there is no need to place an upper limit on an area fraction of the bainite being the balance, the area fraction is practically 15% or less, preferably 10% or less.

**[0042]** A volume ratio of a steel micro-structure is determined according to the following procedure. First, a 1/4 thickness portion of a surface of each steel sheet parallel to a rolling direction and a thickness direction of the steel sheet is mirror-polished and subjected to Nital etching. The surface is then subjected to structure observation under a scanning electron microscope (SEM) or further a transmission electron microscope (TEM), using a photograph of a steel micro-structure obtained by capturing the steel micro-structure, the point counting method or image analysis is performed to determine area fractions of martensite and bainite, and the area fractions are used as volume ratios. In addition, the volume ratio of the retained austenite is determined by the X-ray diffraction method. An area of a region to be observed is set at 1000 $\mu m^2$ or more when a SEM is used, or 100 $\mu m^2$ or more when a TEM is used.

**[0043]** Further, in the present invention, an average block size and an average axial ratio of martensite and bainite are also defined as follows.

Average block size of martensite and bainite: 3.0 $\mu$m or less

**[0044]** A block size of martensite influences the occurrence and the propagation of a brittle fracture at the time of crash deformation; the smaller a value of the block size is, the better impact properties are obtained. If the average block size is more than 3.0 $\mu$m, a fracture of the sheet may occur at a bent portion at the time of crash deformation; therefore, the average block size is set at 3.0 $\mu$m or less. The average block size is preferably 2.7 $\mu$m or less, 2.5 $\mu$m or less, or 2.4 $\mu$m or less.

**[0045]** Here, the block size will be described. As shown in a table in p. 223 of Non-Patent Document 2, martensite and bainite can be classified as being made up of 24 different crystal units (variants) as their substructures. One of methods for grouping these 24 variants is a method using Bain groups, which are described in p. 223 of Non-Patent Document 2, by which martensite and bainite can be classified into three crystal units. The block size in the present invention indicates an average size of group grains when the classification is performed using these Bain groups.

**[0046]** The average block size is measured according to the following procedure. First, each steel sheet is cut such that its surface parallel to its rolling direction and its thickness direction serves as an observation surface, and the cross section is measured between a 1/4 sheet-thickness position and a 1/2 sheet-thickness position of the cross section by the EBSD method within a region having an area of 5000 $\mu m^2$ or more. A step size of the measurement is set at 0.2 $\mu$m. Then, based on crystal orientation information obtained by the EBSD measurement, orientations are classified on the basis of the three Bain groups, their images are displayed, and a size of a crystal unit is determined by the cutting method described in Appendix 2 of JIS G 0552.

Average axial ratio of martensite and bainite: 1.0004 to 1.0100

**[0047]** A crystal structure of a portion of the steel micro-structure other than the retained austenite, that is, martensite and bainite, influences cracking behavior at a stress concentration and a bent portion at the time of crash deformation. It is particularly necessary to appropriately adjust an average axial ratio of martensite and bainite, which have a tetragonal crystal structure. Here, the axial ratio is a value expressed by c/a, where a and c denotes $\alpha$-axis and c-axis lattice constants in a tetragonal crystal structure, respectively. The reason that a magnitude of the axial ratio c/a is associated with cracking behavior at the time of a fast and large deformation in a collision test is unclear, but crystal lattice strain may exert some influence on the cracking behavior.

**[0048]** If the average axial ratio is less than 1.0004, cracking may occur at the time of crash deformation, or there arises a tendency to resist absorption of impact energy. On the other hand, if the average axial ratio is more than 1.0100, there arises a tendency of a brittle fracture to occur from an end face or a bent portion of a member at the time of crash deformation. For that reason, the average axial ratio is set at 1.0004 to 1.0100. From the viewpoint of ensuring the yield stress stably, the average axial ratio is preferably 1.0006 or more. Further, in order to prevent or reduce cracking at the time of crash deformation more reliably, the average axial ratio is preferably 1.0007 or more. On the other hand, from the viewpoint of increasing the absorption of impact energy, the average axial ratio is preferably 1.0080 or less.

**[0049]** Here, the average axial ratio of martensite and bainite is measured by the X-ray diffraction method according to the following procedure. At this time, the average axial ratio c/a is to be determined by any one of the following two methods depending on whether diffraction lines of tetragonal iron or cubic iron are split. Here, an area of a region on a sample irradiated with X-ray is set at 0.2 $mm^2$ or more.

(a) In a case where a 200 diffraction line and a 002 diffraction line are split clearly into two
The pseudo-Voigt function is used to perform peak separation of diffraction lines from a {200} plane, a lattice constant calculated from a 200 diffraction angle is denoted by a, a lattice constant calculated from a 002 diffraction angle is denoted by c, and their ratio is determined as the average axial ratio c/a.
(b) In a case where the diffraction lines are not split clearly into two
A lattice constant calculated from a diffraction angle of a diffraction from a {200} plane is denoted by a, a lattice constant calculated from a diffraction angle from a {110} plane is denoted by c', and their ratio c'/a is approximated as the average axial ratio c/a (see Non Patent Document 3).

Average particle size of iron carbides: 0.005 to 0.20 μm

**[0050]** Iron carbide may be contained in a steel micro-structure of a steel sheet according to another embodiment of the present invention. If an average particle size of iron carbides is more than 0.20 μm, a fracture from a bent portion tends to accelerate during crash deformation; on the other hand, if the average particle size of iron carbides is less than 0.005 μm, a brittle fracture from a bent portion during crash deformation tends to accelerate. For that reason, the average particle size of iron carbides is preferably 0.005 to 0.20 μm. Note that the iron carbide may contain, in addition to Fe, alloying elements such as Mn and Cr.

**[0051]** An average particle size of iron carbides in martensite and bainite is measured by observing their structures under a SEM and a TEM in a region having an area of 10 $\mu m^2$ or more. Fine iron carbides that cannot be identified with the TEM are measured by the atom probe method. In this case, the measurement is to be performed on five or more iron carbides.

(C) Plating layer

**[0052]** A steel sheet according to another embodiment of the present invention may include a plating layer on its surface. A composition of the plating is not limited to a particular composition, and any one of hot-dip galvanizing, galvannealing, and electroplating may be employed.

(D) Mechanical properties

Yield stress: 1000 MPa or more

**[0053]** If the yield stress is less than 1000 MPa, an advantage of reducing a member weight provided by making the member thin-wall, and the yield stress is therefore set at 1000 MPa or more. Here, the yield stress is determined to be a flow stress (0.2% proof stress) at 0.002 strain when a tensile test is performed in conformance with JIS Z 2241 2011.

**[0054]** Although there is no particular limitation imposed on a tensile strength, the tensile strength is preferably 1400 MPa or more from the viewpoint of enhancing impact energy absorption properties.

(E) Producing method

**[0055]** Although there is no particular limitation on conditions for producing the steel sheet according to the present invention, the steel sheet can be produced by subjecting a cast piece having the chemical composition described above to processing including steps described below as (a) to (c). Each of the methods will be described in detail.

**[0056]** Note that the cast piece can be obtained by a conventional method from a molten steel having the chemical composition described above. The cast piece to be subjected to hot rolling is not limited to a particular cast piece. That is, the cast piece may be a continuously cast slab or a cast piece produced by a thin slab caster. In addition, the method is applicable to a process such as continuous-casting direct-rolling, in which hot rolling is performed immediately after casting.

**[0057]** In the following description, the Ms point (°C), the $Ac_3$ point (°C), and the $Ar_3$ point (°C) are expressed by the following formulas, where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol.

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \quad (vi)$$

$$Ac_3 = 910 - 203 \times C^{0.5} + 44.7(Si + Al) - 30 \times Mn + 700 \times P - 15.2 \times Ni - 26 \times Cu - 11 \times Cr + 31.5 \times Mo \quad (vii)$$

$$Ar_3 = 910 - 310 \times C + 33 \times Si - 80 \times Mn - 55 \times Ni - 20 \times Cu - 15 \times Cr - 80 \times Mo \quad (viii)$$

(a) Method including hot-rolling step, cold-rolling step, annealing step, and heat treatment step

**[0058]** The cast piece described above is subjected to a hot-rolling step, a cold-rolling step, an annealing step, and a heat treatment step in this order. In this case, a resultant steel sheet is a cold-rolled steel sheet. Each of the steps will be described in detail.

**[0059]** In the hot-rolling step, the cast piece is first heated. The heating temperature is not limited to a particular temperature but is preferably set at 1200°C or more so that alloy carbo-nitride that has precipitated during casting or rough rolling is remelted.

**[0060]** After the heating, hot rolling is performed. At this time, an average cooling rate for the range from a rolling finish temperature to 650°C is set at 8°C/s or more. If the average cooling rate is less than 8°C/s, a block size of martensite in a finished product increases, resulting in a deterioration in impact properties. Thereafter, the steel sheet is coiled. The coiling temperature is not limited to a particular temperature but is preferably 630°C or less. After being coiled, the steel sheet is further cooled to room temperature.

**[0061]** Subsequently, the steel sheet is subjected to treatment such as pickling then cold rolling. As conditions for the cold rolling, the number of rolling passes and a rolling reduction need not be particularly specified, and the conditions are only required to conform to the conventional method.

**[0062]** In the annealing step, the steel sheet subjected to the cold rolling is retained within the temperature range from the $Ac_3$ point to ($Ac_3$ point + 100)°C for 3 to 90 s. If the annealing temperature is less than the $Ac_3$ point, a predetermined amount of martensite cannot be obtained, and if the annealing temperature is more than ($Ac_3$ point + 100)°C, block size increases. In addition, if the retention time for the temperature range is less than 3 s, the predetermined amount of martensite is not obtained, and a yield stress of 1000 MPa or more cannot be obtained. On the other hand, if the retention time is more than 90 s, the block size increases. From the viewpoint of decreasing the block size, the annealing temperature is preferably as low as possible and is preferably ($Ac_3$ point + 80)°C or less. In addition, the retention time is preferably 10 s or more and is preferably 60 s or less.

**[0063]** After being retained within the temperature range for a predetermined time period, the steel sheet is cooled under a condition that an average cooling rate for the range from 700°C to (Ms point - 50)°C is 10°C/s or more. If this average cooling rate is less than 10°C/s, the predetermined amount of martensite cannot be obtained, resulting in the yield stress to decrease, and further, the block size increases, resulting in a tendency of cracking to occur at the time of impact deformation. In a case where the setting of the average axial ratio at 1.0007 or more is intended for preventing or reducing cracking at the time of crash deformation more reliably, the average cooling rate is preferably 20°C/s or more. Note that a temperature at which this cooling is stopped is only required to be (Ms - 50)°C or less and is not limited to a particular temperature but is preferably 100°C or more from the viewpoint of resistance to fracture.

**[0064]** In the heat treatment step, a heat treatment that results in the following thermal history is performed, according to Ms calculated from the chemical composition of the steel sheet. Note that the following heat treatment may be performed subsequently to stopping the cooling, or heating may be performed to a degree that does not exceed an upper limit of a temperature range in the heat treatment step described below subsequently to stopping the cooling.

**[0065]** In a case where the Ms point calculated from the chemical composition of the steel sheet is 250°C or more, a holding time for the temperature range from (Ms point + 50) to 250°C is set at 100 to 10000 s. If the holding time is less than 100 s, the average axial ratio may exceed a predetermined value, causing a brittle fracture in a collision test or failing to obtain a predetermined yield stress. On the other hand, if the holding time is more than 10000 s, the average axial ratio becomes less than a predetermined value, and additionally iron carbides coarsen, resulting in a tendency of cracking to occur at the time of a crash. The holding time is preferably 400 s or more and is preferably 5000 s or less. In particular, in a case where the setting of the average axial ratio at 1.0007 or more is intended for preventing or reducing cracking at the time of crash deformation more reliably, the holding time is more preferably 1500 s or less.

**[0066]** In a case where the Ms point calculated from the chemical composition of the steel sheet is less than 250°C, a holding time for the temperature range from (Ms point + 80) to 100°C is set at 100 to 50000 s. If the holding time is less than 100 s, the average axial ratio may exceed the predetermined value, causing a brittle fracture in a collision test. On the other hand, if the holding time is more than 50000 s, the average axial ratio becomes less than a predetermined value, and additionally iron carbides coarsen, resulting in a tendency of cracking to occur at the time of a crash. The holding time is preferably 400 s or more and is preferably 30000 s or less, more preferably 10000 s or less.

(b) Method including hot-rolling step, annealing step, and heat treatment step

**[0067]** The cast piece described above is subjected to a hot-rolling step, an annealing step, and a heat treatment step in this order. In this case, a resultant steel sheet is a hot-rolled steel sheet. Each of the steps will be described in detail.

**[0068]** In contrast to the steps described in (a), the cold-rolling step is not performed in the present step. In the annealing step, ferrite being a parent phase is recrystallized while the cold-rolled steel sheet is heated from room temperature to the annealing temperature, and crystallographic texture develops. Under the influence of this preferential orientation of the crystal orientations, crystallographic texture also develops in austenite that exists in retention within the temperature range from the $Ac_3$ point to ($Ac_3$ point + 100)°C. By the development of the crystallographic texture, when austenite with a biased orientation transforms to martensite, crystals of the martensite are formed and grow in a particular direction.

**[0069]** In addition, since the formation and the growth of crystals of the martensite causes the steel to expand, the steel sheet expands biasedly in the particular direction macroscopically. However, allowing a steel strip to expand or deform freely in the annealing step leads to a decrease in strip running properties; therefore, a tension is usually applied to straighten a shape of the steel sheet and to keep the stability of strip running.

**[0070]** Note that if martensitic transformation occurs in a state where such an excessive tension is applied, a residual stress is applied in the steel sheet, and it becomes difficult to obtain an effect of preventing or reducing cracking. In addition, if the residual stress in the steel sheet increases, a crack that occurs when the steel sheet is deformed is likely to form and propagate. For that reason, from the viewpoint of preventing or reducing cracking at the time of crash deformation more reliably, the cold-rolling step is preferably omitted; that is, with an aim of preventing the development of crystallographic texture by the recrystallization of ferrite being a parent phase in the annealing step to align the crystal orientations on a random basis, the steel sheet according to an embodiment of the present invention is preferably a hot-rolled steel sheet.

**[0071]** In the hot-rolling step, the cast piece is first heated. The heating temperature is not limited to a particular temperature but is preferably set at 1200°C or more so that alloy carbo-nitride that has precipitated during casting or rough rolling is remelted.

**[0072]** After the heating, hot rolling is performed. At this time, an average cooling rate for the range from a rolling finish temperature to 650°C is set at 8°C/s or more. If the average cooling rate is less than 8°C/s, a block size of martensite in a finished product increases, resulting in a deterioration in impact properties. Thereafter, the steel sheet may be coiled or need not be coiled but may be cooled to room temperature. In addition, after the cooling, the steel sheet may be subjected to treatment such as pickling or may be subjected to flattening.

**[0073]** In the annealing step, the steel sheet subjected to the hot rolling is retained within the temperature range from the $Ac_3$ point to ($Ac_3$ point + 100)°C for 3 to 90 s. If the annealing temperature is less than the $Ac_3$ point, a predetermined amount of martensite cannot be obtained, and if the annealing temperature is more than ($Ac_3$ point + 100)°C, block size increases. In addition, if the retention time for the temperature range is less than 3 s, the predetermined amount of martensite is not obtained, and as a result, a yield stress of 1000 MPa or more cannot be obtained. On the other hand, if the retention time is more than 90 s, the block size increases. From the viewpoint of decreasing the block size, the annealing temperature is preferably as low as possible and is preferably ($Ac_3$ point + 80)°C or less. In addition, the retention time is preferably 10 s or more and is preferably 60 s or less.

**[0074]** After being retained within the temperature range for a predetermined time period, the steel sheet is cooled under a condition that an average cooling rate for the range from 700°C to (Ms point - 50)°C is 10°C/s or more. If this average cooling rate is less than 10°C/s, the predetermined amount of martensite cannot be obtained, resulting in the yield stress to decrease, and further, the block size increases, resulting in a tendency of cracking to occur at the time of impact deformation. In a case where the setting of the average axial ratio at 1.0007 or more is intended for preventing or reducing cracking at the time of crash deformation more reliably, the average cooling rate is preferably 20°C/s or more. Note that a temperature at which this cooling is stopped is only required to be (Ms - 50)°C or less and is not limited to a particular temperature but is preferably 100°C or more from the viewpoint of resistance to fracture.

**[0075]** In the heat treatment step, a treatment that results in the following thermal history is performed, according to Ms calculated from the chemical composition of the steel sheet. Note that the following heat treatment may be performed subsequently to stopping the cooling in the annealing step, or heating may be performed to a degree that does not exceed an upper limit of a temperature range in the heat treatment step described below subsequently to stopping the cooling.

**[0076]** In a case where the Ms point calculated from the chemical composition of the steel sheet is 250°C or more, a holding time for the temperature range from (Ms point + 50) to 250°C is set at 100 to 10000 s. If the holding time is less than 100 s, the average axial ratio may exceed a predetermined value, causing a brittle fracture in a collision test or failing to obtain a predetermined yield stress. On the other hand, if the holding time is more than 10000 s, the average axial ratio becomes less than a predetermined value, and additionally iron carbides coarsen, resulting in a tendency of cracking to occur at the time of a crash. The holding time is preferably 400 s or more and is preferably 5000 s or less. In particular, in a case where setting of the average axial ratio at 1.0007 or more is intended for preventing or reducing cracking at the time of crash deformation more reliably, the holding time is more preferably 1500 s or less.

**[0077]** In a case where the Ms point calculated from the chemical composition of the steel sheet is less than 250°C, a holding time for the temperature range from (Ms point + 80) to 100°C is set at 100 to 50000 s. If the holding time is less than 100 s, the average axial ratio may exceed the predetermined value, causing a brittle fracture in a collision test. On the other hand, if the holding time is more than 50000 s, the average axial ratio becomes less than a predetermined value, and additionally iron carbides coarsen, resulting in a tendency of cracking to occur at the time of a crash. The holding time is preferably 400 s or more and is preferably 30000 s or less, more preferably 10000 s or less.

(c) Method including hot-rolling step and heat treatment step

**[0078]** The cast piece described above is subjected to a hot-rolling step and a heat treatment step in this order. In this case, a resultant steel sheet is a hot-rolled steel sheet. Each of the steps will be described in detail.

**[0079]** In contrast to the steps described in (b), the annealing step is not performed in the present step. When the annealing is performed, while the heating is performed from the room temperature to the annealing temperature in the annealing step, boundary motion of a martensitic structure occurs. Further, because a crystal interface in a particular orientation of a high mobility preferentially moves in this boundary motion, the randomization of crystal orientations is lost, and a slight residual stress remains in the steel sheet subjected to the annealing step. For that reason, from the viewpoint of reducing the residual stress as much as possible, the annealing step is preferably omitted.

**[0080]** In the hot-rolling step, the cast piece is first heated. The heating temperature is not limited to a particular temperature but is preferably set at 1200°C or more so that alloy carbo-nitride that has precipitated during casting or rough rolling is remelted.

**[0081]** After the heating, hot rolling is performed. At this time, the hot rolling is performed such that the rolling finish temperature becomes the $Ar_3$ point or more. If the rolling finish temperature is less than the $Ar_3$ point, ferrite is formed, which makes it difficult to obtain the predetermined yield stress.

**[0082]** After the hot rolling, the steel sheet is cooled under a condition that an average cooling rate for the range from the rolling finish temperature to (Ms point - 50)°C is 10°C/s or more. If this average cooling rate is less than 10°C/s, a volume ratio of ferrite or bainite increases, the predetermined amount of martensite cannot be obtained, resulting in the yield stress to decrease, and further, the block size increases, resulting in a tendency of cracking to occur at the time of impact deformation. Note that a temperature at which this cooling is stopped is only required to be (Ms - 50)°C or less and is not limited to a particular temperature but is preferably 100°C or more from the viewpoint of resistance to fracture.

**[0083]** In the heat treatment step, a treatment that results in the following thermal history is performed, according to Ms calculated from the chemical composition of the steel sheet. Note that the following heat treatment may be performed subsequently to stopping the cooling in the hot-rolling step, or heating may be performed to a degree that does not exceed an upper limit of a temperature range in the heat treatment step described below subsequently to stopping the cooling.

**[0084]** In a case where the Ms point calculated from the chemical composition of the steel sheet is 250°C or more, a holding time for the temperature range from (Ms point + 50) to 250°C is set at 100 to 10000 s. If the holding time is less than 100 s, the average axial ratio may exceed a predetermined value, causing a brittle fracture in a collision test or failing to obtain a predetermined yield stress. On the other hand, if the holding time is more than 10000 s, the average axial ratio becomes less than a predetermined value, and additionally iron carbides coarsen, resulting in a tendency of cracking to occur at the time of a crash. The holding time is preferably 400 s or more and is preferably 5000 s or less. In particular, in a case where the setting of the average axial ratio at 1.0007 or more is intended for preventing or reducing cracking at the time of crash deformation more reliably, the holding time is more preferably 1500 s or less.

**[0085]** In a case where the Ms point calculated from the chemical composition of the steel sheet is less than 250°C, a holding time for the temperature range from (Ms point + 80) to 100°C is set at 100 to 50000 s. If the holding time is less than 100 s, the average axial ratio may exceed the predetermined value, causing a brittle fracture in a collision test. On the other hand, if the holding time is more than 50000 s, the average axial ratio becomes less than a predetermined value, and additionally iron carbides coarsen, resulting in a tendency of cracking to occur at the time of a crash. The holding time is preferably 1000 s or more and is preferably 30000 s or less, more preferably 10000 s or less.

**[0086]** After any one of the steps of (a) to (c) is finished, skin-pass rolling may be performed for flattening. The elongation percentage is not limited to a particular percentage. In addition, plating treatment may be performed in the middle of the heat treatment or after the heat treatment is finished, as far as the thermal history is satisfied. As a method of plating, the steel sheet.may be produced in a continuous-annealing and plating line or may be produced by using a plating-dedicated facility separate from an annealing line. A composition of the plating is not limited to a particular composition, and any one of hot-dip galvanizing, galvannealing, and electroplating may be employed.

**[0087]** The present invention will be described below more specifically with reference to examples, but the present invention is not limited to these examples.

[Example 1]

**[0088]** Steels having compositions shown in Table 1 were melted and produced into slabs, and the slabs were heated at 1220 to 1260°C and subjected to rough rolling performed as a hot processing. Subsequently, steel sheets were subjected to finish rolling, cooled, then subjected to coiling processing at 500 to 620°C, and cooled to room temperature. Then, as shown in Tables 2 and 3, the average cooling rate (CR1) for the range from the rolling finish temperature (FT) to 650°C was changed.

**[0089]** After being cooled to the room temperature, the steel sheets were subjected to pickling treatment for removing scales, then subjected to cold rolling at a cold rolling ratio of 30 to 70% so that the steel sheets had a thickness of 1.2 mm, and then annealed.

**[0090]** In the annealing, the annealing temperature (ST), the annealing retention time (tl), and the average cooling rate (CR2) for the range from 700°C to (Ms point - 50)°C were changed, and in the heat treatment step, the holding time (t2) for the range from (Ms + 50)°C to 250°C was changed for steels having Ms being 250°C or more, and the holding time (t3) for the range from (Ms + 80)°C to 100°C was changed for steels having Ms being less than 250°C. After the heat treatment step, skin-pass rolling for flattening was performed.

[Table 1]

**[0091]**

Table 1

| Steel | Chemical composition (mass%, balance: Fe and impurities) | | | | | | | | | | | | | | Left side value of Formula (i) | Left side value of Formula (ii) | Left side value of Formula (iii) | Middle side value of Formula (iv) | Left side value of Formula (v) | Ms Formula (vi) | $Ac_3$ Formula (vii) | $Ar_3$ Formula (viii) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Al | Mn | P | S | N | B | Ni | Cu | Cr | Mo | W | Others | | | | | | | | |
| A | 0.19 | 0.10 | 0.05 | 2.00 | 0.015 | 0.0010 | 0.002 | 0.0010 | 0.50 | - | 0.30 | - | - | Ti:0.02, Nb:0.02, REM:0.002 | 0.15 | 0.38 | 2.89 | 0.04 | 0 | 348 | 768 | 662 |
| B | 0.19 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti:0.02, Nb:0.02 | 0.35 | 0.29 | 3.50 | 0.04 | 0 | 369 | 818 | 701 |
| C | 0.30 | 0.30 | 0.05 | 1.30 | 0.015 | 0.0010 | 0.002 | 0.0010 | 0.60 | 0.10 | 0.10 | - | 0.40 | Ti:0.03, Zr:0.01, Hf:0.01, Mg:0.002 | 0.35 | 0.39 | 3.73 | 0.05 | 0 | 303 | 773 | 686 |
| D | 0.30 | 1.50 | 0.05 | 1.90 | 0.015 | 0.0010 | 0.002 | 0.0004 | 0.50 | - | - | 0.20 | - | Ti:0.02, V:0.15, Ta:0.01, Ca:0.001 | 1.55 | 0.57 | 3.20 | 0.18 | 0 | 279 | 820 | 671 |
| E | 0.30 | 0.70 | 1.10 | 1.60 | 0.015 | 0.0010 | 0.003 | 0.0004 | 0.30 | 0.20 | 0.30 | - | - | Ti:0.03, Zr:0.001, REM:0.001, Sb:0.010, Bi:0.001 | 1.80 | 0.48 | 2.49 | 0.03 | 0.011 | 294 | 829 | 687 |
| F | 0.30 | 0.70 | 1.10 | 1.30 | 0.015 | 0.0010 | 0.003 | 0.0004 | 0.80 | 0.20 | 0.20 | - | - | Zr:0.01, Nb:0.01, Sb:0.010, Bi:0.001 | 1.80 | 0.39 | 2.56 | 0.02 | 0.011 | 295 | 831 | 685 |
| G | 0.30 | 1.70 | 0.05 | 2.40 | 0.015 | 0.0010 | 0.002 | 0.0004 | 0.10 | - | 0.20 | 0.10 | - | Ti:0.03, Zr:0.01, Y:0.01, Sb:0.010, Sn:0.003, As:0.003, Mg:0.001 | 1.75 | 0.72 | 3.16 | 0.05 | 0.016 | 267 | 815 | 665 |
| H | 0.40 | 0.10 | 0.05 | 1.00 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | 0.60 | 0.30 | - | Nb:0.05, V:0.14, REM:0.001, Bi:0.001 | 0.15 | 0.40 | 2.98 | 0.19 | 0.001 | 276 | 772 | 676 |
| I | 0.48 | 0.10 | 0.05 | 1.00 | 0.015 | 0.0010 | 0.002 | 0.0010 | 0.70 | - | 0.20 | - | 0.30 | Ti:0.02, Sc:0.04, Mg:0.002 | 0.15 | 0.48 | 3.16 | 0.06 | 0 | 235 | 744 | 643 |
| J | 0.14 | 0.30 | 0.05 | 1.80 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.10 | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.25 | 2.20 | 0.03 | 0 | 393 | 809 | 725 |
| K | 0.65 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.98 | 3.50 | 0.03 | 0 | 173 | 743 | 558 |
| L | 0.12 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.18 | 3.50 | 0.03 | 0 | 411 | 837 | 723 |
| M | 0.30 | 3.50 | 0.05 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 3.55 | 0.45 | 3.50 | 0.03 | 0 | 275 | 939 | 773 |
| N | 0.30 | 1.70 | 1.50 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 3.20 | 0.45 | 3.50 | 0.03 | 0 | 295 | 923 | 713 |
| O | 0.30 | 0.02 | 0.02 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 0.04 | 0.45 | 3.50 | 0.03 | 0 | 314 | 782 | 658 |
| P | 0.30 | 0.30 | 0.05 | 1.50 | 0.050 | 0.0010 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.45 | 3.50 | 0.03 | 0 | 311 | 820 | 667 |
| Q | 0.30 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0100 | 0.002 | 0.0010 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.45 | 3.50 | 0.03 | 0 | 311 | 796 | 667 |
| R | 0.30 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0200 | - | - | - | 0.50 | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.45 | 3.50 | 0.03 | 0 | 311 | 796 | 667 |
| S | 0.30 | 0.30 | 0.05 | 3.00 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | - | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.90 | 3.00 | 0.03 | 0 | 270 | 735 | 587 |
| T | 0.30 | 0.30 | 0.05 | 0.01 | 0.015 | 0.0010 | 0.002 | - | 3.00 | - | - | - | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.00 | 3.01 | 0.03 | 0 | 305 | 779 | 661 |
| U | 0.30 | 0.30 | 0.05 | 0.60 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | - | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.18 | 0.60 | 0.03 | 0 | 342 | 807 | 779 |
| V | 0.48 | 0.30 | 0.05 | 1.00 | 0.015 | 0.0010 | 0.002 | 0.0010 | 0.80 | 0.80 | - | - | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.48 | 2.60 | 0.03 | 0 | 220 | 733 | 631 |
| W | 0.48 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0010 | 0.002 | 0.0010 | 2.10 | - | - | - | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.72 | 3.60 | 0.03 | 0 | 198 | 719 | 536 |
| X | 0.22 | 0.30 | 0.05 | 4.00 | 0.015 | 0.0010 | 0.002 | 0.0010 | - | - | - | - | - | Ti: 0.02, Nb:0.01 | 0.35 | 0.88 | 4.00 | 0.03 | 0 | 281 | 721 | 532 |
| Y | 0.30 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0008 | 0.002 | 0.0010 | - | - | - | - | - | - | 0.35 | 0.45 | 1.50 | 0 | 0 | 315 | 780 | 707 |
| Z | 0.30 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0008 | 0.002 | 0.0010 | - | - | - | - | - | Ti: 0.25 | 0.35 | 0.45 | 1.50 | 0.25 | 0 | 315 | 780 | 707 |
| AA | 0.30 | 0.30 | 0.05 | 1.50 | 0.015 | 0.0008 | 0.002 | 0.0010 | - | - | - | - | - | Ti:0.03, Nb:0.20 | 0.35 | 0.45 | 1.50 | 0.23 | 0 | 315 | 780 | 707 |

*1 $Si+Al \leqq 3.0$ ...(i)

*2 $C \times Mn \leqq 0.8$ ...(ii)

*3 $Mn+Ni+Cu+1.3Cr+4(Mo+W) \geqq 0.8$ ...(iii)

*4 $0.003 \leqq Ti+Zr+Hf+V+Nb+Ta+Sc+Y \leqq 0.2$ ...(iv)

*5 $Sn+As+Sb+Bi \leqq 0.02$ ...(v)

*6 $Ms=546 \times \exp(-1.362 \times C)-11 \times Si-30 \times Mn-18 \times Ni-20 \times Cu-12 \times Cr-8(Mo+W)$ ...(vi)

*7 $Ac_3=910-203 \times C^{0.5}+44.7 \times (Si+Al)-30 \times Mn+700 \times P-15.2 \times Ni-26 \times Cu-11 \times Cr+31.5 \times Mo$ ...(vii)

*8 $Ar_3=910-310 \times C+33 \times Si-80 \times Mn-55 \times Ni-20 \times Cu-15 \times Cr-80 \times Mo$ ...(viii)

**[0092]** [Table 2]

Table 2

| Test No. | Steel | FT (°C) | CR1 (°C/s) | ST (°C) | t1 (s) | CR2 (°C/s) | t2 (s) | t3 (s) | 1M (%) | 1A (%) | Balance | Average axial ratio | db (μm) | dcar (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

(continued)

| Test No. | Steel | FT (°C) | CR1 (°C/s) | ST (°C) | t1 (s) | CR2 (°C/s) | t2 (s) | t3 (s) | 1M (%) | 1A (%) | Balance | Average axial ratio | db (μm) | dcar (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 900 | 10 | 830 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0009 | 2.1 | 0.03 | 1100 | 1450 | C | Inventive example |
| 2 | | 900 | 10 | 868 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0009 | 2.7 | 0.03 | 1110 | 1440 | D | Inventive example |
| 3 | | 900 | 10 | 910 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0009 | 3,4 | 0.03 | 1100 | 1450 | E | Comparative example |
| 4 | | 900 | 10 | 790 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0009 | 2.0 | 0.03 | 1120 | 1460 | c | Inventive example |
| 5 | | 900 | 10 | 750 | 30 | 60 | 400 | | 83 | 0.2 | F | 1.0006 | 1.9 | 0.03 | 890 | 1450 | D | Comparative example |
| 6 | | 900 | 10 | 790 | 1 | 60 | 400 | | 84 | 02 | F | 1,0004 | 20 | 0.15 | 920 | 1450 | D | Comparative example |
| 7 | | 900 | 10 | 790 | 30 | 15 | 400 | | % | 0.2 | B | 1.0006 | 2.0 | 0.04 | 1000 | 1460 | D | Inventive example |
| 8 | | 900 | 10 | 790 | 30 | 5 | 400 | | 80 | 0.2 | B | 1.0004 | 3.4 | 0,06 | 820 | 1430 | E | Comparative example |
| 9 | | 900 | 10 | 790 | 30 | 60 | 3 | | 99.8 | 02 | | 1.0051 | 2.0 | 0003 | 980 | 1440 | c | Comparative example |
| 10 | | 900 | 10 | 790 | 30 | 60 | 900 | | 99.8 | 0.2 | | 1.0007 | 20 | 0.18 | 1130 | 1450 | C | Inventive example |
| 11 | | 900 | 10 | 790 | 30 | 60 | 20000 | | 99.8 | 0.2 | | 1.0002 | 2.0 | 0.22 | 1200 | 1440 | E | Comparative example |
| 12 | | 900 | 3 | 790 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0009 | 3.1 | 0.04 | 1090 | 1450 | D | Comparative example |
| 13 | | 900 | 30 | 790 | 30 | 60 | 400 | | 99.8 | 02 | | 1.0009 | 2.0 | 0.04 | 1130 | 1460 | C | Inventive example |
| 14 | | 900 | 10 | 790 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0009 | 22 | 0.05 | 1110 | 1440 | C | Inventive example |
| 15 | | 900 | 10 | 790 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0009 | 1.5 | 0.05 | 1140 | 1470 | C | Inventive example |

(continued)

| Test No. | Steel | FT (°C) | CR1 (°C/s) | ST (°C) | t1 (s) | CR2 (°C/s) | t2 (s) | t3 (s) | 1M (%) | 1A (%) | Balance | Average axial ratio | db (μm) | dcar (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | B | 900 | 10 | 830 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0012 | 2.1 | 0.07 | 1100 | 1450 | C | Inventive example |
| 17 | C | 900 | 10 | 830 | 30 | 60 | 400 | | 92 | 2 | B | 1.0015 | 2.0 | 0.11 | 1250 | 1700 | C | Inventive example |
| 18 | | 900 | 10 | 840 | 30 | 60 | 500 | | 90 | 10 | | 1.0015 | 1.8 | 0.12 | 1030 | 1500 | C | Inventive example |
| 19 | | 900 | 10 | 800 | 30 | 60 | 500 | | 83 | 10 | F | 1.0015 | 1.8 | 0.12 | 800 | 1480 | c | Comparative example |
| 20 | | 900 | 10 | 930 | 30 | 60 | 500 | | 92 | 8 | | 1.0016 | 32 | 0.10 | 1040 | 1490 | E | Comparative example |
| 21 | | 900 | 10 | 840 | 1 | 60 | 500 | | 84 | 10 | F | 1.0004 | 1.9 | 0.15 | 820 | 1290 | D | Comparative example |
| 22 | | 900 | 10 | 840 | 30 | 5 | 500 | | 83 | 10 | B | 1.0004 | 38 | 0.21 | 900 | 1480 | E | Comparative example |
| 23 | D | 900 | 10 | 840 | 30 | 15 | 500 | | 89 | 10 | 13 | 10004 | 2.4 | 0.18 | 1000 | 1490 | D | Inventive example |
| 24 | | 900 | 10 | 840 | 30 | 60 | 3 | | 90 | 10 | | 1.0110 | 1.8 | 0.002 | 950 | 1480 | E | Comparative example |
| 25 | | 900 | 10 | 840 | 30 | 60 | 200 | | 90 | 10 | | 1.0088 | 1.8 | 0.004 | 1010 | 1480 | D | Inventive example |
| 26 | | 900 | 10 | 840 | 30 | 60 | 1000 | | 90 | 9 | B | 1.0011 | 1.8 | 0.12 | 1060 | 1490 | C | Inventive example |
| 27 | | 900 | 10 | 840 | 30 | 60 | 12000 | | 90 | 6 | B | 1.0003 | 1.8 | 0.22 | 1090 | 1410 | E | Comparative example |
| 28 | | 900 | 5 | 840 | 30 | 60 | 500 | | 90 | 10 | | 1.0015 | 3.1 | 0.12 | 1050 | 1480 | E | Comparative example |
| 29 | E | 900 | 10 | 840 | 30 | 60 | 500 | | 85 | 11 | B | 1.0008 | 1.9 | 0.03 | 1020 | 1500 | c | Inventive example |

(continued)

| Test No. | Steel | FT (°C) | CR1 (°C/s) | ST (°C) | t1 (s) | CR2 (°C/s) | t2 (s) | t3 (s) | 1M (%) | 1A (%) | Balance | Average axial ratio | db (μm) | dcar (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | F | 900 | 10 | 840 | 30 | 60 | 500 | | 85 | 12 | B | 1.0007 | 1.8 | 0.02 | 1030 | 1510 | C | Inventive example |
| 31 | G | 900 | 10 | 840 | 30 | 60 | 500 | | 89 | 11 | | 1.0009 | 1.9 | 0.02 | 1150 | 1600 | c | Inventive example |

**[0093]** [Table 3]

Table 3

| Test No. | Steel | FT C (°C) | CR1 (°C/s) | ST (°C) | t1 (s) | CR2 (°C/s) | t2 (s) | t3 (s) | tM (%) | fA (%) | Balance | Average axial ratio | db (μm) | dcar (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | H | 900 | 10 | 840 | 30 | 60 | 900 | | 97 | 3 | | 1.0032 | 1.6 | 0.04 | 1300 | 1850 | C | Inventive example |
| 33 | | 900 | 10 | 800 | 30 | 60 | | 600 | 96 | 4 | | 1.0090 | 1.3 | 0.03 | 1450 | 2000 | C | Inventive example |
| 34 | | 900 | 10 | 720 | 30 | 60 | | 600 | 83 | 5 | F.B | 1.0040 | 1.5 | 0.28 | 990 | 1950 | C | Comparative example |
| 35 | | 900 | 10 | 860 | 30 | 60 | | 600 | 96 | 4 | | 1.0091 | 3.5 | 0.02 | 1400 | 1980 | E | Comparative example |
| 36 | | 900 | 10 | 800 | 1 | 60 | | 600 | 84 | 4 | F | 1.0022 | 1.5 | 0.15 | 980 | 1980 | c | Comparative example |
| 37 | | 900 | 10 | 800 | 30 | 5 | | 600 | 82 | 5 | B,F | 1.0033 | 3.1 | 0.08 | 940 | 1970 | E | Comparative example |
| 38 | I | 900 | 10 | 800 | 30 | 15 | | 600 | 88 | 5 | B | 1.0033 | 1.7 | 0.16 | 1340 | 1990 | c | Inventive example |
| 39 | | 900 | 10 | 800 | 30 | 60 | | 3 | 96 | 4 | | 1.0230 | 1.6 | 0.001 | 1100 | 2020 | E | Comparative example |
| 40 | | 900 | 10 | 800 | 30 | 60 | | 30 | 96 | 4 | | 1.0200 | 1.6 | 0.003 | 1210 | 2010 | E | Comparative example |
| 41 | | 900 | 10 | 800 | 30 | 60 | | 200 | 96 | 4 | | 1.0090 | 1.6 | 0.015 | 1330 | 2010 | c | Inventive example |
| 42 | | 900 | 10 | 800 | 30 | 60 | | 1000 | 96 | 4 | | 1.0070 | 1.6 | 0.028 | 1400 | 2000 | c | Inventive example |
| 43 | | 900 | 10 | 800 | 30 | 60 | | 12000 | 96 | 4 | | 1.0010 | 1.6 | 0.028 | 1410 | 1980 | C | Inventive example |
| 44 | | 900 | 10 | 800 | 30 | 60 | | 100000 | 96 | 4 | | 1.0003 | 1.6 | 0.16 | 1550 | 1980 | E | Comparative example |
| 45 | J | 900 | 10 | 820 | 30 | 60 | 300 | | 99.8 | 02 | | 1.0006 | 2.4 | 0.04 | 1020 | 1250 | D | Inventive example |

(continued)

| Test No. | Steel | FT C (°C) | CR1 (°C/s) | ST (°C) | t1 (s) | CR2 (°C/s) | t2 (s) | t3 (s) | tM (%) | fA (%) | Balance | Average axial ratio | db (μm) | dcar (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | K | 900 | 10 | 830 | 30 | 60 | | 600 | 93 | 7 | | 1,0240 | 1.2 | 0.03 | 1500 | 2150 | E | Comparative example |
| 47 | L | 900 | 10 | 850 | 30 | 60 | 300 | | 100 | 0 | | 1.0004 | 4.5 | 0.02 | 880 | 1150 | E | Comparative example |
| 48 | M | 900 | 10 | 940 | 30 | 60 | 300 | | 98 | 2 | | 1.0007 | 1.3 | 0.008 | 1050 | 1550 | E | Comparative example |
| 49 | N | 900 | 10 | 940 | 30 | 60 | 300 | | 98 | 2 | | 1.0007 | 1.2 | 0.005 | 1050 | 1500 | E | Comparative example |
| 50 | O | 900 | 10 | 830 | 30 | 60 | 300 | | 99 | 1 | | 1.0007 | 2.8 | 0.01 | 1150 | 1650 | D | Inventive example |
| 51 | P | 900 | 10 | 830 | 30 | 60 | 300 | | 99 | 1 | | 1.0007 | 1.8 | 0.01 | 1150 | 1650 | E | Comparative example |
| 52 | Q | 900 | 10 | 830 | 30 | 60 | 300 | | 99 | 1 | | 1.0007 | 1.7 | 0.01 | 1150 | 1650 | E | Comparative example |
| 53 | R | 900 | 10 | 830 | 30 | 60 | 300 | | 99 | 1 | | 1.0007 | 1.8 | 0.01 | 1200 | 1700 | E | Comparative example |
| 54 | S | 900 | 10 | 830 | 30 | 60 | 300 | | 99 | 1 | | 1.0007 | 1.7 | 0.01 | 1220 | 1700 | E | Comparative example |
| 55 | T | 900 | 10 | 830 | 30 | 60 | 300 | | 97 | 3 | | 1.0007 | 1.7 | 0.01 | 1220 | 1680 | c | Inventive example |
| 56 | U | 900 | 10 | 830 | 30 | 60 | 300 | | 80 | 3 | F,B | 1.0006 | 1.8 | 0.01 | 970 | 1450 | D | Comparative example |
| 57 | V | 900 | 10 | 750 | 30 | 60 | | 600 | 96 | 4 | | 1.0079 | 1.4 | 0.01 | 1250 | 1710 | c | Inventive example |
| 58 | W | 900 | 10 | 750 | 30 | 60 | | 600 | 94 | 6 | | 1.0220 | 1.3 | 0.01 | 1240 | 1720 | E | Comparative example |
| 59 | X | 900 | 10 | 750 | 30 | 60 | 300 | | 97 | 3 | | 1.0008 | 2.8 | 0.01 | 1030 | 1400 | E | Comparative example |

(continued)

| Test No. | Steel | FT C (°C) | CR1 (°C/s) | ST (°C) | t1 (s) | CR2 (°C/s) | t2 (s) | t3 (s) | tM (%) | fA (%) | Balance | Average axial ratio | db (μm) | dcar (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | Y | 900 | 10 | 820 | 30 | 60 | 300 | | 99 | 1 | | 1.0007 | 3.5 | 0.01 | 1150 | 1650 | E | Comparative example |
| 61 | Z | 900 | 10 | 820 | 30 | 60 | 300 | | 99 | 1 | | 1.0008 | 1.4 | 0.004 | 1150 | 1650 | E | Comparative example |
| 62 | AA | 900 | 10 | 820 | 30 | 60 | 300 | | 99 | 1 | | 1.0007 | 1.2 | 0.004 | 1140 | 1640 | E | Comparative example |

**[0094]** Next, steel micro-structure observation was performed on the resultant steel sheets, and volume ratios of steel micro-structures were measured. Specifically, a 1/4 thickness portion of a surface of each steel sheet parallel to a rolling direction and a thickness direction of the steel sheet was mirror-polished, and the surface subjected to Nital etching was observed under a SEM. Using a photograph of its steel micro-structure, the measurement was performed by the point counting method to determine area fractions of steel micro-structures, and their values were used as the volume ratios of the steel micro-structures. At this time, an area of the observation was set at 2500 $\mu m^2$ or more. In addition, the volume ratio of retained austenite was measured by the X-ray diffraction method.

**[0095]** Note that, in the column "Remaining structure" of the tables, F indicates ferrite, B indicates bainite, and P indicates pearlite, and in the tables, fM and fA indicate the volume ratios of martensite and retained austenite with respect to all steel micro-structures, respectively.

**[0096]** The average block size of martensite and bainite was measured according to the following procedure. First, each steel sheet was cut such that its surface parallel to its rolling direction and its thickness direction served as an observation surface, and the cross section was measured between a 1/4 sheet-thickness position and a 1/2 sheet-thickness position of the cross section by the EBSD method within a region having an area of 5000 $\mu m^2$ or more. A step size of the measurement was set at 0.2 $\mu m$.

**[0097]** Next, based on crystal orientation information obtained by the EBSD measurement, orientations are classified on the basis of the three Bain groups, which are shown in the Table in p. 223 of Non-Patent Document 2. Next, with boundaries between these groups considered as block boundaries, and regions surrounded by these boundaries considered as block grains, sizes of the block grains (db) were determined by the cutting method described in Appendix 2 of JIS G0552.

**[0098]** The average axial ratio of martensite and bainite was measured by the X-ray diffraction method according to the following procedure. At this time, the axial ratio c/a was measured by any one of the following two methods depending on whether diffraction lines of tetragonal iron or cubic iron were split, and the average axial ratio was determined.

(a) In a case where a 200 diffraction line and a 002 diffraction line are split clearly into two

**[0099]** The pseudo-Voigt function was used to perform peak separation of diffraction lines from a {200} plane, a lattice constant calculated from a 200 diffraction angle was denoted by a, a lattice constant calculated from a 002 diffraction angle was denoted by c, and their ratio was determined as the average axial ratio c/a.

(b) In a case where the diffraction lines are not split clearly into two

**[0100]** A lattice constant calculated from a diffraction angle of a diffraction from a {200} plane was denoted by a, a lattice constant calculated from a diffraction angle from a {110} plane was denoted by c', and their ratio c'/a was determined as the average axial ratio c/a.

**[0101]** Further, structure observation was performed under a SEM and a TEM to measure the average particle size of iron carbides present in a region having an area of 10 $\mu m^2$ or more, which was calculated as an equivalent circle diameter (dear). Fine iron carbides that could not be identified with the TEM were measured by the atom probe method.

**[0102]** Subsequently, from the resultant steel sheets, tensile test specimens described in JIS Z 2241 (2011) were extracted with a direction perpendicular to a rolling direction (sheet width direction) taken as a longitudinal direction. Then, using the tensile test specimens, a tensile test was conducted in conformance with JIS Z 2241 (2011) to measure the mechanical properties (yield stress YS, tensile strength TS).

**[0103]** Further, in order to investigate collision resistances of the steel sheets, a collision test was conducted according to the following procedure, and the presence or absence of a fracture at that time was evaluated.

**[0104]** First, a steel sheet was subjected to bending or roll forming performed as a cold processing to be formed into a hat-shaped component A, and then the hat-shaped component A and a lid B were joined together by spot welding to be fabricated into a test piece having a shape illustrated in Figure 1. Next, the test piece was placed on a mount D such that A served as a top face, and a cylindrical weight C having a weight of 500 kg was caused to collide with a center portion of the test piece from a height of 3 m. Then, a region bent by the collision and an end face of the test piece were visually observed, by which evaluation of cracking was conducted. The evaluation was conducted according to a maximum length of cracks; the maximum length being 10 mm or more was rated as E, the maximum length being 7 mm or more to less than 10 mm was rated as D, the maximum length being 4 mm or more to less than 7 mm was rated as C, the maximum length being 2 mm or more to less than 4 mm was rated as B, and the maximum length being less than 2 mm was rated as A.

**[0105]** Results of the measurement and results of the evaluation are collectively shown in Tables 2 and 3. As is clear from the results shown in Tables 2 and 3, it is understood that example embodiments of the present invention, which satisfied all specifications, had yield stresses of 1000 MPa or more and caused no cracking after the collision test of their members. From the results, it is clear that the steel sheets according to the present invention are excellent in collision properties.

[Example 2]

**[0106]** Steels having compositions shown in Table 1 were melted and produced into slabs, and the slabs were heated at 1220 to 1260°C, subjected to rough rolling performed as a hot processing, subsequently subjected to finish rolling, and cooled to room temperature. Then, as shown in Table 4, the average cooling rate (CR1) for the range from the rolling finish temperature (FT) to 650°C was changed, and for the range of 650°C or less, cooling at the range from 10°C/s to 20°C/h was performed.

**[0107]** After the heat rolling was finished, the flattening was performed, and then the annealing was performed. In the annealing, the annealing temperature (ST), the annealing retention time (t1), and the average cooling rate (CR2) for the range from 700°C to (Ms point - 50)°C were changed, and in the heat treatment step, the holding time (t2) for the range from (Ms + 50)°C to 250°C was changed for steels having Ms being 250°C or more, and the holding time (t3) for the range from (Ms + 80)°C to 100°C was changed for steels having Ms being less than 250°C. After the heat treatment step, skin-pass rolling for flattening was performed.

**[0108]** The resulting steel sheets were subjected to the measurement of the steel micro-structures and the mechanical properties and the evaluation of the collision resistance, as in Example 1. Results of the measurement and results of the evaluation are shown in Table 4.

[Table 4]

**[0109]**

Table 4

| Test No. | Steel | FT (°C) | CR1 (°C/s) | ST (°C) | t1 (S) | CR2 (°C/s) | t2 (s) | t3 (s) | fM (%) | fA (%) | Balance | Average axial ratio | db (μm) | dear (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63 | A | 900 | 10 | 830 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0012 | 2.0 | 0.03 | 1120 | 1450 | B | Inventive example |
| 64 | B | 900 | 10 | 830 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0017 | 2.0 | 0.07 | 1120 | 1450 | B | Inventive example |
| 65 | C | 900 | 10 | 830 | 30 | 60 | 400 | | 92 | 2 | B | 1.0018 | 2.0 | 0.11 | 1260 | 1700 | B | Inventive example |
| 66 | D | 900 | 10 | 840 | 30 | 60 | 500 | | 90 | 10 | | 1.0018 | 2.0 | 0.13 | 1040 | 1500 | B | Inventive example |
| 67 | | 900 | 10 | 800 | 30 | 60 | 500 | | 83 | 11 | F | 1.0018 | 2.0 | 0.13 | 820 | 1480 | B | Comparative example |
| 68 | | 900 | 10 | 930 | 30 | 60 | 500 | | 92 | 8 | | 1.0018 | 3.5 | 0.12 | 1050 | 1490 | E | Comparative example |
| 69 | | 900 | 10 | 840 | 1 | 60 | 500 | | 84 | 11 | F | 1.0004 | 2.0 | 0.16 | 830 | 1480 | D | Comparative example |
| 70 | | 900 | 10 | 840 | 30 | 5 | 500 | | 82 | 11 | B | 1.0008 | 4.0 | 0.21 | 920 | 1480 | E | Comparative example |
| 71 | | 900 | 10 | 840 | 30 | 15 | 500 | | 89 | 10 | B | 1.0008 | 2.4 | 0.19 | 1030 | 1490 | B | Inventive example |
| 72 | | 900 | 10 | 840 | 30 | 60 | 3 | | 90 | 10 | | 1.0110 | 1.8 | 0.003 | 960 | 1480 | E | Comparative example |
| 73 | | 900 | 10 | 840 | 30 | 60 | 1000 | | 90 | 10 | | 1.0015 | 1.8 | 0.13 | 1070 | 1490 | B | Inventive example |
| 74 | | 900 | 10 | 840 | 30 | 60 | 12000 | | 90 | 6 | B | 1.0002 | 1.8 | 0.25 | 1120 | 1410 | E | Comparative example |
| 75 | | 900 | 5 | 840 | 30 | 60 | 500 | | 90 | 10 | | 1.0016 | 3.5 | 0.13 | 1070 | 1480 | E | Comparative example |
| 76 | II | 900 | 10 | 840 | 30 | 60 | 900 | | 96 | 4 | | 1.0037 | 1.8 | 0.03 | 1310 | 1850 | B | Inventive example |

(continued)

| Test No. | Steel | FT (°C) | CR1 (°C/s) | ST (°C) | t1 (S) | CR2 (°C/s) | t2 (s) | t3 (s) | fM (%) | fA (%) | Balance | Average axial ratio | db (μm) | dear (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77 | I | 900 | 10 | 800 | 30 | 60 | | 600 | 96 | 3 | B | 1.0078 | 1.5 | 0.04 | 1450 | 2000 | B | Inventive example |
| 78 | | 900 | 10 | 720 | 30 | 60 | | 600 | <u>83</u> | 5 | F.B | 1.0100 | 1.5 | <u>0.29</u> | <u>990</u> | 1950 | B | Comparative example |
| 79 | | 900 | 10 | <u>860</u> | 30 | 60 | | 600 | 95 | 5 | | 1.0098 | <u>3.4</u> | 0.03 | 1400 | 1980 | E | Comparative example |
| 80 | | 900 | 10 | 800 | 1 | 60 | | 600 | <u>84</u> | 5 | F | 1.0028 | 1.6 | 0.16 | <u>980</u> | 1980 | B | Comparative example |
| 81 | | 900 | 10 | 800 | 30 | <u>5</u> | | 600 | 82 | 5 | B,F | 1.0037 | <u>3.1</u> | 0.08 | <u>940</u> | 1970 | E | Comparative example |
| 82 | | 900 | 10 | 800 | 30 | 15 | | 600 | 88 | 5 | B | 1.0037 | 1.6 | 0.17 | 1340 | 1990 | B | Inventive example |
| 83 | | 900 | 10 | 800 | 30 | 60 | | <u>3</u> | 95 | 5 | | <u>1.0240</u> | 1.6 | <u>0.001</u> | 1110 | 2020 | E | <u>Comparative example</u> |
| 84 | | 900 | 10 | 800 | 30 | 60 | | <u>30</u> | 95 | 5 | | <u>1.0220</u> | 1.6 | <u>0.003</u> | 1200 | 2010 | E | Comparative example |
| 85 | | 900 | 10 | 800 | 30 | 60 | | 100 | 95 | 5 | | 1.0090 | 1.6 | 0.016 | 1320 | 2010 | B | Inventive example |
| 86 | | 900 | 10 | 800 | 30 | 60 | | 1000 | 95 | 5 | | 1.0070 | 1.6 | 0.029 | 1410 | 2000 | B | Inventive example |
| 87 | | 900 | 10 | 800 | 30 | 60 | | 12000 | 95 | 5 | | 1.0019 | 1.6 | 0.028 | 1420 | 1980 | B | Inventive example |
| 88 | | 900 | 10 | 800 | 30 | 60 | | 100000 | 95 | 5 | | <u>1.0003</u> | 1.6 | 0.21 | 1530 | 1980 | E | <u>Comparative example</u> |
| 89 | J | 900 | 10 | 820 | 30 | 60 | 400 | | 99.8 | 0.2 | | 1.0008 | 2.4 | 0.04 | 1030 | 1250 | B | Inventive example |
| <u>90</u> | <u>K</u> | 900 | 10 | 830 | 30 | 60 | | 600 | 93 | 7 | | <u>1.0240</u> | 1.2 | 0.03 | 1500 | 2150 | E | Comparative example |

(continued)

| Test No. | Steel | FT (°C) | CR1 (°C/s) | ST (°C) | t1 (S) | CR2 (°C/s) | t2 (s) | t3 (s) | fM (%) | fA (%) | Balance | Average axial ratio | db (μm) | dear (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91 | L | 900 | 10 | 830 | 30 | 60 | 400 | | <u>83</u> | 0 | F,B | 1.0008 | 4.5 | 0.02 | <u>890</u> | 1150 | E | Comparative example |

**[0110]** As is clear from the results shown in Table 4, it is understood that example embodiments of the present invention, which satisfied all specifications, had yield stresses of 1000 MPa or more and caused no cracking after the collision test of their members. From the results, it is clear that the steel sheets according to the present invention are excellent in collision properties.

[Example 3]

**[0111]** Steels having compositions shown in Table 1 were melted and produced into slabs, and the slabs were heated at 1220 to 1260°C, subjected to rough rolling performed as a hot processing, subsequently subjected to finish rolling, and the subsequent thermal history was changed. As shown in Table 5, the rolling finish temperature (FT) and the average cooling rate (CR3) for the range from the rolling finish temperature to (Ms - 50)°C were changed. Further, in the heat treatment step, the holding time (t2) for the range from (Ms + 50)°C to 250°C was changed for steels having Ms being 250°C or more, and the holding time (t3) for the range from (Ms + 80)°C to 100°C was changed for steels having Ms being less than 250°C. After the heat treatment step, skin-pass rolling for flattening was performed.
**[0112]** The resulting steel sheets were subjected to the measurement of the steel micro-structures and the mechanical properties and the evaluation of the collision resistance, as in Example 1. Results of the measurement and results of the evaluation are shown in Table 5.

[Table 5]

[0113]

Table 5

| Test No. | Steel | FT (°C) | CR3 (°C/s) | t2 (s) | t3 (s) | fM (%) | fA (%) | Balance | Average axial ratio | db (μm) | (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92 | A | 920 | 50 | 1000 | | 99 | 1 | | 1.0009 | 2.1 | 0.009 | 1130 | 1470 | A | Inventive example |
| 93 | | 650 | 50 | 1000 | | 80 | 1 | F | 1.0010 | 2.3 | 0.01 | 810 | 1430 | A | Comparative example |
| 94 | | 920 | 20 | 1000 | | 99 | 1 | | 1.0010 | 2.2 | 0.01 | 1110 | 1470 | A | Inventive example |
| 95 | | 920 | 7 | 1000 | | 82 | 1 | B | 1.0006 | 3.4 | 0.08 | 930 | 1330 | E | Comparative example |
| 96 | | 920 | 3 | 1000 | | 45 | 1 | B,F,P | 1.0004 | 3.5 | 0.12 | 670 | 970 | E | Comparative example |
| 97 | | 920 | 50 | 200 | | 99 | 1 | | 1.0019 | 2.1 | 0.007 | 1100 | 1470 | A | Inventive example |
| 98 | | 920 | 50 | 5000 | | 99 | 1 | | 1.0006 | 2.1 | 0.04 | 1160 | 1470 | D | Inventive example |
| 99 | | 920 | 50 | 9000 | | 99 | 1 | | 1.0006 | 2.1 | 0.05 | 1170 | 1480 | D | Inventive example |
| 100 | | 920 | 50 | 18000 | | 93 | 2 | B | 1.0002 | 2.1 | 0.21 | 1180 | 1470 | E | Comparative example |
| 101 | B | 920 | 50 | 1000 | | 99.8 | 0.2 | | 1.0012 | 2.1 | 0.07 | 1100 | 1450 | A | Inventive example |
| 102 | C | 920 | 50 | 1000 | | 99 | 1 | | 1.0018 | 20 | 0.11 | 1250 | 1700 | A | Inventive example |

(continued)

| Test No. | Steel | FT (°C) | CR3 (°C/s) | t2 (s) | t3 (s) | fM (%) | fA (%) | Balance | Average axial ratio | db (μm) | (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 103 | D | 920 | 50 | 1000 | | 90 | 4 | B | 1.0019 | 1.8 | 0.12 | 1060 | 1500 | A | Inventive example |
| 104 | | 920 | 7 | 1000 | | 80 | 5 | B | 1.0013 | 3.1 | 0.12 | 950 | 1480 | E | Comparative example |
| 105 | | 920 | 3 | 1000 | | 50 | 10 | B,F | 1.0004 | 3.3 | 0.18 | 820 | 1520 | E | Comparative example |
| 106 | | 920 | 50 | 2 | | 99 | 1 | | 1.0120 | 1.8 | 0.003 | 1050 | 1530 | E | Comparative example |
| 107 | | 920 | 50 | 1000 | | 95 | 4 | B | 1.0030 | 2.0 | 0.005 | 1060 | 1530 | A | Inventive example |
| 108 | | 920 | 50 | 9000 | | 90 | 9 | B | 1.0006 | 2.2 | 0.09 | 1020 | 1550 | D | Inventive example |
| 109 | | 920 | 50 | 18000 | | 90 | 4 | B | 1.0002 | 2.2 | 0.21 | 1030 | 1560 | E | Comparative example |
| 110 | H | 920 | 50 | 1000 | | 97 | 3 | | 1.0080 | 1.6 | 0.02 | 1280 | 1860 | A | Inventive example |
| III | I | 920 | 50 | | 3 | 97 | 3 | | 1.0220 | 1.5 | 0.002 | 1390 | 1980 | E | Comparative example |
| 112 | | 920 | 50 | | 800 | 97 | 3 | | 1.0091 | 1.5 | 0.03 | 1470 | 1950 | A | Inventive example |
| 113 | | 920 | 50 | | 18000 | 90 | 8 | B | 1.0025 | 1.8 | 0.028 | 1260 | 1960 | A | Inventive example |
| 114 | | 920 | 50 | | 60000 | 90 | 3 | B | 1.0002 | 1.7 | 0.21 | 1470 | 1920 | E | Comparative example |
| 115 | J | 920 | 50 | 1000 | | 100 | | | 1.0007 | 2.2 | 0.012 | 1030 | 1250 | A | Inventive example |
| 116 | K | 920 | 50 | | 1000 | 95 | 5 | | 1.0290 | 1.5 | 0.003 | 1510 | 2150 | E | Comparative example |

(continued)

| Test No. | Steel | FT (°C) | CR3 (°C/s) | t2 (s) | t3 (s) | fM (%) | fA (%) | Balance | Average axial ratio | db (μm) | (μm) | YS (MPa) | TS (MPa) | Evaluation of cracking | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117 | L | 920 | 50 | 1000 | | 100 | | | 1.0009 | 4.5 | 0.13 | 960 | 1150 | E | Comparative example |

**[0114]** As is clear from the results shown in Table 5, it is understood that example embodiments of the present invention, which satisfied all specification, had yield stresses of 100 MPa or more and caused no cracking after the collision test of their members. From the results, it is clear that the steel sheets according to the present invention are excellent in collision properties.

INDUSTRIAL APPLICABILITY

**[0115]** According to the present invention, it is possible to obtain a high-strength steel sheet that exerts good reaction force properties when an impact load is applied to a shaped component from the steel sheet, is unlikely to cause a crack from an end face of the component or a region of the component bent at the time of the impact, and has a yield stress of 1000 MPa or more. The steel sheet according to the present invention is therefore suitable for a skeleton component and a reinforcing component of an automobile, and a component of building equipment or industrial equipment.

## Claims

**1.** A steel sheet having a chemical composition consisting of, in mass%:

C: 0.14 to 0.60%,
Si: more than 0% to less than 3.00%,
Al: more than 0% to less than 3.00%,
Mn: 5.00% or less,
P: 0.030% or less,
S: 0.0050% or less,
N: 0.015% or less,
B: 0 to 0.0050%,
Ni: 0 to 5.00%,
Cu: 0 to 5.00%,
Cr: 0 to 5.00%,
Mo: 0 to 1.00%,
W: 0 to 1.00%,
Ti: 0 to 0.20%,
Zr: 0 to 0.20%,
Hf: 0 to 0.20%,
V: 0 to 0.20%,
Nb: 0 to 0.20%,
Ta: 0 to 0.20%,
Sc: 0 to 0.20%,
Y: 0 to 0.20%,
Sn: 0 to 0.020%,
As: 0 to 0.020%,
Sb: 0 to 0.020%,
Bi: 0 to 0.020%,
Mg: 0 to 0.005%,
Ca: 0 to 0.005%, and
REM: 0 to 0.005%,
with the balance: Fe and impurities, and
satisfying following formulas (i) to (v), wherein
a value of Ms expressed by a following formula (vi) is 200 or more,
a steel micro-structure contains, in volume%:

martensite: 85% or more, and
retained austenite: 15% or less,
with the balance: bainite,
an average block size of martensite and bainite: 3.0 μm or less,
an average axial ratio of martensite and bainite: 1.0004 to 1.0100, and
a yield stress is 1000 MPa or more:

$$Si + Al \leq 3.00 \qquad (i)$$

$$C \times Mn \leq 0.80 \qquad (ii)$$

$$Mn + Ni + Cu + 1.3Cr + 4(Mo + W) \geq 0.80 \qquad (iii)$$

$$0.003 \leq Ti + Zr + Hf + V + Nb + Ta + Sc + Y \leq 0.20 \qquad (iv)$$

$$Sn + As + Sb + Bi \leq 0.020 \qquad (v)$$

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \qquad (vi)$$

where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol.

2. The steel sheet according to claim 1, wherein an average particle size of iron carbides included in the steel microstructure is 0.005 to 0.20 μm.

3. The steel sheet according to claim 1 or claim 2, wherein the steel sheet includes a plating layer on a surface of the steel sheet.

4. A method for producing the steel sheet according to any one of claim 1 to claim 3, wherein

a cast piece having the chemical composition according to claim 1 is subjected to a hot-rolling step, a cold-rolling step, an annealing step, and a heat treatment step in this order,
in the hot-rolling step, the steel sheet is cooled to room temperature at an average cooling rate for a range from a rolling finish temperature to 650°C set at 8°C/s or more,
in the annealing step, the steel sheet is held within a temperature range from an $Ac_3$ point to ($Ac_3$ point + 100)°C for 3 to 90 s, and
an average cooling rate for a range from 700°C to (Ms point - 50)°C is set at 10°C/s or more, and
in the heat treatment step,
in a case where the Ms point is 250°C or more,
a holding time for a temperature range from (Ms point + 50) to 250°C is set at 100 to 10000 s, and
in a case where the Ms point is less than 250°C,
a holding time for a temperature range from (Ms point + 80) to 100°C is set at 100 to 50000 s,
where the Ms point (°C) and the $Ac_3$ point (°C) are expressed by following formulas, where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol:

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \qquad (vi)$$

$$Ac_3 = 910 - 203 \times C^{0.5} + 44.7(Si + Al) - 30 \times Mn + 700 \times P - 15.2 \times Ni - 26 \times Cu - 11 \times Cr + 31.5 \times Mo \qquad (vii).$$

5. A method for producing the steel sheet according to any one of claim 1 to claim 3, wherein

a cast piece having the chemical composition according to claim 1 is subjected to a hot-rolling step, an annealing step, and a heat treatment step in this order,
in the hot-rolling step, the steel sheet is cooled to room temperature at an average cooling rate for a range from a rolling finish temperature to 650°C set at 8°C/s or more,
in the annealing step, the steel sheet is held within a temperature range from an $Ac_3$ to $(Ac_3 + 100)$°C for 3 to 90 s, and
an average cooling rate for a range from 700°C to (Ms - 50)°C is set at 10°C/s or more, and
in the heat treatment step,
in a case where the Ms point is 250°C or more,
a holding time for a temperature range from (Ms + 50) to 250°C is set at 100 to 10000 s, and
in a case where the Ms point is less than 250°C,
a holding time for a temperature range from (Ms + 80) to 100°C is set at 100 to 50000 s,
where the Ms point (°C) and the $Ac_3$ point (°C) are expressed by following formulas, where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol:

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \quad (vi)$$

$$Ac_3 = 910 - 203 \times C^{0.5} + 44.7(Si + Al) - 30 \times Mn + 700 \times P - 15.2 \times Ni - 26 \times Cu - 11 \times Cr + 31.5 \times Mo \quad (vii).$$

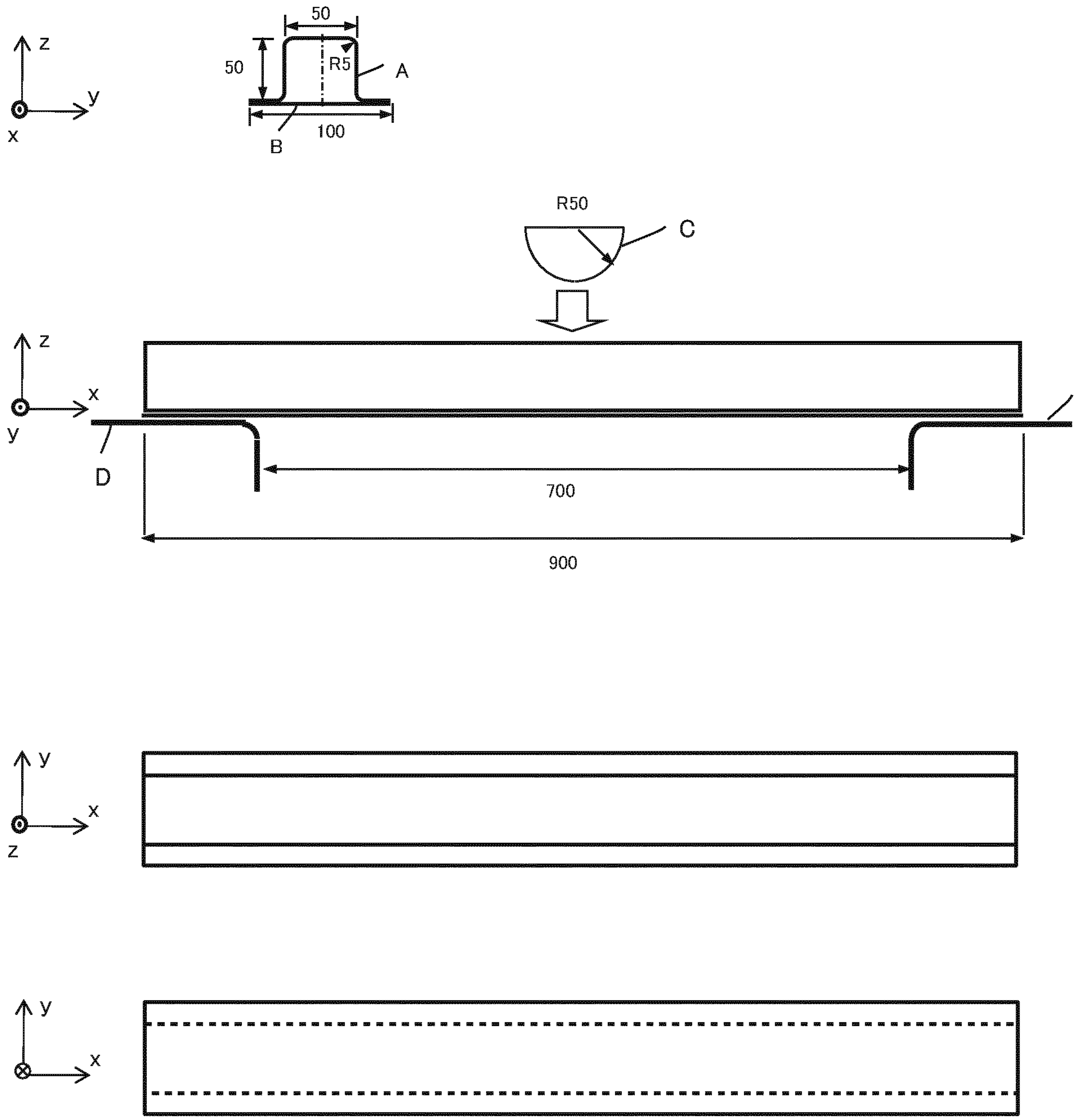
**6.** A method for producing the steel sheet according to any one of claim 1 to claim 3, wherein

a cast piece having the chemical composition according to claim 1 is subjected to a hot-rolling step and a heat treatment step in this order,
in the hot-rolling step, a rolling finish temperature is set at a $Ar_3$ point or more, and
an average cooling rate for a range from a rolling finish temperature to (Ms - 50)°C is set at 10°C/s or more, and
in the heat treatment step,
in a case where the Ms point is 250°C or more,
a holding time for a temperature range from (Ms + 50) to 250°C is set at 100 to 10000 s, and
in a case where the Ms point is less than 250°C,
a holding time for a temperature range from (Ms + 80) to 100°C is set at 100 to 50000 s,
where the Ms point (°C) and the $Ar_3$ point (°C) are expressed by following formulas, where symbols of elements represent contents (mass%) of the elements in the steel sheet, and in a case where an element is not contained, zero is assigned to its symbol:

$$Ms = 546 \times \exp(-1.362 \times C) - 11 \times Si - 30 \times Mn - 18 \times Ni - 20 \times Cu - 12 \times Cr - 8(Mo + W) \quad (vi)$$

$$Ar_3 = 910 - 310 \times C + 33 \times Si - 80 \times Mn - 55 \times Ni - 20 \times Cu - 15 \times Cr - 80 \times Mo \quad (viii).$$

FIGURE 1



**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2021/001658

A. CLASSIFICATION OF SUBJECT MATTER
C21D 9/46(2006.01)i; C22C 38/00(2006.01)i; C22C 38/60(2006.01)i
FI: C22C38/00 301U; C22C38/00 301T; C22C38/00 301W; C22C38/60; C21D9/46 F; C21D9/46 S

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)
C21D9/46-9/48; C22C38/00-38/60

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

| | |
|---|---|
| Published examined utility model applications of Japan | 1922-1996 |
| Published unexamined utility model applications of Japan | 1971-2021 |
| Registered utility model specifications of Japan | 1996-2021 |
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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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| Y | claims, paragraphs [0026]-[0056] | 3, 5 |
| A | | 6 |
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 23 March 2021 (23.03.2021) | 06 April 2021 (06.04.2021) |

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

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**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2021/001658

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No.
PCT/JP2021/001658

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| KR 10-1620744 B1 | 13 May 2016 | (Family: none) | |
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