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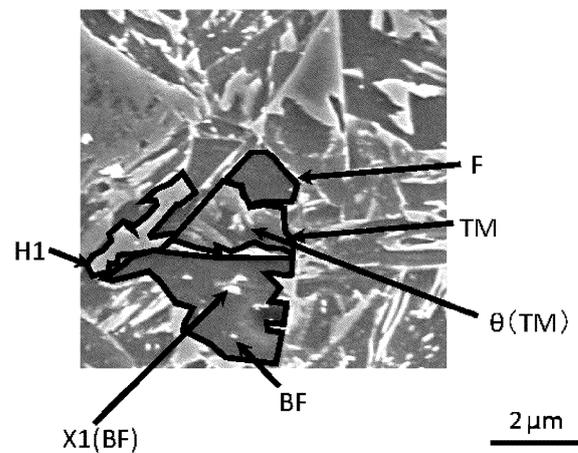
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(54) **STEEL SHEET, MEMBER, AND METHODS FOR PRODUCING SAME**

(57) To provide a steel sheet and a member with a TS of 1180 MPa or more and high YS, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) at the time of compression, and a method for producing them.

A base steel sheet has a specified chemical composition. In a steel microstructure of the base steel sheet, bainitic ferrite, tempered martensite, retained austenite, and fresh martensite are in specified ranges. The concentration of carbon in retained austenite and the density of carbides in tempered martensite are in specified ranges. The amount of diffusible hydrogen is 0.50 ppm by mass or less. A V-VDA bending test is performed to the maximum load point. In an L cross section, a crack has a length of 400  $\mu\text{m}$  or less. In a specified region of VDA bending, a change in the grain size of bainitic ferrite in the thickness direction due to processing is 5.0 or less.

FIG. 1



EP 4 502 195 A1

## Description

## Technical Field

5 **[0001]** The present invention relates to a steel sheet, a member made of the steel sheet, and methods for producing them.

## Background Art

10 **[0002]** In recent years, from the viewpoint of global environmental conservation, improvement of fuel efficiency in automobiles has been an important issue. Thus, there has been an active movement to reduce the weight of automobile bodies by increasing the strength and reducing the thickness of steel sheets used as materials for automotive body parts.

**[0003]** Furthermore, a social demand for improvement of crash safety of automobiles is further increased. Thus, there is a demand for the development of a steel sheet with high strength and enhanced crashworthiness when a vehicle collides while traveling (hereinafter referred to simply as crashworthiness) .

15 **[0004]** For example, Patent Literature 1 discloses, as such a steel sheet serving as a material of an automobile body part, a high-strength steel sheet with high stretch flangeability and enhanced crashworthiness, which has a chemical composition containing, on a mass percent basis, C: 0.04% to 0.22%, Si: 1.0% or less, Mn: 3.0% or less, P: 0.05% or less, S: 0.01% or less, Al: 0.01% to 0.1%, and N: 0.001% to 0.005%, the remainder being Fe and incidental impurities, and which is composed of a ferrite phase as a main phase and a martensite phase as a second phase, the martensite phase having a maximum grain size of 2  $\mu\text{m}$  or less and an area fraction of 5% or more.

20 **[0005]** Patent Literature 2 discloses a high-strength hot-dip galvanized steel sheet with high coating adhesion and formability having a hot-dip galvanized layer on the surface of a cold-rolled steel sheet, which has a surface layer ground off with a thickness of 0.1  $\mu\text{m}$  or more and is precoated with 0.2 g/m<sup>2</sup> or more and 2.0 g/m<sup>2</sup> or less of Ni, wherein the cold-rolled steel sheet contains, on a mass percent basis, C: 0.05% or more and 0.4% or less, Si: 0.01% or more and 3.0% or less, Mn: 0.1% or more and 3.0% or less, P: 0.04% or less, S: 0.05% or less, N: 0.01% or less, Al: 0.01% or more and 2.0% or less, Si + Al > 0.5%, the remainder being Fe and incidental impurities, has a microstructure, on a volume fraction basis, 40% or more ferrite as a main phase, 8% or more retained austenite, two or more of three types of martensite [1], [2], and [3] as specified below including martensite [3], 1% or more bainite, and 0% to 10% pearlite, the three types of martensite [1], [2], and [3] being, on a volume fraction basis, martensite [1]: 0% or more and 50% or less, martensite [2]: 0% or more and less than 20%, and martensite [3]: 1% or more and 30% or less, and having a hot-dip galvanized layer containing less than 7% Fe and the remainder composed of Zn, Al, and incidental impurities, on the surface of the steel sheet, and has TS x EL of 18000 MPa-% or more and TS x  $\lambda$  of 35000 MPa-% or more, wherein TS denotes tensile strength (MPa), EL denotes total elongation percentage (%), and  $\lambda$  denotes hole expansion ratio (%), and a tensile strength of 980 MPa or more (when martensite [1]:C concentration (CM1) is less than 0.8%, hardness Hv1 satisfies  $Hv1/(-982.1 \times CM1^2 + 1676 \times CM1 + 189) \leq 0.60$ , when martensite [2]:C concentration (CM2) is 0.8% or more, the hardness Hv2 satisfies  $Hv2/(-982.1 \times CM2^2 + 1676 \times CM2 + 189) \leq 0.60$ , and when martensite [3]:C concentration (CM3) is 0.8% or more, the hardness Hv3 satisfies  $Hv3/(-982.1 \times CM3^2 + 1676 \times CM3 + 189) \geq 0.80$ ).

30 **[0006]** Patent Literature 3 discloses a high-strength hot-dip galvanized steel sheet that has a chemical composition composed of, on a mass percent basis, C: 0.15% or more and 0.25% or less, Si: 0.50% or more and 2.5% or less, Mn: 2.3% or more and 4.0% or less, P: 0.100% or less, S: 0.02% or less, and Al: 0.01% or more and 2.5% or less, the remainder being Fe and incidental impurities, and that has a steel sheet microstructure having, on an area fraction, a tempered martensite phase: 30% or more and 73% or less, a ferrite phase: 25% or more and 68% or less, a retained austenite phase: 2% or more and 20% or less, and other phases: 10% or less (including 0%), the other phases being a martensite phase: 3% or less (including 0%) and bainitic ferrite phase: less than 5% (including 0%), the tempered martensite phase having an average grain size of 8  $\mu\text{m}$  or less, the retained austenite phase having a C concentration of less than 0.7% by mass.

## Citation List

50 Patent Literature

**[0007]**

55 PTL 1: Japanese Patent No. 3887235  
PTL 2: Japanese Patent No. 5953693  
PTL 3: Japanese Patent No. 6052472

## Summary of Invention

## Technical Problem

5 **[0008]** At present, however, only steel sheets with a tensile strength (hereinafter also referred to as TS) of 590 MPa are used for impact energy absorbing members of automobiles exemplified by front side members and rear side members. **[0009]** Thus, to increase absorbed energy at the time of impact (hereinafter also referred to as impact absorbed energy), it is effective to improve yield stress (hereinafter also referred to as YS). However, a steel sheet with higher TS and YS typically has lower press formability and, in particular, lower ductility, flangeability, bendability, and the like. Thus, when  
10 such a steel sheet with higher TS and YS is applied to the impact energy absorbing members of automobiles, not only press forming is difficult, but also the member cracks in an axial compression test simulating a collision test. In other words, the actual impact absorbed energy is not increased as expected from the value of YS. Thus, the impact energy absorbing members are currently limited to steel sheets with a TS of 590 MPa.

**[0010]** Actually, it also cannot be said that the steel sheets disclosed in Patent Literature 1 to Patent Literature 3 have a  
15 TS of 1180 MPa or more, high YS, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) at the time of compression.

**[0011]** The present invention has been developed in view of such circumstances and aims to provide a steel sheet with a tensile strength TS of 1180 MPa or more, high yield stress YS, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) at the time of compression, together with an advantageous method for producing the steel sheet.  
20

**[0012]** The present invention also aims to provide a member made of the steel sheet and a method for producing the member.

**[0013]** The term "steel sheet", as used herein, includes a galvanized steel sheet, and the galvanized steel sheet is a hot-dip galvanized steel sheet (hereinafter also referred to as GI) or a hot-dip galvanized steel sheet (hereinafter also referred to as GA).  
25

**[0014]** The tensile strength TS is measured in the tensile test according to JIS Z 2241 (2011).

**[0015]** The phrase "with high yield stress YS, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) at the time of compression" refers to satisfying the following.  
30

**[0016]** The phrase "high yield stress YS" means that YS measured in the tensile test according to JIS Z 2241 (2011) satisfies the following formula (A) or (B) depending on TS measured in the tensile test.

(A) For  $1180 \text{ MPa} \leq \text{TS} < 1320 \text{ MPa}$ ,  $750 \text{ MPa} \leq \text{YS}$

(B) For  $1320 \text{ MPa} \leq \text{TS}$ ,  $850 \text{ MPa} \leq \text{YS}$   
35

**[0017]** The phrase "high ductility" means that the total elongation (EI) measured in the tensile test according to JIS Z 2241 (2011) satisfies the following formula (A) or (B) depending on TS measured in the tensile test.

(A) For  $1180 \text{ MPa} \leq \text{TS} < 1320 \text{ MPa}$ ,  $12.0\% \leq \text{EI}$

(B) For  $1320 \text{ MPa} \leq \text{TS}$ ,  $10.0\% \leq \text{EI}$   
40

**[0018]** The phrase "high flangeability" refers to a limiting hole expansion ratio ( $\lambda$ ) of 30% or more as measured in the hole expansion test according to JIS Z 2256 (2020).

**[0019]** The phrase "high bendability" refers to a bending angle ( $\alpha$ ) of 80 degrees or more at the maximum load measured in a bending test according to the VDA standard (VDA 238-100) defined by German Association of the Automotive Industry.  
45

**[0020]** The phrase "good bending fracture characteristics" refers to a stroke ( $S_{F\text{max}}$ ) of 26.0 mm or more at the maximum load measured in a V-VDA bending test.

**[0021]** The phrase "good axial compression characteristics" means that, after an axial compression test, fracture (appearance crack) occurs at three or less positions in the regions of  $R = 5.0 \text{ mm}$  and  $200 \text{ mm}$  of lower two bending ridge line portions in Fig. 6-1(b) (see regions Cx in Fig. 6-1).  
50

**[0022]** EI,  $\lambda$ , and  $\alpha$  described above are characteristics indicating formability at the time of press forming of a steel sheet. On the other hand, the V-VDA bending test is a test simulating the deformation and fracture behavior of a bending ridge line portion in a collision test, and the stroke at the maximum load ( $S_{F\text{max}}$ ) measured in the V-VDA bending test is a characteristic indicating the resistance to cracking of a member.  
55

## Solution to Problem

**[0023]** To achieve the above objects, the present inventors have conducted extensive studies.

**[0024]** As a result, it has been found that a steel sheet with a tensile strength TS of 1180 MPa or more, high YS, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) at the time of compression is produced when the steel sheet has a base steel sheet with an appropriately adjusted chemical composition, the base steel sheet of the steel sheet has a steel microstructure in which the area fraction of bainitic ferrite: 3.0% or more and 20.0% or less, the area fraction of tempered martensite (excluding retained austenite): 40.0% or more and 90.0% or less, the area fraction of retained austenite: more than 3.0% and 15.0% or less, the concentration of carbon in retained austenite: 0.60% by mass or more and 1.30% by mass or less, the area fraction of fresh martensite: 10.0% or less (including 0.0%), and the density of carbides in tempered martensite: 8.0 particles/ $\mu\text{m}^2$  or less, the amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less, a V-VDA bending test is performed to a maximum load point, a crack in an L cross section in an overlap region of a V-bending ridge line portion and a VDA bending ridge line portion has a length of 400  $\mu\text{m}$  or less, in a region formed from each position on a starting line present from a starting point of a bending peak on an outside of a VDA bend to a position of 50  $\mu\text{m}$  in a thickness direction up to a position of 50  $\mu\text{m}$  on each side of the starting line perpendicular to the starting line, and, with respect to the average grain size of bainitic ferrite in the thickness direction, the ratio of the average grain size before processing to the average grain size after the processing (a change due to processing: average grain size before processing (nm)/average grain size after processing (nm)) is 5.0 or less.

**[0025]** The present invention has been accomplished on the basis of these findings after further consideration.

**[0026]** The gist of the present invention can be summarized as follows:

[1] A steel sheet including a base steel sheet, wherein the base steel sheet has a chemical composition containing, on a mass percent basis,

C: 0.050% or more and 0.400% or less,  
Si: more than 0.75% and 3.00% or less,  
Mn: 2.00% or more and less than 3.50%,  
P: 0.001% or more and 0.100% or less,  
S: 0.0001% or more and 0.0200% or less,  
Al: 0.010% or more and 2.000% or less, and  
N: 0.0100% or less,

with the remainder being Fe and incidental impurities,

the base steel sheet has a steel microstructure in which

an area fraction of bainitic ferrite: 3.0% or more and 20.0% or less,  
an area fraction of tempered martensite: 40.0% or more and 90.0% or less,  
an area fraction of retained austenite: more than 3.0% and 15.0% or less,  
a concentration of carbon in retained austenite: 0.60% by mass or more and 1.30% by mass or less,  
an area fraction of fresh martensite: 10.0% or less, and

a density of carbides in tempered martensite: 8.0 particles/ $\mu\text{m}^2$  or less,  
an amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less,  
a V-VDA bending test is performed to a maximum load point,  
in an L cross section,

a crack has a length of 400  $\mu\text{m}$  or less,

in a region formed from each position on a starting line present from a starting point of a bending peak on an outside of a VDA bend to a position of 50  $\mu\text{m}$  in a thickness direction up to a position of 50  $\mu\text{m}$  on each side of the starting line perpendicular to the starting line,

with respect to an average grain size of bainitic ferrite in the thickness direction, a ratio of the average grain size before processing to the average grain size after the processing is 5.0 or less, and

the steel sheet has a tensile strength of 1180 MPa or more.

[2] The steel sheet according to [1], wherein the base steel sheet has a chemical composition further containing, on a mass percent basis, at least one selected from

Nb: 0.200% or less,  
Ti: 0.200% or less,  
V: 0.200% or less,  
B: 0.0100% or less,

Cr: 1.000% or less,  
 Ni: 1.000% or less,  
 Mo: 1.000% or less,  
 5 Sb: 0.200% or less,  
 Sn: 0.200% or less,  
 Cu: 1.000% or less,  
 Ta: 0.100% or less,  
 W: 0.500% or less,  
 10 Mg: 0.0200% or less,  
 Zn: 0.0200% or less,  
 Co: 0.0200% or less,  
 Zr: 0.1000% or less,  
 Ca: 0.0200% or less,  
 15 Se: 0.0200% or less,  
 Te: 0.0200% or less,  
 Ge: 0.0200% or less,  
 As: 0.0500% or less,  
 Sr: 0.0200% or less,  
 20 Cs: 0.0200% or less,  
 Hf: 0.0200% or less,  
 Pb: 0.0200% or less,  
 Bi: 0.0200% or less, and  
 REM: 0.0200% or less.

25 [3] The steel sheet according to [1] or [2], including a galvanized layer as an outermost surface layer on one or both surfaces of the steel sheet.

[4] The steel sheet according to any one of [1] to [3], wherein

30 when a region of 200  $\mu\text{m}$  or less from a surface of the base steel sheet in the thickness direction is defined as a surface layer,

the base steel sheet has, in the surface layer, a surface soft layer with a Vickers hardness of 85% or less with respect to a Vickers hardness at a quarter thickness position, and

35 when nanohardness is measured at 300 points or more in a 50  $\mu\text{m}$  x 50  $\mu\text{m}$  region on a sheet surface at a quarter depth position in the thickness direction and at a half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet,

a ratio of a number of measurements with a nanohardness of 7.0 GPa or more on the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet to a total number of measurements at the quarter depth position in the thickness direction of the surface soft layer is 0.10 or less,

40 the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet has a standard deviation  $\sigma$  of 1.8 GPa or less, and

the nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet has a standard deviation  $\sigma$  of 2.2 GPa or less.

45 [5] The steel sheet according to any one of [1] to [4], including a metal coated layer formed on the base steel sheet on one or both surfaces of the steel sheet.

[6] A member including the steel sheet according to any one of [1] to [5].

[7] A method for producing a steel sheet including:

50 a hot rolling step of hot-rolling a steel slab with the chemical composition according to [1] or [2] to produce a hot-rolled steel sheet;

a pickling step of pickling the hot-rolled steel sheet;

an annealing step of annealing the steel sheet after the pickling step at an annealing temperature of  $(Ac_1 + 0.4 \times (Ac_3 - Ac_1))$  °C or more and 900°C or less for an annealing time of 20 seconds or more;

55 a first cooling step of cooling the steel sheet after the annealing step to a first cooling stop temperature of 400°C or more and 600°C or less;

a second cooling step of cooling the steel sheet after the first cooling step to a second cooling stop temperature of 100°C or more and 300°C or less at an average cooling rate of 25.0°C/s or less,

during the cooling, applying a tension of 2.0 kgf/mm<sup>2</sup> or more to the steel sheet once or more in a temperature range of 300°C or more and 450°C or less, then

5     subjecting the steel sheet to four or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll, and

subjecting the steel sheet to two or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for half a circumference of the roll;

10     a reheating step of performing a reheat treatment of heating the steel sheet after the second cooling step to a tempering temperature range of more than 300°C and 500°C or less, holding the steel sheet in the temperature range for a tempering time of 20 seconds or more and 900 seconds or less, and setting a carbide control parameter CP represented by the following formula (1) to 10,000 or more and 15,000 or less during the reheat treatment; and

optionally a cold rolling step of cold-rolling the steel sheet after the pickling step and before the annealing step to produce a cold-rolled steel sheet,

$$CP = (T + 273) \times (k + 1.2 \times \log t) \quad \text{formula (1)}$$

15     wherein T denotes the tempering temperature (°C), k denotes a material constant depending on a C content, and t denotes the tempering time (second),

$$k = -6 \times C_M + 17.8,$$

20     wherein C<sub>M</sub> denotes a carbon concentration (% by mass) of martensite formed in the second cooling step.

25     [8] The method for producing a steel sheet according to [7], including a galvanizing step of performing a galvanizing treatment on the steel sheet to form a galvanized layer on the steel sheet after the first cooling step and before the second cooling step.

30     [9] The method for producing a steel sheet according to [7] or [8], wherein the annealing in the annealing step is performed in an atmosphere with a dew point of -30°C or more.

[10] The method for producing a steel sheet according to any one of [7] to [9], including a metal coating step of performing metal coating on one or both surfaces of the steel sheet to form a metal coated layer after the pickling step and before the annealing step.

35     [11] A method for producing a member, including a step of subjecting the steel sheet according to any one of [1] to [5] to at least one of forming and joining to produce a member.

#### Advantageous Effects of Invention

40     **[0027]** The present invention provides a steel sheet with a tensile strength TS of 1180 MPa or more, high yield stress YS, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) at the time of compression.

**[0028]** Furthermore, a member including a steel sheet according to the present invention as a material has high strength and enhanced crashworthiness and can therefore be extremely advantageously applied to an impact energy absorbing member or the like of an automobile.

#### 45     Brief Description of Drawings

##### **[0029]**

50     [Fig. 1] Fig. 1 is a SEM microstructure image for explaining identification of a microstructure.

[Fig. 2-1] Fig. 2-1(a) is an explanatory view of V-bending (primary bending) in a V-VDA bending test in Examples. Fig. 2-1(b) is an explanatory view of VDA bending (secondary bending) in the V-VDA bending test in Examples.

[Fig. 2-2] Fig. 2-2(c) is a perspective view of a test specimen subjected to V-bending (primary bending) in V-VDA. Fig. 2-2(d) is a perspective view of a test specimen subjected to VDA bending (secondary bending) in V-VDA.

55     [Fig. 2-3] Fig. 2-3(e) is a perspective view of a test specimen subjected to VDA bending (secondary bending) in V-VDA and an L cross-sectional observation surface. Fig. 2-3(f) is a cross-sectional view of a measurement point of a change in the grain size of bainitic ferrite in the thickness direction due to processing in an L cross-sectional observation surface of a test specimen subjected to VDA bending (secondary bending) in V-VDA.

[Fig. 2-4] Fig. 2-4 is a schematic view for explaining an AB region.

[Fig. 3] Fig. 3 is a schematic view of a stroke-load curve obtained in a V-VDA test.

[Fig. 4] Fig. 4 is a SEM microstructure image for explaining the measurement of the length of a crack specified in the present invention (Inventive Example No. 36 in Examples).

[Fig. 5] Fig. 5(a) is a SEM microstructure image for explaining a method for measuring the grain size of bainitic ferrite before deformation by processing specified in the present invention (Inventive Example No. 35 in Examples). Fig. 5(b) is a SEM microstructure image for explaining a method for measuring the grain size of bainitic ferrite after deformation by processing specified in the present invention (Inventive Example No. 35 in Examples).

[Fig. 6-1] Fig. 6-1(a) is a front view of a test member composed of a hat-shaped member and a steel sheet spotwelded together for an axial compression test in Examples. Fig. 6-1(b) is a perspective view of the test member illustrated in Fig. 6-1(a).

[Fig. 6-2] Fig. 6-2(c) is a schematic explanatory view of an axial compression test in Examples.

#### Description of Embodiments

**[0030]** The present invention is described on the basis of the following embodiments.

##### [1. Steel Sheet]

**[0031]** A steel sheet according to the present invention is a steel sheet including a base steel sheet, wherein the base steel sheet has a chemical composition containing, on a mass percent basis, C: 0.050% or more and 0.400% or less, Si: more than 0.75% and 3.00% or less, Mn: 2.00% or more and less than 3.50%, P: 0.001% or more and 0.100% or less, S: 0.0001% or more and 0.0200% or less, Al: 0.010% or more and 2.000% or less, and N: 0.0100% or less, with the remainder being Fe and incidental impurities, the base steel sheet has a steel microstructure in which an area fraction of bainitic ferrite: 3.0% or more and 20.0% or less, an area fraction of tempered martensite: 40.0% or more and 90.0% or less, an area fraction of retained austenite: more than 3.0% and 15.0% or less, a concentration of carbon in retained austenite: 0.60% by mass or more and 1.30% by mass or less, an area fraction of fresh martensite: 10.0% or less, and a density of carbides in tempered martensite: 8.0 particles/ $\mu\text{m}^2$  or less, an amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less, a V-VDA bending test is performed to a maximum load point, in an L cross section, a crack has a length of 400  $\mu\text{m}$  or less, in a region formed from each position on a starting line present from a starting point of a bending peak on an outside of a VDA bend to a position of 50  $\mu\text{m}$  in a thickness direction up to a position of 50  $\mu\text{m}$  on each side of the starting line perpendicular to the starting line, with respect to an average grain size of bainitic ferrite in the thickness direction, a ratio of the average grain size before processing to the average grain size after the processing is 5.0 or less, and the steel sheet has a tensile strength of 1180 MPa or more.

**[0032]** The steel sheet may have a galvanized layer as an outermost surface layer on one or both surfaces of the steel sheet. A steel sheet with a galvanized layer may be a galvanized steel sheet.

#### Chemical Composition

**[0033]** First, the chemical composition of a base steel sheet of a steel sheet according to an embodiment of the present invention is described. The unit in the chemical composition is "% by mass" and is hereinafter expressed simply in "%" unless otherwise specified.

C: 0.050% or more and 0.400% or less

**[0034]** C is an element effective in forming appropriate amounts of fresh martensite, tempered martensite, bainitic ferrite, and retained austenite and ensuring a tensile strength TS of 1180 MPa or more and high YS. A C content of less than 0.050% results in an increase in the area fraction of ferrite and makes it difficult to achieve a TS of 1180 MPa or more. This also reduces YS.

**[0035]** On the other hand, a C content of more than 0.400% results in an excessive increase in the concentration of carbon in retained austenite. This greatly increases the hardness of fresh martensite formed by deformation-induced transformation when a steel sheet is punched in a hole expansion test or is subjected to V-bending in a V-VDA test, and subsequently promotes void formation and crack growth, resulting in undesired  $\lambda$  and  $S_{F\text{max}}$ .

**[0036]** Thus, the C content is 0.050% or more and 0.400% or less. The C content is preferably 0.100% or more. The C content is preferably 0.300% or less.

## EP 4 502 195 A1

Si: more than 0.75% and 3.00% or less

5 **[0037]** Si suppresses the formation of carbides and promotes the formation of retained austenite during cooling and holding after annealing. Thus, Si is an element that has an influence on the volume fraction of retained austenite and the concentration of carbon in retained austenite. A Si content of 0.75% or less results in a decrease in the volume fraction of retained austenite and lower ductility.

**[0038]** On the other hand, a Si content of more than 3.00% results in an excessive increase in the area fraction of ferrite and makes it difficult to achieve a TS of 1180 MPa or more. This also reduces YS. This also excessively increases the concentration of carbon in austenite during annealing and results in undesired  $\lambda$  and  $S_{Fmax}$ .

10 **[0039]** Thus, the Si content is more than 0.75% and 3.00% or less. The Si content is preferably 2.00% or less.

Mn: 2.00% or more and less than 3.50%

15 **[0040]** Mn is an element that adjusts the area fraction of bainitic ferrite, tempered martensite, or the like. A Mn content of less than 2.00% results in an excessive increase in the area fraction of ferrite and makes it difficult to achieve a TS of 1180 MPa or more. This also reduces YS.

20 **[0041]** On the other hand, a Mn content of 3.50% or more results in a decrease in martensite start temperature  $M_s$  (hereinafter also referred to simply as an  $M_s$  temperature or  $M_s$ ) and a decrease in martensite formed in a second cooling step. This increases martensite formed during final cooling, does not sufficiently temper martensite formed at that time, and increases the area fraction of hard fresh martensite. Fresh martensite acts as a starting point of void formation in a hole expansion test, a VDA bending test, or a V-VDA bending test. An area fraction of fresh martensite exceeding 10% results in undesired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$ .

**[0042]** Thus, the Mn content is 2.00% or more and less than 3.50%. The Mn content is preferably 2.50% or more. The Mn content is preferably 3.20% or less.

25 P: 0.001% or more and 0.100% or less

30 **[0043]** P is an element that has a solid-solution strengthening effect and increases TS and YS of a steel sheet. To produce such effects, the P content is 0.001% or more. On the other hand, a P content of more than 0.100% results in segregation of P at a prior-austenite grain boundary and embrittlement of the grain boundary. Thus, after the steel sheet is punched or is subjected to V-bending in a V-VDA bending test, the number of voids formed increases, and desired  $\lambda$  and  $S_{Fmax}$  cannot be achieved.

**[0044]** Thus, the P content is 0.001% or more and 0.100% or less. The P content is preferably 0.030% or less.

35 S: 0.0001% or more and 0.0200% or less

**[0045]** S is present as a sulfide in steel. In particular, at a S content of more than 0.0200%, after the steel sheet is punched or is subjected to V-bending in a V-VDA bending test, the number of voids formed increases, and desired  $\lambda$  and  $S_{Fmax}$  cannot be achieved.

40 **[0046]** Thus, the S content is 0.0200% or less. The S content is preferably 0.0080% or less. The lower limit of the S content is 0.0001% or more due to constraints on production technology.

Al: 0.010% or more and 2.000% or less

45 **[0047]** Al suppresses the formation of carbides and promotes the formation of retained austenite during cooling and holding after annealing. Thus, Al is an element that has an influence on the volume fraction of retained austenite and the concentration of carbon in retained austenite. To produce such effects, the Al content is preferably 0.010% or more.

50 **[0048]** On the other hand, an Al content of more than 2.000% results in an excessive increase in the area fraction of ferrite and makes it difficult to achieve a TS of 1180 MPa or more. This also reduces YS. This also excessively increases the C concentration of austenite during annealing and results in undesired  $\lambda$  and  $S_{Fmax}$ .

**[0049]** Thus, the Al content is 0.010% or more and 2.000% or less. The Al content is preferably 0.015% or more. The Al content is preferably 1.000% or less.

N: 0.0100% or less

55 **[0050]** N is present as a nitride in steel. In particular, at a N content of more than 0.0100%, after the steel sheet is punched or is subjected to V-bending in a V-VDA bending test, the number of voids formed increases, and desired  $\lambda$  and  $S_{Fmax}$  cannot be achieved.

**[0051]** Thus, the N content is 0.0100% or less. The N content is preferably 0.0050% or less. The N content may have any lower limit but is preferably 0.0005% or more due to constraints on production technology.

**[0052]** A base chemical composition of a base steel sheet of a steel sheet according to an embodiment of the present invention has been described above. A base steel sheet of a steel sheet according to an embodiment of the present invention has a chemical composition that contains the base components and the remainder other than the base components including Fe (iron) and incidental impurities. A base steel sheet of a steel sheet according to an embodiment of the present invention preferably has a chemical composition that contains the base components and the remainder composed of Fe and incidental impurities.

**[0053]** A base steel sheet of a steel sheet according to an embodiment of the present invention may contain, in addition to the base components, at least one selected from the following optional components. As long as the following optional components are contained in an amount equal to or less than their respective upper limits described below, the advantages of the present invention can be achieved. Thus, there is no particular lower limit. Any of the following optional elements contained in amounts below the following appropriate lower limits is considered to be an incidental impurity.

**[0054]** At least one selected from Nb: 0.200% or less, Ti: 0.200% or less, V: 0.200% or less, B: 0.0100% or less, Cr: 1.000% or less, Ni: 1.000% or less, Mo: 1.000% or less, Sb: 0.200% or less, Sn: 0.200% or less, Cu: 1.000% or less, Ta: 0.100% or less, W: 0.500% or less, Mg: 0.0200% or less, Zn: 0.0200% or less, Co: 0.0200% or less, Zr: 0.1000% or less, Ca: 0.0200% or less, Se: 0.0200% or less, Te: 0.0200% or less, Ge: 0.0200% or less, As: 0.0500% or less, Sr: 0.0200% or less, Cs: 0.0200% or less, Hf: 0.0200% or less, Pb: 0.0200% or less, Bi: 0.0200% or less, and REM: 0.0200% or less

Nb: 0.200% or less

**[0055]** Nb forms fine carbide, nitride, or carbonitride during hot rolling or annealing and thereby increases TS and YS. To produce such effects, the Nb content is preferably 0.001% or more. The Nb content is more preferably 0.005% or more. On the other hand, a Nb content of more than 0.200% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Nb is contained, the Nb content is preferably 0.200% or less. The Nb content is more preferably 0.060% or less.

Ti: 0.200% or less

**[0056]** Like Nb, Ti forms fine carbide, nitride, or carbonitride during hot rolling or annealing and thereby increases TS and YS. To produce such effects, the Ti content is preferably 0.001% or more. The Ti content is more preferably 0.005% or more. On the other hand, a Ti content of more than 0.200% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Ti is contained, the Ti content is preferably 0.200% or less. The Ti content is more preferably 0.060% or less.

V: 0.200% or less

**[0057]** Like Nb or Ti, V forms fine carbide, nitride, or carbonitride during hot rolling or annealing and thereby increases TS and YS. To produce such effects, the V content is preferably 0.001% or more. The V content is more preferably 0.005% or more. The V content is even more preferably 0.010% or more, and even further more preferably 0.030% or more. On the other hand, a V content of more than 0.200% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when V is contained, the V content is preferably 0.200% or less. The V content is more preferably 0.060% or less.

B: 0.0100% or less

**[0058]** B is an element that segregates at an austenite grain boundary and enhances hardenability. B is also an element that suppresses the formation and grain growth of ferrite during cooling after annealing. To produce such effects, the B content is preferably 0.0001% or more. The B content is more preferably 0.0002% or more.

**[0059]** The B content is even more preferably 0.0005% or more, and even further more preferably 0.0007% or more.

**[0060]** On the other hand, a B content of more than 0.0100% may result in a crack in a steel sheet during hot rolling. After the steel sheet is punched or is subjected to V-bending in a V-VDA bending test, the number of voids formed increases, and desired  $\lambda$  and  $S_{Fmax}$  may not be achieved.

**[0061]** Thus, when B is contained, the B content is preferably 0.0100% or less. The B content is more preferably 0.0050% or less.

Cr: 1.000% or less

**[0062]** Cr is an element that enhances hardenability, and the addition of Cr forms a large amount of tempered martensite and ensures a TS of 1180 MPa or more and high YS. To produce such effects, the Cr content is preferably 0.0005% or more. The Cr content is more preferably 0.010% or more.

**[0063]** The Cr content is even more preferably 0.030% or more, and even further more preferably 0.050% or more.

**[0064]** On the other hand, at a Cr content of more than 1.000%, the area fraction of hard fresh martensite increases excessively, fresh martensite acts as a starting point of void formation in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Cr is contained, the Cr content is preferably 1.000% or less. The Cr content is more preferably 0.800% or less, even more preferably 0.700% or less.

Ni: 1.000% or less

**[0065]** Ni is an element that enhances hardenability, and the addition of Ni forms a large amount of tempered martensite and ensures a TS of 1180 MPa or more and high YS. To produce such effects, the Ni content is preferably 0.005% or more. The Ni content is more preferably 0.020% or more. The Ni content is even more preferably 0.040% or more, and even further more preferably 0.060% or more.

**[0066]** On the other hand, at a Ni content of more than 1.000%, the area fraction of fresh martensite increases excessively, fresh martensite acts as a starting point of void formation in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Ni is contained, the Ni content is preferably 1.000% or less. The Ni content is more preferably 0.800% or less.

**[0067]** The Ni content is even more preferably 0.600% or less, and even further more preferably 0.400% or less.

Mo: 1.000% or less

**[0068]** Mo is an element that enhances hardenability, and the addition of Mo forms a large amount of tempered martensite and ensures a TS of 1180 MPa or more and high YS. To produce such effects, the Mo content is preferably 0.010% or more. The Mo content is more preferably 0.030% or more.

**[0069]** On the other hand, at a Mo content of more than 1.000%, the area fraction of fresh martensite increases excessively, fresh martensite acts as a starting point of void formation in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Mo is contained, the Mo content is preferably 1.000% or less. The Mo content is more preferably 0.500% or less, even more preferably 0.450% or less, and even further more preferably 0.400% or less. The Mo content is even more preferably 0.350% or less, and even further more preferably 0.300% or less.

Sb: 0.200% or less

**[0070]** Sb is an element effective in suppressing the diffusion of C near the surface of a steel sheet during annealing and controlling the formation of a soft layer near the surface of the steel sheet. An excessive increase of a soft layer near the surface of a steel sheet makes it difficult to achieve a TS of 1180 MPa or more. This also reduces YS. Thus, the Sb content is preferably 0.002% or more. The Sb content is more preferably 0.005% or more.

**[0071]** On the other hand, an Sb content of more than 0.200% may result in no soft layer near the surface of a steel sheet and lower flangeability and bendability. Thus, when Sb is contained, the Sb content is preferably 0.200% or less. The Sb content is more preferably 0.020% or less.

Sn: 0.200% or less

**[0072]** Like Sb, Sn is an element effective in suppressing the diffusion of C near the surface of a steel sheet during annealing and controlling the formation of a soft layer near the surface of the steel sheet. An excessive increase of a soft layer near the surface of a steel sheet makes it difficult to achieve a TS of 1180 MPa or more. This also reduces YS. Thus, the Sn content is preferably 0.002% or more. The Sn content is more preferably 0.005% or more.

**[0073]** On the other hand, a Sn content of more than 0.200% may result in no soft layer near the surface of a steel sheet and lower flangeability and bendability. Thus, when Sn is contained, the Sn content is preferably 0.200% or less. The Sn content is more preferably 0.020% or less.

Cu: 1.000% or less

**[0074]** Cu is an element that enhances hardenability, and the addition of Cu forms a large amount of tempered

## EP 4 502 195 A1

martensite and ensures a TS of 1180 MPa or more and high YS. To produce such effects, the Cu content is preferably 0.005% or more. The Cu content is more preferably 0.008% or more, even more preferably 0.010% or more. The Cu content is even more preferably 0.020% or more.

**[0075]** On the other hand, a Cu content of more than 1.000% may result in an excessive increase in the area fraction of fresh martensite and a large number of coarse precipitates or inclusions. In such a case, fresh martensite and coarse precipitates or inclusions may act as starting points of voids and cracks in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Cu is contained, the Cu content is preferably 1.000% or less. The Cu content is more preferably 0.200% or less.

10 Ta: 0.100% or less

**[0076]** Like Ti, Nb, and V, Ta forms fine carbide, nitride, or carbonitride during hot rolling or annealing and increases TS and YS. Furthermore, Ta partially dissolves in Nb carbide or Nb carbonitride and forms a complex precipitate, such as (Nb, Ta)(C, N). This suppresses coarsening of a precipitate and stabilizes precipitation strengthening. This further improves TS and YS. To produce such effects, the Ta content is preferably 0.001% or more. The Ta content is more preferably 0.002% or more, even more preferably 0.004% or more.

**[0077]** On the other hand, a Ta content of more than 0.100% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Ta is contained, the Ta content is preferably 0.100% or less.

**[0078]** The Ta content is more preferably 0.090% or less, even more preferably 0.080% or less.

W: 0.500% or less

**[0079]** W is an element that enhances hardenability, and the addition of W forms a large amount of tempered martensite and ensures a TS of 1180 MPa or more and high YS. To produce such effects, the W content is preferably 0.001% or more. The W content is more preferably 0.030% or more.

**[0080]** On the other hand, at a W content of more than 0.500%, the area fraction of hard fresh martensite increases excessively, fresh martensite acts as a starting point of void formation in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when W is contained, the W content is preferably 0.500% or less. The W content is more preferably 0.450% or less, even more preferably 0.400% or less. The W content is even further more preferably 0.300% or less.

Mg: 0.0200% or less

**[0081]** Mg is an element effective in spheroidizing the shape of an inclusion of sulfide, oxide, or the like to improve the flangeability of a steel sheet. To produce such effects, the Mg content is preferably 0.0001% or more. The Mg content is more preferably 0.0005% or more, even more preferably 0.0010% or more.

**[0082]** On the other hand, a Mg content of more than 0.0200% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Mg is contained, the Mg content is preferably 0.0200% or less. The Mg content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

Zn: 0.0200% or less

**[0083]** Zn is an element effective in spheroidizing the shape of an inclusion and improving the flangeability of a steel sheet. To produce such effects, the Zn content is preferably 0.0010% or more. The Zn content is more preferably 0.0020% or more, even more preferably 0.0030% or more.

**[0084]** On the other hand, a Zn content of more than 0.0200% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Zn is contained, the Zn content is preferably 0.0200% or less. The Zn content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

Co: 0.0200% or less

**[0085]** Like Zn, Co is an element effective in spheroidizing the shape of an inclusion and improving the flangeability of a

## EP 4 502 195 A1

steel sheet. To produce such effects, the Co content is preferably 0.0010% or more. The Co content is more preferably 0.0020% or more, even more preferably 0.0030% or more.

**[0086]** On the other hand, a Co content of more than 0.0200% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Co is contained, the Co content is preferably 0.0200% or less. The Co content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

Zr: 0.1000% or less

**[0087]** Like Zn and Co, Zr is an element effective in spheroidizing the shape of an inclusion and improving the flangeability of a steel sheet. To produce such effects, the Zr content is preferably 0.0010% or more. On the other hand, a Zr content of more than 0.1000% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Zr is contained, the Zr content is preferably 0.1000% or less.

**[0088]** The Zr content is more preferably 0.0300% or less, even more preferably 0.0100% or less.

Ca: 0.0200% or less

**[0089]** Ca is present as an inclusion in steel. A Ca content of more than 0.0200% may result in a large number of coarse inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when Ca is contained, the Ca content is preferably 0.0200% or less. The Ca content is preferably 0.0020% or less.

**[0090]** The Ca content is more preferably 0.0019% or less, even more preferably 0.0018% or less.

**[0091]** The Ca content may have any lower limit but is preferably 0.0005% or more. Due to constraints on production technology, the Ca content is more preferably 0.0010% or more.

**[0092]** Se: 0.0200% or less, Te: 0.0200% or less, Ge: 0.0200% or less, As: 0.0500% or less, Sr: 0.0200% or less, Cs: 0.0200% or less, Hf: 0.0200% or less, Pb: 0.0200% or less, Bi: 0.0200% or less, REM: 0.0200% or less

**[0093]** Se, Te, Ge, As, Sr, Cs, Hf, Pb, Bi, and REM are elements effective in improving the flangeability of a steel sheet. To produce such effects, each of the Se, Te, Ge, As, Sr, Cs, Hf, Pb, Bi, and REM contents is preferably 0.0001% or more.

**[0094]** On the other hand, a Se, Te, Ge, Sr, Cs, Hf, Pb, Bi, or REM content of more than 0.0200% or an As content of more than 0.0500% may result in a large number of coarse precipitates or inclusions. In such a case, a coarse precipitate or inclusion may act as a starting point of a crack in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{Fmax}$  may not be achieved. Thus, when at least one of Se, Te, Ge, As, Sr, Cs, Hf, Pb, Bi, and REM is contained, each of the Se, Te, Ge, As, Sr, Cs, Hf, Pb, Bi, and REM contents is preferably 0.0200% or less, and the As content is preferably 0.0500% or less.

**[0095]** The Se content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Se content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0096]** The Te content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Te content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0097]** The Ge content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Ge content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0098]** The As content is more preferably 0.0010% or more, even more preferably 0.0015% or more. The As content is more preferably 0.0400% or less, even more preferably 0.0300% or less.

**[0099]** The Sr content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Sr content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0100]** The Cs content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Cs content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0101]** The Hf content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Hf content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0102]** The Pb content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Pb content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0103]** The Bi content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The Bi content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0104]** The REM content is more preferably 0.0005% or more, even more preferably 0.0008% or more. The REM content is more preferably 0.0180% or less, even more preferably 0.0150% or less.

**[0105]** The term "REM", as used herein, refers to scandium (Sc) with atomic number 21, yttrium (Y) with atomic number

39, and lanthanoids from lanthanum (La) with atomic number 57 to lutetium (Lu) with atomic number 71. The term "REM concentration", as used herein, refers to the total content of one or two or more elements selected from the REM.

[0106] REM is preferably, but not limited to, Sc, Y, Ce, or La.

[0107] Thus, a base steel sheet of a steel sheet according to an embodiment of the present invention has a chemical composition containing, on a mass percent basis, C: 0.050% or more and 0.400% or less, Si: more than 0.75% and 3.00% or less, Mn: 2.00% or more and less than 3.50%, P: 0.001% or more and 0.100% or less, S: 0.0001% or more and 0.0200% or less, Al: 0.010% or more and 2.000% or less, and N: 0.0100% or less, and optionally containing at least one selected from Nb: 0.200% or less, Ti: 0.200% or less, V: 0.200% or less, B: 0.0100% or less, Cr: 1.000% or less, Ni: 1.000% or less, Mo: 1.000% or less, Sb: 0.200% or less, Sn: 0.200% or less, Cu: 1.000% or less, Ta: 0.100% or less, W: 0.500% or less, Mg: 0.0200% or less, Zn: 0.0200% or less, Co: 0.0200% or less, Zr: 0.1000% or less, Ca: 0.0200% or less, Se: 0.0200% or less, Te: 0.0200% or less, Ge: 0.0200% or less, As: 0.0500% or less, Sr: 0.0200% or less, Cs: 0.0200% or less, Hf: 0.0200% or less, Pb: 0.0200% or less, Bi: 0.0200% or less, and REM: 0.0200% or less, the remainder being Fe and incidental impurities.

15 Steel Microstructure

[0108] Next, the steel microstructure of a base steel sheet of a steel sheet according to an embodiment of the present invention is described.

[0109] A base steel sheet of a steel sheet according to an embodiment of the present invention has a steel microstructure in which the area fraction of bainitic ferrite: 3.0% or more and 20.0% or less, the area fraction of tempered martensite (excluding retained austenite): 40.0% or more and 90.0% or less, the volume fraction of retained austenite: more than 3.0% and 15.0% or less, the concentration of carbon in retained austenite: 0.60% by mass or more and 1.30% by mass or less, the area fraction of fresh martensite: 10.0% or less (including 0.0%), and the density of carbides in tempered martensite: 8.0 particles/ $\mu\text{m}^2$  or less, the amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less, a V-VDA bending test is performed to a maximum load point, in an L cross section, a crack has a length of 400  $\mu\text{m}$  or less, in a region formed from each position on a starting line present from a starting point of a bending peak on an outside of a VDA bend to a position of 50  $\mu\text{m}$  in a thickness direction up to a position of 50  $\mu\text{m}$  on each side of the starting line perpendicular to the starting line, and with respect to the average grain size of bainitic ferrite in the thickness direction, the ratio of the average grain size before processing to the average grain size after the processing is 5.0 or less.

[0110] The reasons for these limitations are described below.

Area fraction of bainitic ferrite: 3.0% or more and 20.0% or less

[0111] Bainitic ferrite has intermediate hardness as compared with soft ferrite, hard fresh martensite, and the like and is an important phase for ensuring high flangeability, bendability, good bending fracture characteristics and axial compression characteristics. Bainitic ferrite is also a phase useful for utilizing the diffusion of C from bainitic ferrite to non-transformed austenite to form retained austenite with an appropriate area fraction and an appropriate concentration of carbon. Thus, the area fraction of bainitic ferrite is 3.0% or more.

[0112] The area fraction of bainitic ferrite is preferably 5.0% or more, more preferably 8.0% or more.

[0113] On the other hand, an excessive increase in the area fraction of bainitic ferrite results in lower strength and an area fraction of retained austenite higher than a predetermined amount. Thus, the area fraction of bainitic ferrite is 20.0% or less.

[0114] The area fraction of bainitic ferrite is preferably 18.0% or less, more preferably 15.0% or less.

[0115] The term "bainitic ferrite" refers to upper bainite that is formed in a relatively high temperature region and has a small amount of carbide.

Area fraction of tempered martensite (excluding retained austenite): 40.0% or more and 90.0% or less

[0116] Tempered martensite has intermediate hardness as compared with soft ferrite, hard fresh martensite, and the like and is an important phase for ensuring high flangeability, bendability, good bending fracture characteristics and axial compression characteristics. Tempered martensite is also effective in improving TS. Thus, the area fraction of tempered martensite is 40.0% or more. The area fraction of tempered martensite is preferably 60.0% or more. On the other hand, an excessive increase in the area fraction of tempered martensite results in lower ductility. Thus, the area fraction of tempered martensite is 90.0% or less.

[0117] The area fraction of tempered martensite is preferably 85.0% or less, more preferably 80.0% or less.

Area fraction of retained austenite: more than 3.0% and 15.0% or less

**[0118]** From the perspective of high ductility, the area fraction of retained austenite is more than 3.0%. The area fraction of retained austenite is preferably 5.0% or more. On the other hand, an excessive increase in the area fraction of retained austenite results in fresh martensite formed by deformation-induced transformation acting as a starting point of void formation when a steel sheet is punched in a hole expansion test or is subjected to V-bending in a V-VDA test, and desired  $\lambda$  and  $S_{F_{max}}$  cannot be achieved. Thus, the area fraction of retained austenite is 15.0% or less. The area fraction of retained austenite is preferably 12.0% or less, more preferably 10.0% or less.

**[0119]** For example, tension in a second cooling step in a production method described later can be controlled to suppress the area fraction of retained austenite to 15.0% or less. Applying a tension of 2.0 kgf/mm<sup>2</sup> or more once or more after a first cooling step (after a galvanizing treatment when the galvanizing treatment is performed (when necessary, after an alloying treatment)), then subjecting a steel sheet to four or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll, and subjecting the steel sheet to two or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for half the circumference of the roll cause deformation-induced transformation of unstable retained austenite to fresh martensite, temper the fresh martensite during subsequent cooling, and finally form tempered martensite.

Concentration of carbon in retained austenite: 0.60% by mass or more and 1.30% by mass or less

**[0120]** The concentration of carbon in retained austenite is an indicator that has an influence on stability with which retained austenite transforms to martensite during deformation. When the concentration of carbon in retained austenite is less than 0.60% by mass, the retained austenite is unstable, and deformation-induced martensite transformation occurs after stress application and before plastic deformation, so that required elongation cannot be achieved. On the other hand, when the concentration of carbon in retained austenite is more than 1.30% by mass, when a steel sheet is punched in a hole expansion test or is subjected to V-bending in a V-VDA test, the hardness of fresh martensite formed from the retained austenite greatly increases, the formation and connection of voids are promoted, and desired  $\lambda$  and  $S_{F_{max}}$  cannot be achieved. Thus, the concentration of carbon in retained austenite is 0.60% by mass or more and 1.30% by mass or less. The concentration of carbon in retained austenite is preferably 0.80% by mass or more. The concentration of carbon in retained austenite is preferably 1.20% by mass or less.

Area fraction of fresh martensite: 10.0% or less (including 0.0%)

**[0121]** An excessive increase in the area fraction of fresh martensite results in fresh martensite acting as a starting point of void formation in a hole expansion test, a VDA bending test, or a V-VDA bending test, and desired  $\lambda$ ,  $\alpha$ , and  $S_{F_{max}}$  cannot be achieved. As the area fraction of fresh martensite increases, the amount of diffusible hydrogen in a steel sheet increases, and flangeability and bendability further decrease. From the perspective of ensuring high flangeability and bendability, the area fraction of fresh martensite is 10.0% or less, preferably 5.0% or less. The area fraction of fresh martensite may have any lower limit and may be 0.0%.

**[0122]** The term "fresh martensite" refers to as-quenched (untempered) martensite.

Density (number density) of carbides in tempered martensite: 8.0 / $\mu\text{m}^2$  or less

**[0123]** In the present invention, when the density of carbides in tempered martensite is more than 8.0 particles/ $\mu\text{m}^2$ , the number of voids caused by carbides increases in a hole expansion test, a VDA bending test, or a V-VDA bending test, which promotes the formation and growth of a crack, and desired  $\lambda$ ,  $\alpha$ , and  $S_{F_{max}}$  cannot be achieved. Thus, the density of carbides in tempered martensite is 8.0 particles/ $\mu\text{m}^2$  or less. The density of carbides in tempered martensite is preferably 7.0 particles/ $\mu\text{m}^2$  or less, more preferably 6.0 particles/ $\mu\text{m}^2$  or less.

**[0124]** Although the lower limit is not particularly limited, the density of carbides in tempered martensite is preferably 1.0 particles/ $\mu\text{m}^2$  or more, more preferably 2.0 particles/ $\mu\text{m}^2$  or more.

**[0125]** The remaining microstructure other than those described above is, for example, ferrite, lower bainite, pearlite, or carbide such as cementite. To ensure a TS of 1180 MPa or more and high YS, the area fraction of pearlite is preferably 5.0% or less.

**[0126]** The type of the remaining microstructure can be determined, for example, by scanning electron microscope (SEM) observation.

**[0127]** The area fractions of bainitic ferrite, tempered martensite, and a hard second phase (retained austenite + fresh martensite) are measured at a quarter thickness position of a base steel sheet as described below.

**[0128]** A sample is cut out from a base steel sheet to form a thickness cross section parallel to the rolling direction of the base steel sheet as an observation surface. The observation surface of the sample is then mirror-polished with a diamond

paste. The observation surface of the sample is then subjected to final polishing with colloidal silica and is then etched with 3% by volume nital to expose the microstructure.

**[0129]** Three visual fields of  $25.6 \mu\text{m} \times 17.6 \mu\text{m}$  on the observation surface of the sample are then photographed with a scanning electron microscope (SEM) under the conditions of an acceleration voltage of 15 kV and a magnification of 5000 times.

**[0130]** From a microstructure image thus photographed, bainitic ferrite, tempered martensite, the hard second phase (retained austenite + fresh martensite), and the remaining microstructure are identified as described below.

**[0131]** Bainitic ferrite: a black to dark gray region of a massive form, an indefinite form, or the like. No or a relatively small number of iron-based carbides is contained.

**[0132]** Tempered martensite: a gray region of an indefinite form. A relatively large number of iron-based carbides is contained.

**[0133]** Hard second phase (retained austenite + fresh martensite): a white to light gray region of an indefinite form. No iron-based carbide is contained. One with a relatively large size has a gradually darker color with the distance from the interface with another microstructure and may have a dark gray interior.

**[0134]** Ferrite: a massive black region. Almost no iron-based carbide is contained. When an iron-based carbide is contained, however, the area of ferrite includes the area of the iron-based carbide. The same applies to the bainitic ferrite and tempered martensite.

**[0135]** Cementite: a dotted or linear white region. It is contained in tempered martensite, bainitic ferrite, and ferrite.

**[0136]** Lower bainite, pearlite, and the like: these forms and the like are known.

**[0137]** Next, the region of each phase identified in the microstructure image is subjected to calculation by the following method. On the 5000x SEM image, a  $20 \times 20$  grid spaced at regular intervals is placed on a region with an actual length of  $23.1 \mu\text{m} \times 17.6 \mu\text{m}$ , and the area fractions of bainitic ferrite, tempered martensite, and the hard second phase are calculated by a point counting method of counting the number of points on each phase. Each area fraction is the average value of three area fractions determined from different 5000x SEM images.

**[0138]** The area fraction of retained austenite is measured as described below.

**[0139]** A base steel sheet is mechanically ground to a quarter thickness position in the thickness direction (depth direction) and is then chemically polished with oxalic acid to form an observation surface. The observation surface is then observed by X-ray diffractometry. A  $\text{MoK}\alpha$  radiation source is used for incident X-rays to determine the ratio of the diffraction intensity of each of (200), (220), and (311) planes of fcc iron (austenite) to the diffraction intensity of each of (200), (211), and (220) planes of bcc iron. The volume fraction of retained austenite is calculated from the ratio of the diffraction intensity of each plane. On the assumption that retained austenite is three-dimensionally homogeneous, the volume fraction of retained austenite is defined as the area fraction of the retained austenite.

**[0140]** For the distribution of the concentration of carbon in retained austenite, the lattice constant of the retained austenite is determined using a diffraction peak of the

**[0141]** (220) plane of fcc iron (austenite) measured by the X-ray diffractometry. The concentration of carbon in retained austenite is then determined using the following formula:

$$C_{\gamma} = ((A - (3.572 + 0.0012 \times [\text{Mn}\%] - 0.00157 \times [\text{Si}\%] + 0.0056 \times [\text{Al}\%]))/0.033$$

wherein A denotes the lattice constant of the retained austenite,

**[0142]**  $C_{\gamma}$  denotes the concentration of carbon in the retained austenite, and [Mn%], [Si%], and [Al%] denote the Mn, Si, and Al contents (% by mass), respectively, in the steel sheet.

**[0143]** The area fraction of fresh martensite is determined by subtracting the area fraction of retained austenite from the area fraction of the hard second phase determined as described above.

$$[\text{Area fraction of fresh martensite (\%)}] = [\text{area fraction (\%)} \text{ of hard second phase}] - [\text{area fraction (\%)} \text{ of retained austenite}]$$

**[0144]** The area fraction of the remaining microstructure is determined by subtracting the area fraction of bainitic ferrite, the area fraction of tempered martensite, and the area fraction of the hard second phase, which are determined as described above, from 100.0%.

$$[\text{Area fraction of remaining microstructure (\%)}] = 100.0 - [\text{area fraction of bainitic ferrite (\%)}] - [\text{area fraction of tempered martensite (\%)}] - [\text{area fraction of hard second phase (\%)}]$$

**[0145]** The density of carbides in tempered martensite is measured as described below.

**[0146]** On the SEM microstructure image used for the microstructure fraction measurement, tempered martensite and

carbides are extracted by manual color-coding to obtain an image of only the tempered martensite or the carbides. Carbide with a diameter (equivalent circular diameter) of 100 nm or more is targeted. The area of the tempered martensite and the number of carbides in the tempered martensite are determined using ImageJ from an open source. The density of carbides in the tempered martensite is determined by dividing the number of carbides in the tempered martensite by the area of the tempered martensite, and the density of carbides in the tempered martensite is determined by extracting 10 pieces of tempered martensite at random from different SEM images and averaging them.

**[0147]** For a piece of carbide, in the SEM image, a granular region with the outer periphery surrounded by tempered martensite and integrally formed without interruption is regarded as a piece to be measured.

10 Amount of diffusible hydrogen: 0.50 ppm by mass or less

**[0148]** From the perspective of higher flangeability and bendability, the amount of diffusible hydrogen in the base steel sheet is preferably 0.50 ppm by mass or less. The amount of diffusible hydrogen in the base steel sheet is more preferably 0.30 ppm by mass or less. The amount of diffusible hydrogen in the base steel sheet may have any lower limit and may be 0 ppm by mass. Due to constraints on production technology, the amount of diffusible hydrogen in the base steel sheet is preferably 0.01 ppm by mass or more.

**[0149]** The amount of diffusible hydrogen in the base steel sheet is measured as described below.

**[0150]** A test specimen with a length of 30 mm and a width of 5 mm is taken from a steel sheet. When a galvanized layer is formed on the steel sheet, the galvanized layer is removed with an alkali. The amount of hydrogen released from the test specimen is then measured by a temperature-programmed desorption analysis method. More specifically, the test specimen is continuously heated from room temperature (-5°C to 55°C) to 300°C at a heating rate of 200°C/h and is then cooled to room temperature. The amount of hydrogen (the integrated amount of hydrogen) released from the test specimen is measured in the temperature range of room temperature to 210°C during the continuous heating. The amount of hydrogen thus measured is then divided by the mass of the test specimen (the test specimen after removal of the galvanized layer and before the continuous heating), and the value converted to ppm by mass is taken as the amount of diffusible hydrogen in the base steel sheet. The amount of diffusible hydrogen is preferably measured after the completion of the production of the steel sheet. The amount of hydrogen is more preferably measured within one week after the completion of the production of the steel sheet.

**[0151]** The room temperature should be within the range of annual temperature variations at the location in consideration of global production. Typically, it preferably ranges from 10°C to 50°C.

**[0152]** For a product (member) produced by forming or joining a steel sheet, a test specimen is cut out from the product placed in a typical operating environment, the amount of diffusible hydrogen in a base steel sheet portion is measured in the same manner as described above, and when the value is 0.50 ppm by mass or less, the amount of diffusible hydrogen in the base steel sheet of the steel sheet at the material stage before forming or joining can also be considered to be 0.50 ppm by mass or less.

#### Surface Soft Layer

**[0153]** A base steel sheet of a steel sheet according to an embodiment of the present invention preferably has a surface soft layer on the surface of the base steel sheet. The surface soft layer contributes to the suppression of the development of flex cracking during press forming and in case of a collision of an automobile body and therefore further improves bending fracture resistance characteristics. The term "surface soft layer" means a decarburized layer and refers to a surface layer region with a Vickers hardness of 85% or less with respect to the Vickers hardness of a cross section at a quarter thickness position.

**[0154]** The surface soft layer is formed in a region of 200 μm or less from the surface of the base steel sheet in the thickness direction. The region where the surface soft layer is formed is preferably 150 μm or less, more preferably 120 μm or less, from the surface of the base steel sheet in the thickness direction. The thickness of the surface soft layer may have any lower limit but is preferably 8 μm or more, more preferably 11 μm or more. The surface soft layer is preferably 30 μm or more, more preferably 40 μm or more.

**[0155]** The quarter thickness position of the base steel sheet where the Vickers hardness is measured is a non-surface-soft layer (a layer that does not satisfy the condition of the hardness of the surface soft layer defined in the present invention).

**[0156]** The Vickers hardness is measured at a load of 10 gf in accordance with JIS Z 2244-1 (2020).

55 Nanohardness of Surface Soft Layer

**[0157]** When the nanohardness is measured at 300 points or more in a 50 μm × 50 μm region on a sheet surface at each of a quarter depth position in the thickness direction and a half depth position in the thickness direction of the surface soft

layer from the surface of the base steel sheet, the ratio of the number of measurements in which the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet is 7.0 GPa or more is 0.10 or less with respect to the total number of measurements at the quarter depth position in the thickness direction of the surface soft layer.

5 **[0158]** In the present invention, to achieve high bendability during press forming and good bending fracture characteristics in case of a collision, when the nanohardness is measured at 300 points or more in a  $50\ \mu\text{m} \times 50\ \mu\text{m}$  region on a sheet surface at each of a quarter depth position in the thickness direction and a half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet, the ratio of the number of measurements in which the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet is 7.0 GPa or more is preferably 0.10 or less with respect to the total number of measurements at the quarter depth position in the thickness direction of the surface soft layer. When the ratio of the nanohardness of 7.0 GPa or more is 0.10 or less, it means a low ratio of a hard microstructure (martensite or the like), an inclusion, or the like, and this can further suppress the formation and connection of voids and crack growth in the hard microstructure (martensite and the like), inclusion, or the like during press forming and in case of a collision, thus resulting in good R/t,  $\alpha$ , and  $S_{F\text{max}}$ .

10 **[0159]** The nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the steel sheet has a standard deviation  $\sigma$  of 1.8 GPa or less, and the nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the steel sheet has a standard deviation  $\sigma$  of 2.2 GPa or less.

20 **[0160]** In the present invention, to achieve high bendability during press forming and good bending fracture characteristics in case of a collision, the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the steel sheet preferably has a standard deviation  $\sigma$  of 1.8 GPa or less, and the nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the steel sheet preferably has a standard deviation  $\sigma$  of 2.2 GPa or less. When the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the steel sheet has a standard deviation  $\sigma$  of 1.8 GPa or less, and the nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the steel sheet has a standard deviation  $\sigma$  of 2.2 GPa or less, this means a small difference in microstructure hardness in a micro region and can further suppress the formation and connection of voids and crack growth during press forming or in case of a collision, thus resulting in good R/t,  $\alpha$ , and  $S_{F\text{max}}$ .

25 **[0161]** The nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet preferably has a standard deviation  $\sigma$  of 1.7 GPa or less. The nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet more preferably has a standard deviation  $\sigma$  of 1.3 GPa or less. The standard deviation  $\sigma$  of the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet may have any lower limit and may be 0.5 GPa or more.

30 **[0162]** The nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet more preferably has a standard deviation  $\sigma$  of 2.1 GPa or less. The nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet more preferably has a standard deviation  $\sigma$  of 1.7 GPa or less. The standard deviation  $\sigma$  of the nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet may have any lower limit and may be 0.6 GPa or more.

35 **[0163]** The phrase "nanohardness of a sheet surface at a quarter depth position and at a half depth position in the thickness direction" refers to a hardness measured by the following method.

40 **[0164]** When a coated layer is formed, after the coated layer is peeled off, mechanical polishing is performed to the quarter depth position -  $5\ \mu\text{m}$  in the thickness direction of the surface soft layer from the surface of the base steel sheet, buffing with diamond and alumina is performed to the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet, and colloidal silica polishing is further performed. The coated layer to be peeled off is a galvanized layer when the galvanized layer is formed, is a metal coated layer when the metal coated layer is formed, or is a galvanized layer and a metal coated layer when the galvanized layer and the metal coated layer are formed.

45 **[0165]** The nanohardness is measured with Hysitron tribo-950 and a Berkovich diamond indenter under the conditions of a load of  $500\ \mu\text{N}$ , a measurement area of  $50\ \mu\text{m} \times 50\ \mu\text{m}$ , and a dot-to-dot distance of  $2\ \mu\text{m}$ .

50 **[0166]** Mechanical polishing, buffing with diamond and alumina, and colloidal silica polishing are then performed to the half depth position in the thickness direction of the surface soft layer. The nanohardness is measured with Hysitron tribo-950 and a Berkovich diamond indenter under the conditions of a load of  $500\ \mu\text{N}$ , a measurement area of  $50\ \mu\text{m} \times 50\ \mu\text{m}$ , and a dot-to-dot distance of  $2\ \mu\text{m}$ .

55 **[0167]** The nanohardness is measured at 300 points or more at the quarter depth position in the thickness direction, and the nanohardness is measured at 300 points or more at the half depth position in the thickness direction.

**[0168]** For example, when the surface soft layer has a thickness of  $100\ \mu\text{m}$ , the quarter position is a position of  $25\ \mu\text{m}$

from the surface of the surface soft layer, and the half position is a position of 50  $\mu\text{m}$  from the surface of the surface soft layer. The nanohardness is measured at 300 points or more at the position of 25  $\mu\text{m}$ , and the nanohardness is also measured at 300 points or more at the position of 50  $\mu\text{m}$ .

## 5 Metal Coated Layer (First Coated Layer)

**[0169]** A steel sheet according to an embodiment of the present invention preferably has a metal coated layer (first coated layer, pre-coated layer) on one or both surfaces of a base steel sheet (the metal coated layer (first coated layer) excludes a hot-dip galvanized layer and a galvanized layer of a hot-dip galvanized layer). The metal coated layer is preferably a metal electroplated layer, and the metal electroplated layer is described below as an example.

**[0170]** When the metal electroplated layer is formed on the surface of a steel sheet, the metal electroplated layer as the outermost surface layer contributes to the suppression of the occurrence of flex cracking during press forming and in case of a collision of an automobile body and therefore further improves the bending fracture resistance characteristics.

**[0171]** In the present invention, the dew point can be more than  $-5^{\circ}\text{C}$  to further increase the thickness of the soft layer and significantly improve axial compression characteristics. In this regard, in the present invention, due to a metal coated layer, even when the dew point is  $-5^{\circ}\text{C}$  or less and the soft layer has a small thickness, axial compression characteristics equivalent to those in the case where the soft layer has a large thickness can be achieved.

**[0172]** The metal species of the metal electroplated layer may be any of Cr, Mn, Fe, Co, Ni, Cu, Ga, Ge, As, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Os, Ir, Rt, Au, Hg, Ti, Pb, and Bi and is preferably Fe. Although an Fe-based electroplated layer is described below as an example, the following conditions for Fe can also be applied to other metal species.

**[0173]** The coating weight of the Fe-based electroplated layer is more than  $0\text{ g/m}^2$ , preferably  $2.0\text{ g/m}^2$  or more. The upper limit of the coating weight per side of the Fe-based electroplated layer is not particularly limited, and from the perspective of cost, the coating weight per side of the Fe-based electroplated layer is preferably  $60\text{ g/m}^2$  or less. The coating weight of the Fe-based electroplated layer is preferably  $50\text{ g/m}^2$  or less, more preferably  $40\text{ g/m}^2$  or less, even more preferably  $30\text{ g/m}^2$  or less.

**[0174]** The coating weight of the Fe-based electroplated layer is measured as described below. A sample with a size of  $10 \times 15\text{ mm}$  is taken from the Fe-based electroplated steel sheet and is embedded in a resin to prepare a cross-section embedded sample. Three arbitrary places on the cross section are observed with a scanning electron microscope (SEM) at an acceleration voltage of  $15\text{ kV}$  and at a magnification of 2,000 to 10,000 times depending on the thickness of the Fe-based coated layer. The average thickness of the three visual fields is multiplied by the specific gravity of iron to convert it into the coating weight per side of the Fe-based electroplated layer.

**[0175]** The Fe-based electroplated layer may be, in addition to pure Fe, an alloy coated layer, such as an Fe-B alloy, an Fe-C alloy, an Fe-P alloy, an Fe-N alloy, an Fe-O alloy, an Fe-Ni alloy, an Fe-Mn alloy, an Fe-Mo alloy, or an Fe-W alloy. The Fe-based electroplated layer may have any chemical composition and preferably has a chemical composition containing 10% by mass or less in total of one or two or more elements selected from the group consisting of B, C, P, N, O, Ni, Mn, Mo, Zn, W, Pb, Sn, Cr, V, and Co, with the remainder being Fe and incidental impurities. When the total amount of elements other than Fe is 10% by mass or less, this can prevent a decrease in electrolysis efficiency and can form an Fe-based electroplated layer at low cost. For an Fe-C alloy, the C content is preferably 0.08% by mass or less.

**[0176]** A surface soft layer is more preferably provided under an Fe-based electroplated layer, and this can significantly improve bending fracture resistance characteristics. In the presence of an Fe-based electroplated layer, the Vickers hardness distribution is measured by the method described above from the interface between the Fe-based electroplated layer and the base steel sheet in the thickness direction, and the depth of the surface soft layer in the thickness direction is evaluated.

**[0177]** In a V-VDA bending test performed to the maximum load point, the length of a crack in an L cross section:  $400\text{ }\mu\text{m}$  or less

**[0178]** In the present invention, in a steel sheet with a crack length of more than  $400\text{ }\mu\text{m}$ , a void is rapidly formed and grown in the steel sheet microstructure and impairs the bending fracture resistance characteristics. Thus, the crack length is  $400\text{ }\mu\text{m}$  or less. The crack length is preferably  $300\text{ }\mu\text{m}$  or less, more preferably  $200\text{ }\mu\text{m}$  or less. The lower limit is not particularly limited and may be  $0\text{ }\mu\text{m}$ .

**[0179]** A V-VDA bending test is performed to the maximum load point; in an L cross section, in a region formed from each position on a starting line present from a starting point of a bending peak on the outside of a VDA bend to a position of  $50\text{ }\mu\text{m}$  in a thickness direction up to a position of  $50\text{ }\mu\text{m}$  on each side of the starting line perpendicular to the starting line, with respect to the average grain size of bainitic ferrite in the thickness direction, the ratio of the average grain size before processing to the average grain size after the processing (a change in average grain size due to processing): 5.0 or less

**[0180]** Next, a change in the grain size of the bainitic ferrite in the thickness direction due to processing is described below.

**[0181]** In Fig. 1, the symbol BF indicates bainitic ferrite, the symbol F indicates ferrite, and the symbol TM indicates tempered martensite. In Fig. 1,  $\theta(\text{TM})$  indicates carbide in tempered martensite, H1 indicates a hard second phase, and

X1(BF) indicates an island-like second phase in bainitic ferrite.

**[0182]** As shown in Fig. 1, the bainitic ferrite BF in the steel sheet microstructure forms internal island-like retained austenite due to carbon partitioning. When the bainitic ferrite BF is deformed by processing, a void is likely to be formed at the boundary between the bainitic ferrite BF and hard fresh martensite formed by the deformation-induced transformation of the island-like retained austenite. When the change in the average grain size of the bainitic ferrite BF in the thickness direction due to processing is more than 5.0, the bainitic ferrite BF is subjected to tensile stress in the rolling direction, and an increase in the number of voids promotes the formation and growth of a crack, thus impairing the bending fracture resistance characteristics. Thus, the change in the average grain size of the bainitic ferrite in the thickness direction due to processing is 5.0 or less. The change is preferably 4.8 or less, more preferably 4.5 or less.

**[0183]** When the change in the average grain size of the bainitic ferrite due to processing is less than 0.2, in the bainitic ferrite subjected to compressive stress, similarly, a void may easily occur at a boundary with the hard fresh martensite formed by the deformation-induced transformation of the island-like retained austenite inside the bainitic ferrite and may impair the bending fracture resistance characteristics. Thus, the change in the average grain size of the bainitic ferrite in the thickness direction due to processing is preferably 0.2 or more. The change is preferably 0.3 or more, more preferably 0.5 or more.

**[0184]** The V-VDA bending test is performed as described below.

**[0185]** A 60 mm x 65 mm test specimen is taken from the steel sheet by shearing. The sides of 60 mm are parallel to the rolling (L) direction. 90-degree bending (primary bending) is performed at a radius of curvature/thickness ratio of 4.2 in the rolling (L) direction with respect to an axis extending in the width (C) direction to prepare a test specimen. In the 90-degree bending (primary bending), as illustrated in Fig. 2-1(a), a punch B1 is pressed against a steel sheet on a die A1 with a V-groove to prepare a test specimen T1. Next, as illustrated in 2-1(b), the test specimen T1 on support rolls A2 is subjected to orthogonal bending (secondary bending) by pressing a punch B2 against the test specimen T1 in the direction perpendicular to the rolling direction. In Fig. 2-1(a) and 2-1(b), the symbol D1 denotes the width (C) direction, and the symbol D2 denotes the rolling (L) direction.

**[0186]** Fig. 3 is a schematic view of a stroke-load curve obtained in a V-VDA test. A sample obtained by performing the V-VDA test to the maximum load point P and then removing the load when the load reaches 94.9% to 99.9% of the maximum load (see the symbol R in Fig. 3) is used as an evaluation sample in the V-VDA bending test.

**[0187]** Fig. 2-2(c) illustrates the test specimen T1 prepared by subjecting the steel sheet to V-bending (primary bending) in the V-VDA bending test. Fig. 2-2(d) illustrates a test specimen T2 obtained by subjecting the test specimen T1 to VDA bending (secondary bending). The position indicated by the broken line in the test specimen T2 in Fig. 2-2(d) is the V-bending ridge line portion and corresponds to the position indicated by the broken line in the test specimen T1 in Fig. 2-2(c) before the VDA bending is performed. The phrase "overlap region of a V-bending ridge line portion and a VDA bending ridge line portion", as used herein, refers to a VDA bending peak and the middle position of the broken line indicated by "a" in Fig. 2-2(d).

**[0188]** More specifically, the term "V-bending ridge line portion" refers to the region within 5 mm on both sides of a V-bending corner portion (peak) that is subjected to V-bending and extends in the width direction. A region other than the V-bending ridge line portion is a V-bending flat portion.

**[0189]** The term "VDA bending ridge line portion" refers to the region within 5 mm on both sides of a VDA bending corner portion (peak) that is subjected to VDA bending and extends in the rolling direction.

**[0190]** The dotted line in Fig. 2-3(e) shows the positional relationship between an L cross section AL of the V-bending ridge line portion and the VDA bending ridge line portion and the test specimen T2. Fig. 2-3(f) shows the L cross section AL with the D2 direction being perpendicular to the drawing and the D1 direction being parallel to the drawing.

**[0191]** The V-VDA bending test is performed to the maximum load point, and the length of a crack in the L cross section (hereinafter also referred to as the AL surface) in the overlap region of the V-bending ridge line portion and the VDA bending ridge line portion is determined as described below.

**[0192]** A sample is cut out from the base steel sheet such that the AL surface of the steel sheet subjected to the V-VDA bending test to the maximum load point is an observation surface. The observation surface of the sample is then mirror-polished with a diamond paste. The observation surface of the sample is then subjected to final polishing with colloidal silica and is then etched with 3% by volume nital to expose the microstructure.

**[0193]** A  $25.6 \mu\text{m} \times 17.6 \mu\text{m}$  visual field is photographed with a scanning electron microscope (SEM) under the conditions of an acceleration voltage of 15 kV and a magnification of 200 times such that the symmetry axis of the AL surface is perpendicular to the bending peak of the observation surface of the sample, and a crack is observed as a whole.

**[0194]** In an image of the crack, the distance in the vertical direction between the starting point and the end point of the crack is defined as the length of the crack. Fig. 4 shows an example of an image of an actually measured crack. In Fig. 4, the symbol D2 denotes the rolling (L) direction, and the symbol D4 denotes the thickness direction. The symbol L indicates the length of the crack.

**[0195]** Next, the V-VDA bending test is performed to the maximum load point. In the L cross section in the overlap region of the V-bending ridge line portion and the VDA bending ridge line portion, a method for measuring the change in the

average grain size of bainitic ferrite in the thickness direction due to processing is described below in a region (an AB region indicated by the dotted line in Fig. 2-3(f), hereinafter also referred to as the AB region) of 0 to 50  $\mu\text{m}$  from the surface of the steel sheet on the outside of a VDA bend and 50  $\mu\text{m}$  on the left and right sides of the bending peak of the VDA bend.

5 [0196] First, the AB region is described below with reference to Fig. 2-4. Fig. 2-4 is a schematic view for explaining the AB region. As illustrated in Fig. 2-4, the term "AB region" refers to a region formed from each position of a starting line  $L_0$ , which extends from a starting point of a bending peak  $t_0$  on the outside of a VDA bend to a position of 50  $\mu\text{m}$  in the thickness direction, to a position of 50  $\mu\text{m}$  on each side of the starting line  $L_0$  perpendicular to the starting line  $L_0$ .

10 [0197] As a method for measuring the change, first, five  $25.6 \mu\text{m} \times 17.6 \mu\text{m}$  visual fields are photographed for each sample with a scanning electron microscope (SEM) under the conditions of an acceleration voltage of 15 kV and a magnification of 3000 times using a sample having the AL surface as an observation surface after the V-VDA bending test performed to the maximum load point (hereinafter also referred to as a sample after deformation) and using a sample used to measure the area fraction of the steel sheet microstructure (hereinafter also referred to as a sample before deformation). In the sample after deformation, the AB region is photographed to observe bainitic ferrite deformed by processing (hereinafter also referred to as bainitic ferrite after deformation). The sample before deformation is photographed from the surface of the base steel sheet to a position of 50  $\mu\text{m}$  in the thickness direction to observe bainitic ferrite not deformed (hereinafter also referred to as bainitic ferrite before deformation).

15 [0198] In the microstructure image thus photographed, 10 pieces of each of bainitic ferrite after deformation and bainitic ferrite before deformation are randomly extracted by manual color-coding, and the longest portion of each bainitic ferrite in the thickness direction is defined as the grain size.

20 [0199] The grain sizes of ten pieces of bainitic ferrite after deformation and ten pieces of bainitic ferrite before deformation in the thickness direction are respectively averaged, and the value obtained by dividing the average grain size of bainitic ferrite before deformation in the thickness direction by the average grain size of bainitic ferrite after deformation in the thickness direction (the ratio of the average grain size before processing to the average grain size after processing: average grain size before processing (nm)/average grain size after processing (nm) is defined as the change in the average grain size of the bainitic ferrite in the thickness direction due to processing.

25 [0200] Fig. 5 shows examples of images of bainitic ferrite before deformation and bainitic ferrite after deformation. In Fig. 5, the symbol BF1 indicates bainitic ferrite before deformation, and the symbol BF2 indicates bainitic ferrite after deformation.

30 [0201] For a piece of bainitic ferrite, in the SEM image, a granular region with the outer periphery surrounded by another microstructure and integrally formed without interruption is regarded as a piece to be measured.

[0202] Next, mechanical characteristics of a steel sheet according to an embodiment of the present invention are described.

Tensile strength (TS): 1180 MPa or more

35 [0203] A steel sheet according to an embodiment of the present invention has a tensile strength TS of 1180 MPa or more. The tensile strength TS may have any upper limit but is preferably less than 1470 MPa.

40 [0204] The yield stress (YS), the total elongation (EI), the limiting hole expansion ratio ( $\lambda$ ), the reference values of the critical bending angle ( $\alpha$ ) in the VDA bending test and the stroke at the maximum load ( $S_{F_{\max}}$ ) in the V-VDA bending test, and the presence or absence of axial compression fracture of a steel sheet according to an embodiment of the present invention are as described above.

45 [0205] The tensile strength (TS), the yield stress (YS), and the total elongation (EI) are measured in the tensile test according to JIS Z 2241 (2011) described later in Examples. The limiting hole expansion ratio ( $\lambda$ ) is measured in the hole expansion test according to JIS Z 2256 (2020) described later in Examples. The critical bending angle ( $\alpha$ ) in the VDA bending test is measured in the VDA bending test according to VDA 238-100 described later in Examples. The stroke at the maximum load ( $S_{F_{\max}}$ ) in the V-VDA bending test is measured in a V-VDA bending test described later in Examples. The presence or absence of axial compression fracture is measured in an axial compression test described later in Examples.

Galvanized Layer (Second Coated Layer)

50 [0206] A steel sheet according to an embodiment of the present invention may have a galvanized layer formed on a base steel sheet (on the surface of the base steel sheet or on the surface of a metal coated layer when the metal coated layer is formed) as the outermost surface layer, and the galvanized layer may be provided on only one surface or both surfaces of the base steel sheet.

55 [0207] Thus, a steel sheet according to the present invention may have a base steel sheet and a second coated layer (a galvanized layer) formed on the base steel sheet or may have a base steel sheet and a metal coated layer (a first coated layer (excluding a second coated layer of a galvanized layer) and a second coated layer (a galvanized layer) sequentially formed on the base steel sheet.

[0208] A steel sheet with a galvanized layer may be a galvanized steel sheet.

[0209] The term "galvanized layer", as used herein, refers to a coated layer containing Zn as a main component (Zn content: 50.0% or more), for example, a hot-dip galvanized layer or a hot-dip galvanized annealed layer.

5 [0210] The hot-dip galvanized layer is preferably composed of, for example, Zn, 20.0% by mass or less of Fe, and 0.001% by mass or more and 1.0% by mass or less of Al. The hot-dip galvanized layer may optionally contain one or two or more elements selected from the group consisting of Pb, Sb, Si, Sn, Mg, Mn, Ni, Cr, Co, Ca, Cu, Li, Ti, Be, Bi, and REM in a total amount of 0.0% by mass or more and 3.5% by mass or less. The hot-dip galvanized layer more preferably has an Fe content of less than 7.0% by mass. The remainder other than these elements is incidental impurities.

10 [0211] The hot-dip galvanized annealed layer is preferably composed of, for example, Zn, 20.0% by mass or less of Fe, and 0.001% by mass or more and 1.0% by mass or less of Al. The hot-dip galvanized annealed layer may optionally contain one or two or more elements selected from the group consisting of Pb, Sb, Si, Sn, Mg, Mn, Ni, Cr, Co, Ca, Cu, Li, Ti, Be, Bi, and REM in a total amount of 0.0% by mass or more and 3.5% by mass or less. The hot-dip galvanized annealed layer more preferably has an Fe content of 7.0% by mass or more, even more preferably 8.0% by mass or more. The hot-dip galvanized annealed layer more preferably has an Fe content of 15.0% by mass or less, even more preferably 12.0% by mass or less. The remainder other than these elements is incidental impurities.

15 [0212] Furthermore, the coating weight per side of the galvanized layer is preferably, but not limited to, 20 g/m<sup>2</sup> or more. The coating weight per side of the galvanized layer is preferably 80 g/m<sup>2</sup> or less.

[0213] The coating weight of the galvanized layer is measured as described below.

20 [0214] A treatment liquid is prepared by adding 0.6 g of a corrosion inhibitor for Fe ("IBIT 700BK" (registered trademark) manufactured by Asahi Chemical Co., Ltd.) to 1 L of 10% by mass aqueous hydrochloric acid. A steel sheet as a sample is immersed in the treatment liquid to dissolve a galvanized layer. The mass loss of the sample due to the dissolution is measured and is divided by the surface area of a base steel sheet (the surface area of a coated portion) to calculate the coating weight (g/m<sup>2</sup>).

25 [0215] The thickness of a steel sheet according to an embodiment of the present invention is preferably, but not limited to, 0.5 mm or more, more preferably 0.6 mm or more.

[0216] The thickness is more preferably more than 0.8 mm. The thickness is even more preferably 0.9 mm or more. The thickness is more preferably 1.0 mm or more. The thickness is even more preferably 1.2 mm or more.

[0217] The steel sheet preferably has a thickness of 3.5 mm or less. The thickness is more preferably 2.3 mm or less.

30 [0218] The width of a steel sheet according to the present invention is preferably, but not limited to, 500 mm or more, more preferably 750 mm or more. The steel sheet preferably has a width of 1600 mm or less, more preferably 1450 mm or less.

[2. Method for Producing Steel Sheet]

35 [0219] Next, a method for producing a steel sheet according to an embodiment of the present invention is described.

[0220] A method for producing a steel sheet according to an embodiment of the present invention includes: a hot rolling step of hot-rolling a steel slab with the chemical composition described above to produce a hot-rolled steel sheet; a pickling step of pickling the hot-rolled steel sheet; an annealing step of annealing the steel sheet after the pickling step at an annealing temperature of  $(Ac_1 + 0.4 \times (Ac_3 - Ac_1))$  °C or more and 900°C or less for an annealing time of 20 seconds or more; a first cooling step of cooling the steel sheet after the annealing step to a first cooling stop temperature of 400°C or more and 600°C or less; a second cooling step of cooling the steel sheet after the first cooling step to a second cooling stop temperature of 100°C or more and 300°C or less at an average cooling rate of 25.0°C/s or less, during the cooling, applying a tension of 2.0 kgf/mm<sup>2</sup> or more to the steel sheet once or more in a temperature range of 300°C or more and 450°C or less, then subjecting the steel sheet to four or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll, and subjecting the steel sheet to two or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for half a circumference of the roll; a reheating step of performing a reheat treatment of heating the steel sheet after the second cooling step to a tempering temperature range of more than 300°C and 500°C or less, holding the steel sheet in the temperature range for a tempering time of 20 seconds or more and 900 seconds or less, and setting a carbide control parameter CP represented by the following formula (1) to 10,000 or more and 15,000 or less during the reheat treatment; and optionally a cold rolling step of cold-rolling the steel sheet after the pickling step and before the annealing step to produce a cold-rolled steel sheet,

55 
$$CP = (T + 273) \times (k + 1.2 \times \log t) \quad \text{formula (1)}$$

wherein T denotes the tempering temperature (°C), k denotes the material constant depending on the C content, and t denotes the tempering time (second),

$$k = -6 \times C_M + 17.8,$$

wherein  $C_M$  denotes a carbon concentration (% by mass) of martensite formed in the second cooling step.

**[0221]** Unless otherwise specified, the temperatures described above mean the surface temperatures of a steel slab and a steel sheet.

**[0222]** First, a steel slab with the chemical composition described above is prepared. For example, a steel material is melted to produce a molten steel with the chemical composition described above. The melting method may be, but is not limited to, any known melting method using a converter, an electric arc furnace, or the like. The resulting molten steel is then solidified into a steel slab. The steel slab may be produced from the molten steel by any method, for example, a continuous casting method, an ingot casting method, a thin slab casting method, or the like. From the perspective of preventing macrosegregation, a continuous casting method is preferred.

[Hot Rolling Step]

**[0223]** Next, in the hot rolling step, the steel slab is hot-rolled to produce a hot-rolled steel sheet.

**[0224]** The hot-rolling may be performed in an energy-saving process. The energy-saving process may be hot charge rolling (a method of charging a furnace with the steel slab as a hot piece not cooled to room temperature and hot-rolling the steel slab), hot direct rolling (a method of keeping the steel slab slightly warm and then immediately rolling the steel slab), or the like.

**[0225]** The hot rolling may be performed under any conditions, for example, under the following conditions.

**[0226]** The steel slab is temporarily cooled to room temperature and is then reheated and rolled. The slab heating temperature (reheating temperature) is preferably 1100°C or more from the perspective of melting carbide and reducing rolling force. The slab heating temperature is preferably 1300°C or less to prevent an increase in scale loss. The slab heating temperature is based on the temperature of the steel slab surface.

**[0227]** The steel slab is then rough-rolled in the usual manner to form a rough-rolled sheet (hereinafter also referred to as a sheet bar). The sheet bar is then finish-rolled to form a hot-rolled steel sheet. When the slab is heated at a slightly lower temperature, the sheet bar is preferably heated with a bar heater or the like before finish rolling to prevent trouble in the finish rolling. The finish rolling temperature is preferably 800°C or more to reduce the rolling load. Furthermore, when the rolling reduction of austenite in an unrecrystallized state is increased, an abnormal microstructure elongated in the rolling direction may be developed and impair the workability of an annealed sheet. Furthermore, at a finish rolling temperature of 800°C or more, not only the steel microstructure of the hot-rolled steel sheet but also the steel microstructure of the final product is likely to be uniform. A nonuniform steel microstructure tends to result in lower bendability.

**[0228]** On the other hand, at a finish rolling temperature of more than 950°C, the amount of oxide (scale) formed increases. This may roughen the interface between a steel substrate and the oxide and impair the surface quality of the steel sheet after pickling and cold rolling. This may also coarsen crystal grains and reduce the strength and bendability of the steel sheet. Thus, the finish rolling temperature is preferably 950°C or more. Thus, the finish rolling temperature is preferably 800°C or more and 950°C or more.

**[0229]** After the finish rolling, the hot-rolled steel sheet is coiled. The coiling temperature is preferably 450°C or more. The coiling temperature is preferably 750°C or less.

**[0230]** Sheet bars may be joined together during hot rolling to continuously perform the finish rolling. The sheet bar may be temporarily coiled before the finish rolling. Furthermore, to reduce the rolling force during hot rolling, the finish rolling may be partly or entirely rolling with lubrication. The rolling with lubrication is also effective in making the shape and the material quality of a steel sheet uniform. The friction coefficient in the rolling with lubrication is preferably 0.10 or more and 0.25 or less.

**[0231]** In the hot rolling step including rough rolling and finish rolling (hot rolling step), the steel slab is typically formed into a sheet bar by the rough rolling and then into a hot-rolled steel sheet by the finish rolling. Depending on the mill capacity or the like, however, such classification is not concerned, provided that a predetermined size is obtained.

[Pickling Step]

**[0232]** The hot-rolled steel sheet after the hot rolling step is pickled. The pickling can remove an oxide from the surface of the steel sheet and ensure high chemical convertibility and coating quality. The pickling may be performed once or multiple times. The pickling may be performed under any conditions and may be performed in the usual manner.

[Cold Rolling Step]

**[0233]** Next, when necessary, the hot-rolled steel sheet is cold-rolled to produce a cold-rolled steel sheet. The cold rolling is, for example, multi-pass rolling requiring two or more passes, such as tandem multi-stand rolling or reverse rolling.

**[0234]** The rolling reduction (cumulative rolling reduction ratio) in the cold rolling is preferably, but not limited to, 20% or more. The rolling reduction in the cold rolling is preferably 80% or less. A rolling reduction of less than 20% in the cold rolling tends to result in coarsening or a lack of uniformity of the steel microstructure in the annealing step and may result in the final product with lower TS or bendability. On the other hand, a rolling reduction of more than 80% in the cold rolling tends to result in a steel sheet with a poor shape and may result in an uneven galvanizing coating weight.

**[0235]** Optionally, a cold-rolled steel sheet after the cold rolling may be pickled.

[Metal Coating (Metal Electroplating, First Coating) Step]

**[0236]** An embodiment of the present invention may include a first coating step of performing metal coating on one or both surfaces of the steel sheet after the hot rolling step (after the pickling step or after the cold rolling step after the pickling step when cold rolling is performed) and before the annealing step to form a metal coated layer (first coated layer).

**[0237]** For example, a metal electroplating treatment may be performed on the surface of the hot-rolled steel sheet or the cold-rolled steel sheet thus formed to produce a metal electroplated steel sheet before annealing in which a metal electroplated layer before annealing is formed on at least one surface thereof. The term "metal coating", as used herein, excludes galvanizing (second coating).

**[0238]** Although the metal electroplating treatment method is not particularly limited, as described above, the metal coated layer formed on the base steel sheet is preferably a metal electroplated layer, and the metal electroplating treatment is therefore preferably performed.

**[0239]** For example, a sulfuric acid bath, a hydrochloric acid bath, a mixture of both, or the like can be used as an Fe-based electroplating bath. The coating weight of the metal electroplated layer before annealing can be adjusted by the energization time or the like. The phrase "metal electroplated steel sheet before annealing" means that the metal electroplated layer is not subjected to an annealing step, and does not exclude a hot-rolled steel sheet, a pickled sheet after hot rolling, or a cold-rolled steel sheet, each annealed in advance before a metal electroplating treatment.

**[0240]** A metal species of the electroplated layer may be any of Cr, Mn, Fe, Co, Ni, Cu, Ga, Ge, As, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Os, Ir, Rt, Au, Hg, Ti, Pb, and Bi and is preferably Fe. Thus, a production method using Fe-based electroplating is described below. However, the following conditions for the Fe-based electroplating can be applied to another metal electroplating as well.

**[0241]** The Fe ion content of an Fe-based electroplating bath before the start of energization is preferably 0.5 mol/L or more in terms of  $\text{Fe}^{2+}$ . When the Fe ion content of an Fe-based electroplating bath is 0.5 mol/L or more in terms of  $\text{Fe}^{2+}$ , a sufficient Fe coating weight can be obtained. To obtain a sufficient Fe coating weight, the Fe ion content of the Fe-based electroplating bath before the start of energization is preferably 2.0 mol/L or less.

**[0242]** The Fe-based electroplating bath may contain an Fe ion and at least one element selected from the group consisting of B, C, P, N, O, Ni, Mn, Mo, Zn, W, Pb, Sn, Cr, V, and Co. The total content of these elements in the Fe-based electroplating bath is preferably such that the total content of these elements in an Fe-based electroplated layer before annealing is 10% by mass or less. A metal element may be contained as a metal ion, and a non-metal element can be contained as part of boric acid, phosphoric acid, nitric acid, an organic acid, or the like. An iron sulfate coating solution may contain a conductive aid, such as sodium sulfate or potassium sulfate, a chelating agent, or a pH buffer.

**[0243]** Other conditions of the Fe-based electroplating bath are also not particularly limited. The temperature of an Fe-based electroplating solution is preferably 30°C or more and 85°C or less in view of constant temperature retention ability. The pH of the Fe-based electroplating bath is also not particularly limited, is preferably 1.0 or more from the perspective of preventing a decrease in current efficiency due to hydrogen generation, and is preferably 3.0 or less in consideration of the electrical conductivity of the Fe-based electroplating bath. The electric current density is preferably 10 A/dm<sup>2</sup> or more from the perspective of productivity and is preferably 150 A/dm<sup>2</sup> or less from the perspective of facilitating the control of the coating weight of an Fe-based electroplated layer. The line speed is preferably 5 mpm or more from the perspective of productivity and is preferably 150 mpm or less from the perspective of stably controlling the coating weight.

**[0244]** A degreasing treatment and water washing for cleaning the surface of a steel sheet and also a pickling treatment and water washing for activating the surface of a steel sheet can be performed as a treatment before Fe-based electroplating treatment. These pretreatments are followed by an Fe-based electroplating treatment. The degreasing treatment and water washing may be performed by any method, for example, by a usual method. In the pickling treatment, various acids, such as sulfuric acid, hydrochloric acid, nitric acid, and mixtures thereof can be used. Among them, sulfuric acid, hydrochloric acid, or a mixture thereof is preferred. The acid concentration is not particularly limited and preferably ranges from approximately 1% to 20% by mass in consideration of the capability of removing an oxide film, prevention of a rough surface (surface defect) due to overpickling, and the like. A pickling treatment liquid may contain an antifoaming agent, a pickling accelerator, a pickling inhibitor, or the like.

## [Annealing Step]

**[0245]** In an embodiment of the present invention, after the pickling step (after the cold rolling step when cold rolling is performed, after a metal coating (first coating) step when metal coating is performed to form a metal coated layer (first coated layer), or after the metal coating (first coating) step when cold rolling and metal coating are performed), the steel sheet thus produced is annealed at an annealing temperature of  $(Ac_1 + 0.4 \times (Ac_3 - Ac_1))$  °C or more and 900°C or less for an annealing time of 20 seconds or more. The number of annealing processes may be two or more but is preferably one from the perspective of energy efficiency.

**[0246]** Annealing temperature:  $(Ac_1 + 0.4 \times (Ac_3 - Ac_1))$  °C or more and 900°C or less

An annealing temperature lower than  $(Ac_1 + 0.4 \times (Ac_3 - Ac_1))$ °C results in an insufficient proportion of austenite formed during heating in a two-phase region of ferrite and austenite. This results in an excessive increase in the area fraction of ferrite after annealing and lower YS. This may also excessively increase the C concentration in austenite during annealing and result in undesired  $\lambda$  and  $S_{Fmax}$ . This also makes it difficult to achieve a TS of 1180 MPa or more.

**[0247]** On the other hand, an annealing temperature of more than 900°C results in excessive grain growth of austenite, a higher MS temperature, and a large amount of tempered martensite containing carbides, makes it difficult to form more than 3.0% of retained austenite, and results in lower ductility. Thus, the annealing temperature is  $(Ac_1 + 0.4 \times (Ac_3 - Ac_1))$  °C or more and 900°C or less. The annealing temperature is preferably 880°C or less. The annealing temperature is more preferably 870°C or less. The annealing temperature is preferably  $(Ac_1 + 0.5 \times (Ac_3 - Ac_1))$  °C or more, more preferably  $(Ac_1 + 0.6 \times (Ac_3 - Ac_1))$  °C or more.

**[0248]** The annealing temperature is the highest temperature reached in the annealing step.

**[0249]** The  $Ac_1$  point (°C) and the  $Ac_3$  point (°C) are calculated using the following formula:

$$Ac_1 \text{ point (}^\circ\text{C)} = 727.0 - 32.7 \times [\%C] + 14.9 \times [\%Si] + 2.0 \times [\%Mn]$$

$$Ac_3 \text{ point (}^\circ\text{C)} = 912.0 - 230 \times [\%C] + 31.6 \times [\%Si] - 20.4 \times [\%Mn]$$

wherein [%C] denotes the C content (% by mass), [%Si] denotes the Si content (% by mass), and [%Mn] denotes the Mn content (% by mass).

Annealing time: 20 seconds or more

**[0250]** An annealing time of less than 20 seconds results in an insufficient proportion of austenite formed during heating in a two-phase region of ferrite and austenite. This results in an excessive increase in the area fraction of ferrite after annealing and lower YS. This also excessively increases the C concentration in austenite during annealing and results in undesired  $\lambda$  and  $S_{Fmax}$ . This also makes it difficult to achieve a TS of 1180 MPa or more. Thus, the annealing time is 20 seconds or more. The annealing time is preferably 30 seconds or more, more preferably 50 seconds or more. The annealing time may have any upper limit and is preferably 900 seconds or less, more preferably 800 seconds or less. The annealing time is even more preferably 300 seconds or less, even further more preferably 220 seconds or less.

**[0251]** The term "annealing time" refers to the holding time in the temperature range of (annealing temperature - 40°C) or more and the annealing temperature or less. Thus, the annealing time includes, in addition to the holding time at the annealing temperature, the residence time in the temperature range of (annealing temperature - 40°C) or more and the annealing temperature or less in heating and cooling before and after reaching the annealing temperature.

Dew point of annealing atmosphere in annealing step: - 30°C or more

**[0252]** In an embodiment of the present invention, the dew point of the atmosphere in the annealing step (annealing atmosphere) is preferably -30°C. Annealing at a dew point of -30°C or more in the annealing atmosphere in the annealing step can promote a decarburization reaction and more deeply form a surface soft layer. The dew point of the annealing atmosphere in the annealing step is more preferably -25°C or more, even more preferably -15°C or more, most preferably more than -5°C.

**[0253]** The dew point of the annealing atmosphere in the annealing step may have any upper limit and is preferably 30°C or less in order to suitably prevent oxidation of the surface of an Fe-based electroplated layer and to improve the coating adhesion when a galvanized layer is provided.

## [First Cooling Step]

**[0254]** The steel sheet annealed as described above is then cooled to a first cooling stop temperature of 400°C or more

and 600°C or less.

First cooling stop temperature: 400°C or more and 600°C or less

5 **[0255]** A first cooling stop temperature of less than 400°C results in an excessive increase in the area fraction of bainitic ferrite, retained austenite with a volume fraction more than a predetermined amount, and undesired  $\lambda$  and  $S_{Fmax}$ . On the other hand, a first cooling stop temperature of more than 600°C may result in an increase in the area fraction of pearlite and lower strength. Thus, the first cooling stop temperature is 400°C or more and 600°C or less. The first cooling stop temperature is preferably 460°C or more. The first cooling stop temperature is preferably 550°C or less.

10

[Holding Step (Preferred Requirement)]

**[0256]** After the first cooling step, when necessary, a holding step of holding the steel sheet in the temperature range of 400°C or more and 600°C or less (hereinafter also referred to as a holding temperature range) for less than 80 seconds may be performed. The holding temperature range may be the first cooling stop temperature.

15

Holding time in holding temperature range: less than 80 seconds

**[0257]** In the holding step, bainitic ferrite is formed, and C diffuses from the formed bainitic ferrite to non-transformed austenite adjacent to the bainitic ferrite. This ensures a predetermined area fraction of retained austenite.

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**[0258]** A holding time of 80 seconds or more in the holding temperature range may result in an excessive increase in the area fraction of bainitic ferrite and lower YS. This may also result in excessive diffusion of C from bainitic ferrite to non-transformed austenite, retained austenite with an area fraction of more than 15.0%, and undesired  $\lambda$  and  $S_{Fmax}$ . Thus, the holding time in the holding temperature range is preferably less than 80 seconds. The holding time in the holding temperature range is more preferably less than 60 seconds. The holding time in the holding temperature range does not include the residence time in the temperature range after the galvanizing treatment in the coating step.

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[Galvanizing Step (Second Coating Step)]

**[0259]** After the first cooling step (after the holding step when the holding step is performed), the steel sheet may be subjected to a galvanizing treatment. A galvanized steel sheet can be produced by the galvanizing treatment. The galvanizing treatment is, for example, a hot-dip galvanizing treatment or a galvannealing treatment.

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**[0260]** In the hot-dip galvanizing treatment, preferably, the steel sheet is immersed in a galvanizing bath at 440°C or more and 500°C or less, and the coating weight is then adjusted by gas wiping or the like. The hot-dip galvanizing bath is not particularly limited as long as the galvanized layer has the composition described above. For example, the galvanizing bath preferably has a composition with an Al content of 0.10% by mass or more, the remainder being Zn and incidental impurities. The Al content is preferably 0.23% by mass or less.

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**[0261]** In the galvannealing treatment, after the hot-dip galvanizing treatment performed in the manner described above, the galvanized steel sheet is preferably heated to an alloying temperature of 450°C or more to perform an alloying treatment. The alloying temperature is preferably 600°C or less.

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**[0262]** An alloying temperature of less than 450°C may result in a low Zn-Fe alloying speed and make alloying difficult. On the other hand, an alloying temperature of more than 600°C results in transformation of non-transformed austenite into pearlite, makes it difficult to achieve a TS of 1180 MPa or more, and results in lower ductility. The alloying temperature is more preferably 470°C or more. The alloying temperature is more preferably 570°C or less.

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**[0263]** The coating weight of each of the hot-dip galvanized steel sheet (GI) and the hot-dip galvanized steel sheet (GA) is preferably 20 g/m<sup>2</sup> or more per side. The coating weight per side of the galvanized layer is preferably 80 g/m<sup>2</sup> or less. The coating weight can be adjusted by gas wiping or the like.

[Second Cooling Step]

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**[0264]** The steel sheet after the first cooling step is then cooled to a second cooling stop temperature of 100°C or more and 300°C or less at an average cooling rate of 25.0°C/s or less.

Second cooling stop temperature: 100°C or more and 300°C or less

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**[0265]** The second cooling step is a step necessary to control the area fraction of tempered martensite and the area fraction of retained austenite, formed in the subsequent reheating step within predetermined ranges. At a second cooling stop temperature of less than 100°C, almost all the non-transformed austenite present in the steel is transformed into

martensite in the second cooling step. This finally results in an excessive increase in the area fraction of tempered martensite, makes it difficult to form more than 3.0% of retained austenite, and results in lower ductility. On the other hand, a second cooling stop temperature of more than 300°C results in a decrease in the area fraction of tempered martensite and an increase in the area fraction of fresh martensite. This may also result in an increase in the amount of diffusible hydrogen in the steel sheet. Consequently, desired  $\lambda$  and  $S_{Fmax}$  cannot be achieved. Furthermore, desired  $\alpha$  may not be achieved. Thus, the second cooling stop temperature is 100°C or more and 300°C or less. The second cooling stop temperature is preferably 120°C or more. The first cooling stop temperature is preferably 280°C or less.

Average cooling rate in second cooling step: 25.0°C/s or less

**[0266]** A cooling rate of more than 25.0°C/s in the second cooling step results in the formation of fine carbides and a density of carbides in tempered martensite higher than a predetermined level. Consequently, desired  $\lambda$  and  $S_{Fmax}$  cannot be achieved. Furthermore, desired  $\alpha$  may not be achieved. Thus, the average cooling rate in the second cooling step is 25.0°C/s or less.

**[0267]** The average cooling rate can be calculated by "(cooling start temperature (°C) - second cooling stop temperature (°C))/cooling time (s)".

**[0268]** In the present invention, when a steel sheet is cooled to the second cooling stop temperature, a tension of 2.0 kgf/mm<sup>2</sup> or more is applied once or more in the temperature range of 300°C or more and 450°C or less. The steel sheet to which the tension has been applied is subjected to four or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll, and is subjected to two or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for half a circumference of the roll.

**[0269]** As described above, applying a tension of 2.0 kgf/mm<sup>2</sup> or more to the steel sheet once or more and subjecting the steel sheet to a specified number of passes cause deformation-induced transformation of retained austenite excessively formed in the steel sheet microstructure into martensite and then into tempered martensite during subsequent cooling. Consequently, desired  $\lambda$  and  $S_{Fmax}$  can be achieved.

**[0270]** The number of passes to which the steel sheet is subjected during contact with the roll for a quarter circumference of the roll is preferably five or more passes, more preferably six or more passes.

**[0271]** Although the upper limit is not particularly limited, the number of passes to which the steel sheet is subjected during contact with the roll for a quarter circumference of the roll is preferably 12 or less passes, more preferably 10 or less passes.

**[0272]** The number of passes to which the steel sheet is subjected during contact with the roll for half a circumference of the roll is preferably three or more passes, more preferably four or more passes.

**[0273]** Although the upper limit is not particularly limited, the number of passes to which the steel sheet is subjected during contact with the roll for half a circumference of the roll is preferably six or less passes, more preferably five or less passes.

**[0274]** The tension is calculated by dividing the total load (kgf) of a load cell on the left and right of the roll by the cross-sectional area of the steel sheet (= sheet thickness (mm) x sheet width (mm)) (mm<sup>2</sup>). The load cells should be arranged parallel to the direction of the tension.

**[0275]** The load cells are preferably disposed at a position of 200 mm from both ends of the roll. The length of the roll to be used is preferably 1500 mm or more. The length of the roll to be used is preferably 2500 mm or less.

**[0276]** The tension is preferably 2.2 kgf/mm<sup>2</sup> or more, more preferably 2.4 kgf/mm<sup>2</sup> or more.

**[0277]** The tension is preferably 15.0 kgf/mm<sup>2</sup> or less, more preferably 10.0 kgf/mm<sup>2</sup> or less. The tension is even more preferably 7.0 kgf/mm<sup>2</sup> or less, even further more preferably 4.0 kgf/mm<sup>2</sup> or less.

**[0278]** With respect to the tension applied once or more, for example, the application of the tension twice means that a first tension of 2.0 kgf/mm<sup>2</sup> or more is applied once, and after the tension becomes less than 2.0 kgf/mm<sup>2</sup> a second tension of 2.0 kgf/mm<sup>2</sup> or more is applied. The application of the tension three times means that a first tension of 2.0 kgf/mm<sup>2</sup> or more is applied once, after the tension becomes less than 2.0 kgf/mm<sup>2</sup> a second tension of 2.0 kgf/mm<sup>2</sup> or more is applied, and after the tension becomes less than 2.0 kgf/mm<sup>2</sup> a third tension of 2.0 kgf/mm<sup>2</sup> or more is applied.

[Reheating Step]

**[0279]** The steel sheet is then reheated in the temperature range of more than 300°C and 500°C or less (hereinafter also referred to as a reheating temperature range) and is held in the temperature range of more than 300°C and 500°C or less for 20 seconds or more and 900 seconds or less.

**[0280]** This tempers martensite present in the steel at the end of the second cooling step. Furthermore, C dissolved in a supersaturated state in martensite is diffused into non-transformed austenite to form austenite stable at room temperature, that is, retained austenite.

## EP 4 502 195 A1

Reheating temperature (tempering temperature): more than 300°C and 500°C or less

5 **[0281]** A reheating temperature (tempering temperature) of 300°C or less results in insufficient tempering of martensite present in the steel at the end of the second cooling step, an excessive increase in fresh martensite, insufficient coarsening of carbides in tempered martensite, a density of carbides in the tempered martensite higher than a predetermined level, and consequently undesired  $\lambda$ ,  $\alpha$ , and  $S_{F_{max}}$ . This also results in insufficient release of hydrogen contained in the base steel sheet to the outside and increases the amount of diffusible hydrogen in the base steel sheet. This further reduces the flangeability and bendability.

10 **[0282]** On the other hand, a reheating temperature (tempering temperature) of more than 500°C results in excessive tempering of martensite present in the steel at the end of the second cooling step and makes it difficult to achieve a TS of 1180 MPa or more. This also results in lower ductility because non-transformed austenite present in the steel at the end of the second cooling step is decomposed as carbide (pearlite). This may also result in insufficient release of hydrogen contained in the base steel sheet to the outside and increase the amount of diffusible hydrogen in the base steel sheet. This reduces the flangeability. Thus, the reheating temperature is more than 300°C and 500°C or less. The reheating temperature is the highest temperature reached in the reheating step. The reheating temperature is preferably 340°C or more, more preferably 360°C or more. The reheating temperature is preferably 460°C or less, more preferably 440°C or less.

20 Holding time (tempering time) in reheating temperature range: 20 seconds or more and 900 seconds or less

25 **[0283]** A holding time (tempering time) of less than 20 seconds in the reheating temperature range results in insufficient tempering of martensite present in the steel at the end of the second cooling step and an excessive increase in fresh martensite. This may also result in insufficient coarsening of carbides in tempered martensite and a density of carbides in the tempered martensite higher than a predetermined level. Consequently, desired  $\lambda$ ,  $\alpha$ , and  $S_{F_{max}}$  cannot be achieved. This also results in insufficient release of hydrogen contained in the base steel sheet to the outside and increases the amount of diffusible hydrogen in the base steel sheet. This further reduces the flangeability and bendability.

30 **[0284]** On the other hand, a holding time (tempering time) of more than 900 seconds in the reheating temperature range results in excessive tempering of martensite present in the steel at the end of the second cooling step and makes it difficult to achieve a TS of 1180 MPa or more. This also results in lower ductility because non-transformed austenite present in the steel at the end of the second cooling step is decomposed as carbide (pearlite). Thus, the holding time in the reheating temperature range is 20 seconds or more and 900 seconds or less. The holding time is preferably 30 seconds or more, more preferably 40 seconds or more. The holding time is preferably 500 seconds or less, more preferably 100 seconds or less.

35 **[0285]** The holding time in the reheating temperature range includes, in addition to the holding time at the reheating temperature, the residence time in the temperature range during heating and cooling before and after the reheating temperature is reached.

Carbide control parameter CP during reheating: 10,000 or more and 15,000 or less

40 **[0286]** A carbide control parameter CP of less than 10,000 during reheating results in insufficient tempering of martensite present in the steel at the end of the second cooling step, an excessive increase in fresh martensite, insufficient coarsening of carbides in tempered martensite, a density of carbides in the tempered martensite higher than a predetermined level, and consequently undesired  $\lambda$ ,  $\alpha$ , and  $S_{F_{max}}$ . This also results in insufficient release of hydrogen contained in the base steel sheet to the outside and increases the amount of diffusible hydrogen in the base steel sheet. This further reduces the flangeability and bendability.

45 **[0287]** On the other hand, a carbide control parameter CP of more than 15,000 during reheating results in excessive tempering of martensite present in the steel at the end of the second cooling step and makes it difficult to achieve a TS of 1180 MPa or more. This also results in lower ductility because non-transformed austenite present in the steel at the end of the second cooling step is decomposed as carbide (pearlite). Thus, the carbide control parameter CP during reheating is 10,000 or more and 15,000 or less.

50 **[0288]** The carbide control parameter CP during reheating is preferably 11,000 or more, more preferably 12,000 or more. The carbide control parameter CP during reheating is preferably 14,500 or less, more preferably 14,000 or less.

**[0289]** The carbide control parameter during reheating is calculated using the following formula:

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$$CP = (T + 273) \times (k + 1.2 \times \log t) \quad \text{formula (1)}$$

wherein CP denotes the carbide control parameter, T denotes the tempering temperature (°C), k denotes the material constant depending on the C content, t denotes the tempering time (second), and 1.2 in the term of  $1.2 \times \log t$  is a correction

## EP 4 502 195 A1

factor (predetermined correction factor) in consideration of the cooling time after the reheating step.

**[0290]** The material constant  $k$  is calculated using the following formula:

$$k = -6 \times C_M + 17.8$$

wherein  $C_M$  denotes the carbon concentration (% by mass) of martensite formed in the second cooling step.

**[0291]** The carbon concentration of martensite formed in the second cooling step can be measured as described below.

**[0292]** First, the carbon concentration of each phase immediately before the second cooling step satisfies the following relationship:

$$V_{\gamma 1} \times C_{\gamma 1} + V_F \times C_F + V_{BF} \times C_{BF} = C_T \quad \text{formula (2)}$$

$$V_{\gamma 1} = 1 - V_F - V_{BF} \quad \text{formula (3)}$$

wherein  $V_{\gamma 1}$  and  $C_{\gamma 1}$  denote the area fraction (%) of non-transformed austenite and the concentration of carbon (% by mass) in the non-transformed austenite immediately before the second cooling step,

$V_F$  and  $C_F$  denote the area fraction (%) of ferrite and the concentration of carbon (% by mass) in the ferrite immediately before the second cooling step,

$V_{BF}$  and  $C_{BF}$  denote the area fraction (%) of bainitic ferrite and the concentration of carbon (% by mass) in the bainitic ferrite immediately before the second cooling step, and

$C_T$  denotes the concentration of carbon (% by mass) in the steel (immediately before the second cooling step).

**[0293]** Furthermore, the area fraction  $V_F$  (%) of ferrite and the area fraction  $V_{BF}$  (%) of bainitic ferrite immediately before the second cooling step can be equivalent to the area fraction (%) of ferrite and the area fraction (%) of bainitic ferrite in the final microstructure (the steel microstructure of the steel sheet finally produced). The concentration of carbon  $C_F$  (% by mass) in ferrite and the concentration of carbon  $C_{BF}$  (% by mass) in bainitic ferrite may be zero.

**[0294]** Thus, the formula (2) is

$$C_T = V_{\gamma 1} \times C_{\gamma 1} + V_F \times 0 + V_{BF} \times 0 = V_{\gamma 1} \times C_{\gamma 1} \quad \text{formula (2-2)} .$$

**[0295]** From the formula (2-2) and the formula (3),  $C_T = (1 - V_F - V_{BF}) \times C_{\gamma 1}$ , and  $C_{\gamma 1} = C_T / (1 - V_F - V_{BF})$ . Furthermore, since the transformation from  $\gamma 1$  (non-transformed austenite) to martensite in the second cooling step is a transformation not accompanied by the diffusion of C,  $C_M = C_{\gamma 1}$ , that is,  $C_M = C_{\gamma 1} = C_T / (1 - V_F - V_{BF})$ .

**[0296]** The cooling condition after holding in the reheating temperature range is not particularly limited and may be based on a usual method. The cooling method is, for example, gas jet cooling, mist cooling, roll cooling, water cooling, natural cooling, or the like. From the perspective of preventing surface oxidation, after holding in the reheating temperature range, cooling to 50°C or less is preferred, and cooling to approximately room temperature is more preferred. The average cooling rate in cooling after holding in the reheating temperature range is preferably, for example, 1°C/s or more and 50°C/s or less.

**[0297]** The steel sheet thus produced may be further subjected to temper rolling. A rolling reduction of more than 2.00% in the temper rolling may result in an increase in yield stress and a decrease in dimensional accuracy when the steel sheet is formed into a member. Thus, the rolling reduction in the temper rolling is preferably 2.00% or less. The lower limit of the rolling reduction in the temper rolling is preferably, but not limited to, 0.05% or more from the perspective of productivity. The temper rolling may be performed with an apparatus coupled to an annealing apparatus for each step (on-line) or with an apparatus separated from the annealing apparatus for each step (offline). The number of temper rolling processes may be one or two or more. The rolling may be performed with a leveler or the like, provided that the elongation can be equivalent to that in the temper rolling.

**[0298]** Conditions other than those described above are not particularly limited and may be based on a usual method.

[3. Member]

**[0299]** Next, a member according to an embodiment of the present invention is described. A member according to an embodiment of the present invention is a member produced by using the steel sheet described above (as a material). For example, the steel sheet as a material is subjected to at least one of forming and joining to produce a member.

**[0300]** The steel sheet has a TS of 1180 MPa or more, high YS, high press formability (ductility, flangeability, and

bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) at the time of compression. Thus, a member according to an embodiment of the present invention has high strength and enhanced crashworthiness. Thus, a member according to an embodiment of the present invention is suitable for an impact energy absorbing member used in the automotive field.

#### [4. Method for Producing Member]

**[0301]** Next, a method for producing a member according to an embodiment of the present invention is described.

**[0302]** A method for producing a member according to an embodiment of the present invention includes a step of subjecting the steel sheet (for example, a steel sheet produced by the method for producing a steel sheet) to at least one of forming and joining to produce a member.

**[0303]** The forming method is, for example, but not limited to, a typical processing method, such as press working. The joining method is also, for example, but not limited to, typical welding, such as spot welding, laser welding, or arc welding, riveting, caulking, or the like. The forming conditions and the joining conditions are not particularly limited and may be based on a usual method.

#### EXAMPLES

**[0304]** A steel material with the chemical composition (the remainder being Fe and incidental impurities) listed in Table 1 was produced by steelmaking in a converter and was formed into a steel slab in a continuous casting method. In Table 1, "-" indicates the content at the level of incidental impurities.

**[0305]** The calculated transformation points  $Ac_1$  (°C) and  $Ac_3$  (°C) in Table 1 are calculated using the following formula:

$$Ac_1 \text{ point (}^\circ\text{C)} = 727.0 - 32.7 \times [\%C] + 14.9 \times [\%Si] + 2.0 \times [\%Mn]$$

$$Ac_3 \text{ point (}^\circ\text{C)} = 912.0 - 230 \times [\%C] + 31.6 \times [\%Si] - 20.4 \times [\%Mn]$$

wherein [%C] denotes the C content (% by mass), [%Si] denotes the Si content (% by mass), and [%Mn] denotes the Mn content (% by mass).

**[0306]** The steel slab was heated to 1200°C and, after the heating, was subjected to hot rolling composed of rough rolling and finish rolling at a finish rolling temperature of 900°C to form a hot-rolled steel sheet. Hot-rolled steel sheets No. 1 to No. 61, No. 64 to No. 78, No. 84 to No. 98, and No. 104 to No. 109 thus produced were pickled and cold-rolled (rolling reduction: 50%) to produce cold-rolled steel sheets with thicknesses shown in Tables 3, 6, and 9. Hot-rolled steel sheets No. 62 and No. 63, No. 79 to No. 83, and No. 99 to No. 103 were pickled to produce hot-rolled steel sheets (pickled) with thicknesses shown in Tables 3, 6, and 9.

**[0307]** The cold-rolled steel sheets or hot-rolled steel sheets (pickled) were subjected to treatments in the annealing step, the first cooling step, the holding step, the galvanizing step, the second cooling step, and the reheating step under the conditions shown in Table 2 and were subjected to treatments in the first coating step (metal coating step), the annealing step, the first cooling step, the holding step, the second coating step (galvanizing step), the second cooling step, and the reheating step under the conditions shown in Tables 5 and 8 to produce steel sheets (galvanized steel sheets).

**[0308]** Tables 5 and 8 show the presence or absence of the first coating step (metal coating step) and the coating type in the treatment in the metal coating step for the steel sheets No. 64 to No. 109. Tables 6 and 9 show the thickness of the surface soft layer, the metal coating weight, and the hardness distribution of the surface soft layer for the steel sheets No. 64 to No. 109.

**[0309]** In the galvanizing step, the hot-dip galvanizing treatment or the galvannealing treatment was performed to produce a hot-dip galvanized steel sheet (hereinafter also referred to as GI) or a hot-dip galvanized steel sheet (hereinafter also referred to as GA). In Tables 2, 5, and 8, the type in the coating step is also denoted by "GI" and "GA". In the GI steel sheets in Tables 2, 5, and 8, no alloying treatment was performed, and the alloying temperature is indicated by "-". In Table 8, a cold-rolled steel sheet formed without the galvanizing treatment in the galvanizing step is denoted by "CR", and a hot-rolled steel sheet formed without the galvanizing treatment in the galvanizing step is denoted by "HR".

**[0310]** The galvanizing bath temperature was 470°C in the production of GI and GA.

**[0311]** The galvanizing coating weight ranged from 45 to 72 g/m<sup>2</sup> per side to produce GI and was 45 g/m<sup>2</sup> per side to produce GA.

**[0312]** The composition of the galvanized layer of the final galvanized steel sheet in GI contained Fe: 0.1% to 1.0% by mass and Al: 0.2% to 0.33% by mass, the remainder being Zn and incidental impurities. GA contained Fe: 8.0% to 12.0% by mass and Al: 0.1% to 0.23% by mass, the remainder being Zn and incidental impurities.

**[0313]** In both cases, the galvanized layer was formed on both surfaces of the base steel sheet.

**[0314]** In Tables 2, 5, and 8, the phrase "the number of passes 1" refers to the number of passes to which the steel sheet is subjected, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll, after an average tension of 2.0 kgf/mm<sup>2</sup> or more is applied once or more in the temperature range of 300°C or more and 450°C or less in the second cooling step, and the phrase "the number of passes 2" refers to the number of passes to which the steel sheet is subsequently subjected, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for half a circumference of the roll.

**[0315]** In the steel sheet thus produced, in the manner described above, the steel microstructure of the base steel sheet was identified, and the amount of diffusible hydrogen was measured. Tables 3, 6, and 9 show the measurement results. In Tables 3, 6, and 9, BF denotes bainitic ferrite, TM denotes tempered martensite, RA denotes retained austenite, FM denotes fresh martensite, LB denotes lower bainite, P denotes pearlite, and  $\theta$  denotes carbide.  $C_M$  denotes the concentration of carbon in martensite formed in the second cooling step,  $C_\gamma$  denotes the carbon concentration of retained austenite, and  $\rho_c$  denotes the density of carbides in tempered martensite.

**[0316]** Measurement is performed on the surface soft layer as described below. After smoothing a thickness cross section (L cross section) parallel to the rolling direction of the steel sheet by wet grinding, measurement was performed in accordance with JIS Z 2244-1 (2020) using a Vickers hardness tester at a load of 10 gf from a 1- $\mu$ m position to a 100- $\mu$ m position in the thickness direction from the surface of the steel sheet at intervals of 1  $\mu$ m. Measurement was then performed at intervals of 20  $\mu$ m to the central portion in the thickness direction. A region with hardness corresponding to 85% or less of the hardness at the quarter thickness position is defined as a soft layer (surface soft layer), and the thickness of the region in the thickness direction is defined as the thickness of the soft layer.

**[0317]** A tensile test, a hole expansion test, a VDA bending test, a V-VDA bending test, and an axial compression test were performed in the manner described below. The tensile strength (TS), the yield stress (YS), the total elongation (EI), the limiting hole expansion ratio ( $\lambda$ ), the critical bending angle ( $\alpha$ ) in the VDA bending test, the stroke at the maximum load ( $S_{Fmax}$ ) in the V-VDA bending test, and the presence or absence of axial compression fracture were evaluated in accordance with the following criteria.

**[0318]**

- TS

Good (pass): 1180 MPa or more

Poor (fail): less than 1180 MPa

- YS

Good (pass):

(A) For 1180 MPa  $\leq$  TS < 1320 MPa, 750 MPa  $\leq$  YS

(B) For 1320 MPa  $\leq$  TS, 850 MPa  $\leq$  YS

Poor (fail):

(A) For 1180 MPa  $\leq$  TS < 1320 MPa, 750 MPa > YS

(B) For 1320 MPa  $\leq$  TS, 850 MPa > YS

- EI

Good (pass):

(A) For 1180 MPa  $\leq$  TS < 1320 MPa, 12.0%  $\leq$  EI

(B) For 1320 MPa  $\leq$  TS, 10.0%  $\leq$  EI

Poor (fail):

(A) For 1180 MPa  $\leq$  TS < 1320 MPa, 12.0% > EI

(B) For 1320 MPa  $\leq$  TS, 10.0% > EI

-  $\lambda$

Good (pass): 30% or more

## EP 4 502 195 A1

Poor (fail): less than 30%

-  $\alpha$

5 Good (pass): 80 degrees or more  
Poor (fail): less than 80 degrees

-  $S_{Fmax}$

10 Good (pass): 26.0 mm or more  
Poor (fail): less than 26.0 mm

- Presence or absence of axial compression fracture

15 A (pass): No crack was observed in a sample after the axial compression test  
B (pass): Two or less cracks were observed in a sample after the axial compression test  
C (pass): Three or less cracks were observed in a sample after the axial compression test  
D (fail): Four or more cracks were observed in a sample after the axial compression test, or a sample after the axial  
compression test was broken

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### (1) Tensile Test

25 **[0319]** The tensile test was performed in accordance with JIS Z 2241 (2011). A JIS No. 5 test specimen was taken from the steel sheet such that the longitudinal direction was perpendicular to the rolling direction of the base steel sheet. TS, YS, and El of the test specimen were measured at a crosshead speed of 10 mm/min in the tensile test. Tables 4, 7, and 10 show the results.

### (2) Hole Expansion Test

30 **[0320]** The hole expansion test was performed in accordance with JIS Z 2256 (2020). A 100 mm x 100 mm test specimen was taken from the steel sheet by shearing. A hole with a diameter of 10 mm was punched in the test specimen with a clearance of 12.5%. Using a die with an inner diameter of 75 mm, a blank holding force of 9 ton (88.26 kN) was then applied to the periphery of the hole, a conical punch with a vertex angle of 60 degrees was pushed into the hole, and the hole diameter of the test specimen at the crack initiation limit (in crack initiation) was measured. The limiting hole expansion ratio  $\lambda$  (%) was determined using the following formula.  $\lambda$  is a measure for evaluating stretch flangeability. Tables 4, 7, and 10 show the results.

$$\lambda (\%) = \{ (D_f - D_0) / D_0 \} \times 100$$

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$D_f$ : diameter (mm) of hole of test specimen in crack initiation  
 $D_0$ : hole diameter (mm) of initial test specimen

### (3) VDA Bending Test

45 **[0321]** The VDA bending test was performed in a bending test according to the VDA standard (VDA 238-100) defined by German Association of the Automotive Industry.

**[0322]** More specifically, a 70 mm x 60 mm test specimen was taken from the steel sheet by shearing. The sides of 60 mm are parallel to the rolling (L) direction.

50 **[0323]** The test specimen was subjected to the VDA bending test under the following conditions.

Test method: roll support, punch pressing  
Roll diameter:  $\phi 30$  mm  
Punch tip R: 0.4 mm  
55 Distance between rolls: (sheet thickness x 2) + 0.5 mm  
Stroke speed: 20 mm/min  
Bending direction: direction (C) perpendicular to rolling direction

**[0324]** When the load  $F$  applied with a press bending jig from above reaches the maximum, the angle on the outside of a bend at the central portion of a plate-like test specimen is measured as the critical bending angle (degree). The average value of the critical bending angle at the maximum load in the VDA bending test performed three times is defined as  $\alpha$  (degree). Tables 4, 7, and 10 show the results.

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(4) V-VDA Bending Test (V-Bending + Orthogonal VDA Bending Test)

**[0325]** The V-VDA bending test was performed as described below.

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**[0326]** A 60 mm x 65 mm test specimen was taken from the steel sheet by shearing. The sides of 60 mm are parallel to the rolling (L) direction. 90-degree bending (primary bending) was performed at a radius of curvature/thickness ratio of 4.2 in the rolling (L) direction with respect to an axis extending in the width (C) direction to prepare a test specimen. In the 90-degree bending (primary bending), as illustrated in Fig. 2-1(a), a punch B1 was pressed against a steel sheet on a die A1 with a V-groove to prepare a test specimen T1. Next, as illustrated in 2-1(b), the test specimen T1 on support rolls A2 was subjected to orthogonal bending (secondary bending) by pressing a punch B2 against the test specimen T1 in the direction perpendicular to the rolling direction. In Fig. 2-1(a) and 2-1(b), the symbol D1 denotes the width (C) direction, and the symbol D2 denotes the rolling (L) direction.

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**[0327]** The V-bending conditions in the V-VDA bending test (V-bending + orthogonal VDA bending test) are as follows:

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Test method: die support, punch pressing  
 Forming load: 10 t  
 Test speed: 30 mm/min  
 Holding time: 5 s  
 Bending direction: rolling (L) direction

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**[0328]** The conditions for VDA bending in the V-VDA bending test are as follows:

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Test method: roll support, punch pressing  
 Roll diameter:  $\phi 30$  mm  
 Punch tip R: 0.4 mm  
 Distance between rolls: (sheet thickness x 2) + 0.5 mm  
 Stroke speed: 20 mm/min  
 Test specimen size: 60 mm x 60 mm  
 Bending direction: direction (C) perpendicular to rolling direction

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**[0329]** The stroke at the maximum load is determined in a stroke-load curve of the VDA bending. The average value of the stroke at the maximum load in the V-VDA bending test performed three times is defined as  $S_{F_{max}}$  (mm). Tables 4, 7, and 10 show the results.

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(5) Axial Compression Test

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**[0330]** A 160 mm x 200 mm test specimen was taken from the steel sheet by shearing. The sides of 160 mm are parallel to the rolling (L) direction. A hat-shaped member 10 with a depth of 40 mm illustrated in Figs. 6-1 (a) and 6-1 (b) was produced by forming (bending) with a die having a punch corner radius of 5.0 mm and a die corner radius of 5.0 mm. The steel sheet used as the material of the hat-shaped member was separately cut into a size of 80 mm x 200 mm. Next, the cut-out steel sheet 20 and the hat-shaped member 10 were spot-welded together to produce a test member 30 as illustrated in Figs. 6-1 (a) and 6-1 (b). Fig. Figs. 6-1 (a) is a front view of the test member 30 produced by spot-welding the hat-shaped member 10 and the steel sheet 20. 6-1 (b) is a perspective view of the test member 30. As illustrated in 6-1 (b), spot welds 40 were positioned such that the distance between an end portion of the steel sheet and a weld was 10 mm and the distance between the welds was 45 mm. Next, as illustrated in Fig. 6-2(c), the test member 30 was joined to a base plate 50 by TIG welding to prepare an axial compression test sample. Next, the axial compression test sample was collided with an impactor 60 at a constant collision speed of 10 mm/min to compress the axial compression test sample by 70 mm. As illustrated in Fig. 6-2(c), the compression direction D3 was a direction parallel to the longitudinal direction of the test member 30.

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**[0331]** The compressed sample was evaluated as described above, and the results are shown in Tables 4, 7, and 10.

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**[0332]** The VDA bending test, the V-VDA bending test, and the axial compression test of a steel sheet with a thickness of more than 1.2 mm were all performed on a steel sheet with a thickness of 1.2 mm in consideration of the influence of the sheet thickness. A steel sheet with a thickness of more than 1.2 mm was ground on one side to have a thickness of 1.2 mm. Since grinding may affect the bendability of the surface of a steel sheet, the ground surface in the VDA bending test was the

inside of the bend (the side in contact with the punch), and the ground surface in the V-VDA bending test was the outside of the bend (the side in contact with the die) in the V-bending test and was the inside of the bend (the side in contact with the punch) in the subsequent VDA bending test.

**[0333]** On the other hand, in the VDA bending test, the V-VDA bending test, and the axial compression test of a steel sheet with a thickness of 1.2 mm or less, the sheet thickness has a small influence, and the test was performed without the grinding treatment.

**[0334]** Furthermore, "1" and "2" in Tables 4, 7, and 10 refer to the length of a crack formed in the L cross section of the V-bending ridge line portion and the VDA bending ridge line portion when the V-VDA bending test is performed to the maximum load point, and the change in the grain size of bainitic ferrite in the thickness direction due to processing in a region of 50 μm from the surface of the steel sheet on the outside of a VDA bend and 50 μm on the left and right sides of the bending peak of the VDA bend (a region formed from each position on a starting line present from a starting point of a bending peak on the outside of a VDA bend to a position of 50 μm in the thickness direction up to a position of 50 μm on each side of the starting line perpendicular to the starting line), respectively.

<Nanohardness Measurement>

**[0335]** To achieve high bendability during press forming and good bending fracture characteristics in case of a collision, when the nanohardness is measured at 300 points or more in a 50 μm x 50 μm region on the sheet surface at each of a quarter depth position in the thickness direction and a half depth position in the thickness direction of the surface soft layer from a base surface layer, the ratio of the number of measurements in which the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet is 7.0 GPa or more is more preferably 0.10 or less with respect to the total number of measurements at the quarter depth position in the thickness direction. When the ratio of the nanohardness of 7.0 GPa or more is 0.10 or less, it means a low ratio of a hard microstructure (martensite or the like), an inclusion, or the like, and this could further suppress the formation and connection of voids and crack growth in the hard microstructure (martensite and the like), inclusion, or the like during press forming and in case of a collision, thus resulting in good R/t and  $S_{Fmax}$ .

**[0336]** When galvanizing was performed, peeling the coated layer was followed by mechanical polishing to the quarter depth position - 5 μm in the thickness direction of the surface soft layer from the surface of the base steel sheet, by buffing with diamond and alumina to the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet, and then by colloidal silica polishing. The nanohardness was measured at 512 points in total with Hysitron tribo-950 and a Berkovich diamond indenter under the conditions of

- Load: 500 μN,
- Measurement area: 50 μm x 50 μm, and
- Dot-to-dot distance: 2 μm.

**[0337]** The coated layer to be peeled off is a galvanized layer when the galvanized layer is formed, is a metal coated layer when the metal coated layer is formed, or is a galvanized layer and a metal coated layer when the galvanized layer and the metal coated layer are formed.

**[0338]** Mechanical polishing, buffing with diamond and alumina, and colloidal silica polishing were then performed to the half depth position in the thickness direction of the surface soft layer. The nanohardness was measured at 512 points in total with Hysitron tribo-950 and a Berkovich diamond indenter under the conditions of

- Load: 500 μN,
- Measurement area: 50 μm x 50 μm, and
- Dot-to-dot distance: 2 μm.

[Table 1-1]

| Steel grade | Chemical composition (mass%) |      |      |       |        |       |        |        | Calculated transformation point (°C) |                 | Note             |
|-------------|------------------------------|------|------|-------|--------|-------|--------|--------|--------------------------------------|-----------------|------------------|
|             | C                            | Si   | Mn   | P     | S      | Al    | N      | Others | Ac <sub>1</sub>                      | Ac <sub>3</sub> |                  |
| A           | 0.081                        | 1.03 | 3.32 | 0.004 | 0.0017 | 0.016 | 0.0045 | -      | 746                                  | 858             | Conforming steel |

EP 4 502 195 A1

(continued)

| Steel grade | Chemical composition (mass%) |             |             |       |        |       |        |                                    | Calculated transformation point (°C) |                 | Note              |
|-------------|------------------------------|-------------|-------------|-------|--------|-------|--------|------------------------------------|--------------------------------------|-----------------|-------------------|
|             | C                            | Si          | Mn          | P     | S      | Al    | N      | Others                             | Ac <sub>1</sub>                      | Ac <sub>3</sub> |                   |
| B           | 0.257                        | 0.82        | 2.37        | 0.003 | 0.0010 | 0.019 | 0.0030 | -                                  | 736                                  | 830             | Conforming steel  |
| C           | 0.311                        | 1.59        | 2.58        | 0.009 | 0.0012 | 0.038 | 0.0049 | -                                  | 746                                  | 838             | Conforming steel  |
| D           | 0.250                        | 2.10        | 3.16        | 0.008 | 0.0018 | 0.025 | 0.0022 | -                                  | 756                                  | 856             | Conforming steel  |
| E           | 0.229                        | 0.96        | 2.54        | 0.003 | 0.0008 | 0.021 | 0.0043 | -                                  | 739                                  | 838             | Conforming steel  |
| F           | 0.209                        | 0.77        | 3.03        | 0.003 | 0.0016 | 0.755 | 0.0031 | -                                  | 738                                  | 826             | Conforming steel  |
| G           | 0.332                        | 0.88        | 3.30        | 0.004 | 0.0014 | 0.028 | 0.0039 | -                                  | 736                                  | 796             | Conforming steel  |
| <u>H</u>    | <u>0.041</u>                 | 0.83        | 2.92        | 0.004 | 0.0009 | 0.038 | 0.0026 | -                                  | 744                                  | 869             | Comparative steel |
| <u>I</u>    | <u>0.439</u>                 | 1.89        | 2.59        | 0.003 | 0.0011 | 0.020 | 0.0031 | -                                  | 746                                  | 818             | Comparative steel |
| <u>J</u>    | 0.285                        | <u>0.22</u> | 2.65        | 0.016 | 0.0004 | 0.021 | 0.0034 | -                                  | 726                                  | 799             | Comparative steel |
| <u>K</u>    | 0.257                        | <u>3.16</u> | 2.55        | 0.004 | 0.0007 | 0.012 | 0.0026 | -                                  | 771                                  | 901             | Comparative steel |
| <u>L</u>    | 0.166                        | 0.86        | <u>1.92</u> | 0.003 | 0.0005 | 0.024 | 0.0025 | -                                  | 738                                  | 862             | Comparative steel |
| <u>M</u>    | 0.270                        | 1.92        | <u>3.95</u> | 0.019 | 0.0014 | 0.036 | 0.0048 | -                                  | 755                                  | 830             | Comparative steel |
| N           | 0.230                        | 1.47        | 2.85        | 0.007 | 0.0012 | 0.040 | 0.0046 | Ti:0.022                           | 747                                  | 847             | Conforming steel  |
| O           | 0.196                        | 1.53        | 2.58        | 0.004 | 0.0014 | 0.032 | 0.0050 | Nb:0.028                           | 749                                  | 863             | Conforming steel  |
| P           | 0.174                        | 1.35        | 2.90        | 0.007 | 0.0012 | 0.035 | 0.0025 | V:0.043                            | 747                                  | 855             | Conforming steel  |
| Q           | 0.186                        | 1.49        | 2.83        | 0.015 | 0.0004 | 0.035 | 0.0024 | Ti:0.021,<br>B:0.0015              | 749                                  | 859             | Conforming steel  |
| R           | 0.207                        | 1.22        | 2.78        | 0.007 | 0.0004 | 0.025 | 0.0031 | Ti:0.025,<br>Nb:0.030,<br>B:0.0021 | 744                                  | 846             | Conforming steel  |
| S           | 0.306                        | 0.91        | 2.99        | 0.008 | 0.0015 | 0.011 | 0.0029 | Ti:0.016,<br>Nb:0.025,<br>B:0.0018 | 737                                  | 809             | Conforming steel  |
| T           | 0.253                        | 1.11        | 2.74        | 0.018 | 0.0011 | 0.014 | 0.0043 | Cu:0.151                           | 741                                  | 833             | Conforming steel  |
| U           | 0.298                        | 1.66        | 2.56        | 0.009 | 0.0010 | 0.039 | 0.0040 | Cr:0.058                           | 747                                  | 844             | Conforming steel  |

**EP 4 502 195 A1**

(continued)

| Steel grade   | Chemical composition (mass%) |      |      |       |        |       |        |                       | Calculated transformation point (°C) |                 | Note             |
|---|------------------------------|------|------|-------|--------|-------|--------|-----------------------|--------------------------------------|-----------------|------------------|
|   | C                            | Si   | Mn   | P     | S      | Al    | N      | Others                | Ac <sub>1</sub>                      | Ac <sub>3</sub> |                  |
| V   | 0.198                        | 0.98 | 2.76 | 0.007 | 0.0004 | 0.010 | 0.0046 | Ni:0.114              | 741                                  | 841             | Conforming steel |
| W   | 0.162                        | 0.89 | 2.54 | 0.008 | 0.0013 | 0.016 | 0.0039 | Mo:0.033              | 740                                  | 851             | Conforming steel |
| X   | 0.296                        | 1.91 | 2.77 | 0.010 | 0.0012 | 0.039 | 0.0026 | Sb:0.009              | 751                                  | 848             | Conforming steel |
| Y   | 0.227                        | 1.43 | 3.00 | 0.009 | 0.0012 | 0.027 | 0.0027 | Sn:0.011              | 747                                  | 844             | Conforming steel |
| Z   | 0.174                        | 1.07 | 3.14 | 0.007 | 0.0007 | 0.028 | 0.0035 | Nb:0.019,<br>Ta:0.008 | 744                                  | 842             | Conforming steel |
| - The remainder other than these is Fe and incidental impurities. |                              |      |      |       |        |       |        |                       |                                      |                 |                  |

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[Table 1-2]

| Steel grade | Chemical composition (mass%) |      |      |       |        |       |        |           |                 |                 | Calculated transformation point (°C) |  | Note |
|-------------|------------------------------|------|------|-------|--------|-------|--------|-----------|-----------------|-----------------|--------------------------------------|--|------|
|             | C                            | Si   | Mn   | P     | S      | Al    | N      | Others    | Ac <sub>1</sub> | Ac <sub>3</sub> |                                      |  |      |
| AA          | 0.224                        | 1.38 | 2.87 | 0.007 | 0.0019 | 0.039 | 0.0026 | Ta:0.009  | 746             | 846             | Conforming steel                     |  |      |
| AB          | 0.273                        | 1.55 | 2.77 | 0.014 | 0.0003 | 0.033 | 0.0026 | W:0.036   | 747             | 842             | Conforming steel                     |  |      |
| AC          | 0.120                        | 1.02 | 3.08 | 0.017 | 0.0006 | 0.016 | 0.0048 | Mg:0.0054 | 744             | 854             | Conforming steel                     |  |      |
| AD          | 0.240                        | 0.86 | 2.78 | 0.014 | 0.0011 | 0.022 | 0.0050 | Zn:0.0058 | 738             | 827             | Conforming steel                     |  |      |
| AE          | 0.199                        | 1.51 | 2.96 | 0.011 | 0.0005 | 0.026 | 0.0038 | Co:0.0076 | 749             | 854             | Conforming steel                     |  |      |
| AF          | 0.211                        | 0.77 | 2.71 | 0.007 | 0.0017 | 0.023 | 0.0035 | Zr:0.0031 | 737             | 833             | Conforming steel                     |  |      |
| AG          | 0.256                        | 1.86 | 2.79 | 0.015 | 0.0008 | 0.015 | 0.0039 | Ca:0.0011 | 752             | 855             | Conforming steel                     |  |      |
| AH          | 0.183                        | 0.99 | 2.98 | 0.013 | 0.0018 | 0.010 | 0.0022 | Se:0.0088 | 742             | 840             | Conforming steel                     |  |      |
| AI          | 0.160                        | 1.51 | 2.88 | 0.017 | 0.0012 | 0.036 | 0.0044 | Te:0.0105 | 750             | 864             | Conforming steel                     |  |      |
| AJ          | 0.282                        | 0.92 | 2.56 | 0.005 | 0.0006 | 0.018 | 0.0042 | Ge:0.0099 | 737             | 824             | Conforming steel                     |  |      |
| AK          | 0.206                        | 1.45 | 2.79 | 0.014 | 0.0009 | 0.022 | 0.0036 | As:0.0248 | 747             | 854             | Conforming steel                     |  |      |
| AL          | 0.253                        | 1.37 | 2.67 | 0.016 | 0.0011 | 0.012 | 0.0040 | Sr:0.0091 | 744             | 843             | Conforming steel                     |  |      |
| AM          | 0.147                        | 1.12 | 2.94 | 0.020 | 0.0015 | 0.016 | 0.0026 | Cs:0.0125 | 745             | 854             | Conforming steel                     |  |      |
| AN          | 0.227                        | 1.11 | 2.53 | 0.017 | 0.0017 | 0.034 | 0.0032 | Hf:0.0062 | 741             | 843             | Conforming steel                     |  |      |

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(continued)

| Steel grade | Chemical composition (mass%) |      |      |       |        |       |        |  | Calculated transformation point (°C) |                 | Note             |
|-------------|------------------------------|------|------|-------|--------|-------|--------|--|--------------------------------------|-----------------|------------------|
|             | C                            | Si   | Mn   | P     | S      | Al    | N      | Others   | Ac <sub>1</sub>                      | Ac <sub>3</sub> |                  |
| AO          | 0.167                        | 0.87 | 2.58 | 0.003 | 0.0002 | 0.026 | 0.0042 | Pb:0.0101  | 740                                  | 848             | Conforming steel |
| AP          | 0.275                        | 1.84 | 3.14 | 0.006 | 0.0003 | 0.014 | 0.0042 | Bi:0.0027  | 752                                  | 843             | Conforming steel |
| AQ          | 0.244                        | 1.36 | 2.77 | 0.008 | 0.0001 | 0.026 | 0.0049 | REM:0.0036   | 745                                  | 842             | Conforming steel |
| AR          | 0.190                        | 1.25 | 2.86 | 0.011 | 0.0005 | 0.015 | 0.0034 | Nb:0.195, Ti:0.185, V:0.190, B:0.0098, Cr:0.970, Ni:0.950, Mo:0.980, Sb:0.180, Sn:0.190, Cu:0.920, Ta:0.091, W:0.480, Mg:0.0190, Zn:0.0180, Co:0.0180, Zr:0.0930, Ca:0.0180, Se:0.0180, Te:0.0195, Ge:0.0185, As:0.0450, Sr:0.0195, Cs:0.0180, Hf:0.0185, Pb:0.0194, Bi:0.0189, REM:0.0185 | 745                                  | 849             | Conforming steel |

- The remainder other than these is Fe and incidental impurities.

[Table 2-1]

| No. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step                    |   | Second cooling step |                           |                                      |                             |                                  |                           | Reheating cooling         |                           |                  |                    | Note                |
|-----|-------------|----------------------------|--------------------|--------------------|--------------|-------------------------------------|---|---------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|------------------|--------------------|---------------------|
|     |             | Annealing temperature (°C) | Annealing time (s) |                    |              | First cooling stop temperature (°C) | Presence or absence of holding (holding time (s)) | Type                | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C) | Tempering time (s) |                     |
| 1   | A           | 870                        | 20                 | 480                | Absent       | GA                                  | 530   | 170                 | 11.4                      | 4.0                                  | 2                           | 8                                | 6                         | 480                       | 40                        | 144-79           | 17-3               | Inventive example   |
| 2   | B           | 810                        | 40                 | 470                | Absent       | GA                                  | 560   | 140                 | 22.8                      | 3.6                                  | 3                           | 5                                | 5                         | 480                       | 60                        | 137-17           | 16-1               | Inventive example   |
| 3   | C           | 790                        | 70                 | 490                | Absent       | GA                                  | 530   | 290                 | 14.7                      | 3.1                                  | 3                           | 4                                | 6                         | 410                       | 30                        | 117-74           | 15-5               | Inventive example   |
| 4   | D           | 890                        | 20                 | 490                | Present(40)  | GA                                  | 500   | 250                 | 16.7                      | 3.2                                  | 3                           | 8                                | 6                         | 340                       | 100                       | 114-37           | 16-3               | Inventive example   |
| 5   | E           | 820                        | 70                 | 530                | Present(20)  | GI                                  |   | 240                 | 7.4                       | 3.1                                  | 1                           | 6                                | 2                         | 380                       | 30                        | 117-96           | 16-3               | Inventive example   |
| 6   | F           | 780                        | 120                | 480                | Absent       | GA                                  | 590   | 230                 | 6.1                       | 3.6                                  | 2                           | 7                                | 3                         | 360                       | 80                        | 118-29           | 16-4               | Inventive example   |
| 7   | G           | 800                        | 70                 | 520                | Present(30)  | GA                                  | 500   | 200                 | 9.6                       | 2.1                                  | 3                           | 5                                | 10                        | 430                       | 50                        | 125-35           | 15-8               | Inventive example   |
| 8   | H           | 830                        | 50                 | 480                | Present(50)  | GI                                  |   | 180                 | 20.1                      | 3.3                                  | 3                           | 8                                | 8                         | 440                       | 80                        | 141-02           | 17-5               | Comparative example |
| 9   | I           | 800                        | 40                 | 480                | Absent       | GA                                  | 530   | 120                 | 13.3                      | 3.6                                  | 2                           | 10                               | 2                         | 500                       | 70                        | 132-34           | 14-9               | Comparative example |
| 10  | J           | 790                        | 100                | 490                | Absent       | GA                                  | 540   | 130                 | 18.8                      | 4.0                                  | 2                           | 4                                | 3                         | 390                       | 80                        | 121-26           | 16-0               | Comparative example |

(continued)

| No. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step                    |   | Second cooling step |                           |                                      |                             |                                  |                           | Reheating cooling         |                           |                  |                    | Note                |
|-----|-------------|----------------------------|--------------------|--------------------|--------------|-------------------------------------|---|---------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|------------------|--------------------|---------------------|
|     |             | Annealing temperature (°C) | Annealing time (s) |                    |              | First cooling stop temperature (°C) | Presence or absence of holding (holding time (s)) | Type                | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C) | Tempering time (s) |                     |
| 11  | <u>K</u>    | 850                        | 40                 | 470                | Absent       | GA                                  | 580   | 250                 | 12.6                      | 3.4                                  | 2                           | 8                                | 7                         | 310                       | 130                       | 104-65           | 15-4               | Comparative example |
| 12  | <u>L</u>    | 840                        | 90                 | 480                | Present(40)  | GA                                  | 500   | 240                 | 62                        | 22                                   | 3                           | 6                                | 9                         | 430                       | 40                        | 130-34           | 16-6               | Comparative example |
| 13  | <u>M</u>    | 810                        | 90                 | 510                | Present(10)  | GI                                  |   | 200                 | 16.4                      | 3.3                                  | 2                           | 8                                | 7                         | 460                       | 90                        | 134-47           | 16-0               | Comparative example |
| 14  | B           | <u>760</u>                 | 140                | 450                | Absent       | GA                                  | 550   | 110                 | 21.6                      | 3.0                                  | 2                           | 5                                | 2                         | 410                       | 60                        | 117-37           | 15-1               | Comparative example |
| 15  | B           | <u>920</u>                 | 50                 | 480                | Absent       | GI                                  |   | 180                 | 19.3                      | 2.5                                  | 3                           | 5                                | 3                         | 450                       | 20                        | 128-83           | 16-3               | Comparative example |
| 16  | B           | 800                        | <u>5</u>           | 460                | Absent       | GA                                  | 600   | 260                 | 14.1                      | 3.5                                  | 3                           | 6                                | 6                         | 470                       | 140                       | 135-27           | 15-6               | Comparative example |
| 17  | B           | 830                        | 20                 | <u>380</u>         | Present(50)  | GI                                  |   | 240                 | 7.5                       | 2.6                                  | 2                           | 8                                | 7                         | 340                       | 430                       | 111-16           | 16-2               | Comparative example |
| 18  | B           | 890                        | 140                | <u>650</u>         | Present(10)  | GA                                  | 600   | 200                 | 18.1                      | 3.0                                  | 2                           | 7                                | 8                         | 430                       | 70                        | 121-94           | 16-3               | Comparative example |

(continued)

| No. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step                    |   | Second cooling step |                           |                                      |                             |                                  |                           | Reheating cooling         |                           |                  |                    | Note                |
|-----|-------------|----------------------------|--------------------|--------------------|--------------|-------------------------------------|---|---------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|------------------|--------------------|---------------------|
|     |             | Annealing temperature (°C) | Annealing time (s) |                    |              | First cooling step temperature (°C) | Presence or absence of holding (holding time (s)) | Type                | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C) | Tempering time (s) |                     |
| 19  | E           | 810                        | 250                | 470                | Absent       | GA                                  | 570   | <u>50</u>           | 11.0                      | 2.0                                  | 2                           | 8                                | 3                         | 500                       | 100                       | <u>144-61</u>    | 16-3               | Comparative example |
| 20  | E           | 790                        | 130                | 490                | Absent       | GI                                  |   | <u>400</u>          | 12.4                      | 3.3                                  | 1                           | 10                               | 7                         | 450                       | 60                        | <u>131-06</u>    | 16-0               | Comparative example |
| 21  | E           | 850                        | 90                 | 490                | Present(10)  | GA                                  | 530   | 140                 | <u>30.0</u>               | 3.0                                  | 3                           | 8                                | 3                         | 400                       | 30                        | <u>122-48</u>    | 16-4               | Comparative example |
| 22  | E           | 860                        | 100                | 500                | Absent       | GA                                  | 540   | 250                 | 18.8                      | 22                                   | 3                           | 7                                | 9                         | <u>200</u>                | 900                       | <u>9446</u>      | 16-4               | Comparative example |
| 23  | E           | 840                        | 110                | 460                | Present(40)  | GA                                  | 560   | 100                 | 8.0                       | 2.9                                  | 2                           | 8                                | 5                         | <u>600</u>                | 60                        | <u>162-03</u>    | 16-4               | Comparative example |
| 24  | E           | 830                        | 50                 | 450                | Absent       | GI                                  |   | 160                 | 6.8                       | 2.1                                  | 1                           | 6                                | 4                         | 420                       | 5                         | <u>119-26</u>    | 16-4               | Comparative example |
| 25  | E           | 820                        | 130                | 470                | Present(30)  | GA                                  | 530   | 290                 | 24.3                      | 3.4                                  | 2                           | 9                                | 10                        | 490                       | <u>1000</u>               | <u>152-26</u>    | 16-4               | Comparative example |
| 26  | E           | 780                        | 160                | 490                | Present(20)  | GA                                  | 560   | 120                 | 10.5                      | 2.0                                  | 2                           | 9                                | 5                         | 320                       | 20                        | <u>103-09</u>    | 15-8               | Comparative example |

(continued)

| No. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step                    |   | Second cooling step |                           |                                      |                             |                                  |                           |                           | Reheating cooling         |                  |                    |                     | Note |
|-----|-------------|----------------------------|--------------------|--------------------|--------------|-------------------------------------|---|---------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|------------------|--------------------|---------------------|------|
|     |             | Annealing temperature (°C) | Annealing time (s) |                    |              | First cooling stop temperature (°C) | Presence or absence of holding (holding time (s)) | Type                | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C) | Tempering time (s) | CP (-)              |      |
| 27  | E           | 840                        | 80                 | 470                | Absent       | GI                                  |   | 270                 | 18.9                      | 2.8                                  | 1                           | 7                                | 6                         | 500                       | 330                       | 150-21           | 16-4               | Comparative example |      |
| 28  | F           | 800                        | 120                | 430                | Present(10)  | GA                                  | 530   | 170                 | 152                       | 0.3                                  | 1                           | 10                               | 6                         | 350                       | 150                       | 117-95           | 16-3               | Comparative example |      |
| 29  | F           | 780                        | 60                 | 530                | Present(30)  | GA                                  | 500   | 240                 | 18.3                      | 0.0                                  | 0                           | 4                                | 7                         | 310                       | 60                        | 106-77           | 16-2               | Comparative example |      |
| 30  | F           | 810                        | 110                | 400                | Present(70)  | GI                                  |   | 260                 | 8.8                       | 2.0                                  | 3                           | 2                                | 10                        | 320                       | 90                        | 111-53           | 16-5               | Comparative example |      |
| 31  | F           | 850                        | 120                | 530                | Present(20)  | GA                                  | 530   | 270                 | 5.7                       | 3.1                                  | 3                           | 7                                | 0                         | 420                       | 40                        | 127-99           | 16-5               | Comparative example |      |

\*1: Tension applied in the temperature range of 300°C or more and 450°C or less

\*2: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll

\*3: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for half the circumference of the roll

[Table 2-2]

| N. o. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step |                           | Second cooling step                  |                             |                                  |                           |                           |                           | Reheating cooling |                    |        |       | Note              |
|-------|-------------|----------------------------|--------------------|--------------------|--------------|------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|-------------------|--------------------|--------|-------|-------------------|
|       |             | Annealing temperature (°C) | Annealing time (s) |                    |              | Type             | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C)  | Tempering time (s) | CP (-) | k (-) |                   |
| 32    | N           | 830                        | 120                | 490                | Absent       | GA               | 510                       | 140                                  | 7.5                         | 2.9                              | 2                         | 7                         | 6                         | 440               | 80                 | 132-76 | 16-3  | Inventive example |
| 33    | O           | 840                        | 100                | 500                | Absent       | GA               | 540                       | 160                                  | 13.5                        | 2.1                              | 3                         | 7                         | 3                         | 430               | 140                | 134-41 | 16-5  | Inventive example |
| 34    | P           | 840                        | 130                | 480                | Absent       | GI               | -                         | 260                                  | 23.7                        | 2.4                              | 2                         | 8                         | 5                         | 370               | 30                 | 118-58 | 16-7  | Inventive example |
| 35    | Q           | 850                        | 60                 | 480                | Absent       | GA               | 530                       | 250                                  | 52                          | 2.5                              | 1                         | 9                         | 4                         | 400               | 60                 | 126-62 | 16-7  | Inventive example |
| 36    | R           | 825                        | 60                 | 470                | Present(50)  | GA               | 510                       | 200                                  | 9.3                         | 2.7                              | 1                         | 4                         | 5                         | 410               | 70                 | 127-37 | 16-4  | Inventive example |
| 37    | S           | 800                        | 30                 | 500                | Present(60)  | GI               | -                         | 130                                  | 15.6                        | 22                               | 1                         | 9                         | 2                         | 450               | 60                 | 129-91 | 15-8  | Inventive example |
| 38    | T           | 800                        | 100                | 480                | Absent       | GA               | 580                       | 140                                  | 8.4                         | 2.1                              | 1                         | 9                         | 3                         | 310               | 70                 | 106-08 | 16-0  | Inventive example |
| 39    | U           | 810                        | 20                 | 440                | Absent       | GA               | 540                       | 120                                  | 16.0                        | 2.5                              | 2                         | 10                        | 3                         | 360               | 80                 | 113-52 | 15-6  | Inventive example |

(continued)

| N. o. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step |                           | Second cooling step                  |                             |                                  |                           |                           |                           | Reheating cooling |                    |        |       | Note   |      |                   |
|-------|-------------|----------------------------|--------------------|--------------------|--------------|------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|-------------------|--------------------|--------|-------|--------|------|-------------------|
|       |             | Annealing temperature (°C) | Annealing time (s) |                    |              | Type             | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C)  | Tempering time (s) | CP (-) | k (-) |        |      |                   |
| 40    | V           | 820                        | 70                 | 500                | Absent       | GA               | 560                       | 150                                  | 19.9                        | 2.3                              | 3                         | 6                         | 3                         | 6                 | 3                  | 490    | 80    | 143-10 | 16-5 | Inventive example |
| 41    | W           | 830                        | 80                 | 470                | Absent       | GI               | -                         | 230                                  | 9.2                         | 3.6                              | 3                         | 5                         | 7                         | 5                 | 7                  | 460    | 100   | 140-10 | 16-7 | Inventive example |
| 42    | X           | 820                        | 20                 | 410                | Present(30)  | GA               | 510                       | 250                                  | 6.6                         | 2.0                              | 3                         | 4                         | 9                         | 4                 | 9                  | 360    | 140   | 115-92 | 15-7 | Inventive example |
| 43    | Y           | 830                        | 60                 | 500                | Absent       | GA               | 560                       | 170                                  | 22.4                        | 3.9                              | 1                         | 9                         | 10                        | 9                 | 10                 | 310    | 70    | 108-15 | 16-3 | Inventive example |
| 44    | Z           | 810                        | 30                 | 460                | Absent       | GI               | -                         | 290                                  | 25.0                        | 3.9                              | 2                         | 8                         | 4                         | 8                 | 4                  | 380    | 80    | 123-04 | 16-6 | Inventive example |
| 45    | AA          | 790                        | 50                 | 440                | Absent       | GA               | 550                       | 160                                  | 6.4                         | 2.5                              | 3                         | 7                         | 9                         | 7                 | 9                  | 340    | 20    | 107-59 | 16-0 | Inventive example |
| 46    | AB          | 820                        | 90                 | 480                | Absent       | GA               | 530                       | 120                                  | 12.8                        | 2.2                              | 2                         | 9                         | 3                         | 9                 | 3                  | 430    | 50    | 126-40 | 15-9 | Inventive example |
| 47    | AC          | 880                        | 50                 | 500                | Present(10)  | GA               | 520                       | 200                                  | 8.8                         | 3.1                              | 2                         | 8                         | 8                         | 8                 | 8                  | 360    | 60    | 121-62 | 17-1 | Inventive example |

(continued)

| N. o. | Stel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step |                           | Second cooling step                  |                             |                                  |                           |                           |                           | Reheating cooling |                    |        |       | Note              |
|-------|------------|----------------------------|--------------------|--------------------|--------------|------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|-------------------|--------------------|--------|-------|-------------------|
|       |            | Annealing temperature (°C) | Annealing time (s) |                    |              | Type             | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C)  | Tempering time (s) | CP (-) | k (-) |                   |
| 48    | AD         | 810                        | 90                 | 420                | Present(70)  | GA               | 580                       | 100                                  | 7.2                         | 3.7                              | 1                         | 7                         | 2                         | 390               | 40                 | 120-85 | 16-3  | Inventive example |
| 49    | AE         | 800                        | 140                | 480                | Present(20)  | GI               | -                         | 200                                  | 17.3                        | 32                               | 2                         | 8                         | 7                         | 410               | 70                 | 126-27 | 16-3  | Inventive example |
| 50    | AF         | 840                        | 100                | 470                | Present(60)  | GA               | 500                       | 300                                  | 10.4                        | 2.8                              | 1                         | 9                         | 3                         | 410               | 210                | 131-96 | 16-5  | Inventive example |
| 51    | AG         | 800                        | 30                 | 500                | Absent       | GI               |                           | 170                                  | 19.9                        | 3.9                              | 1                         | 6                         | 5                         | 440               | 80                 | 128-69 | 15-8  | Inventive example |
| 52    | AH         | 820                        | 70                 | 490                | Absent       | GA               | 560                       | 270                                  | 12.6                        | 3.6                              | 1                         | 9                         | 9                         | 320               | 110                | 113-06 | 16-6  | Inventive example |
| 53    | AI         | 820                        | 100                | 470                | Present(10)  | GA               | 570                       | 180                                  | 24.3                        | 2.4                              | 2                         | 9                         | 7                         | 480               | 50                 | 141-16 | 16-7  | Inventive example |
| 54    | AJ         | 870                        | 40                 | 490                | Absent       | GA               | 580                       | 200                                  | 13.8                        | 2.5                              | 3                         | 7                         | 2                         | 430               | 140                | 131-34 | 16-1  | Inventive example |
| 55    | AK         | 840                        | 30                 | 500                | Absent       | GA               | 550                       | 110                                  | 5.6                         | 3.7                              | 1                         | 10                        | 8                         | 310               | 130                | 110-83 | 16-5  | Inventive example |

(continued)

| No. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step |                           | Second cooling step                  |                             |                                  |                           |                           |                           | Reheating cooling |                    |        | Note |                   |
|-----|-------------|----------------------------|--------------------|--------------------|--------------|------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|-------------------|--------------------|--------|------|-------------------|
|     |             | Annealing temperature (°C) | Annealing time (s) |                    |              | Type             | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C)  | Tempering time (s) | CP (-) |      | k (-)             |
| 56  | AL          | 830                        | 70                 | 480                | Absent       | GA               | 500                       | 230                                  | 9.6                         | 3.7                              | 2                         | 9                         | 6                         | 320               | 50                 | 108-04 | 16-2 | Inventive example |
| 57  | AM          | 860                        | 40                 | 460                | Absent       | GI               | -                         | 270                                  | 16.0                        | 2.5                              | 2                         | 5                         | 8                         | 390               | 70                 | 126-85 | 16-9 | Inventive example |
| 58  | AN          | 820                        | 100                | 440                | Absent       | GI               | -                         | 190                                  | 11.8                        | 3.6                              | 2                         | 9                         | 6                         | 330               | 100                | 112-51 | 16-3 | Inventive example |
| 59  | AO          | 810                        | 80                 | 490                | Present(30)  | GA               | 520                       | 110                                  | 7.3                         | 2.0                              | 1                         | 5                         | 6                         | 380               | 70                 | 123-15 | 16-6 | Inventive example |
| 60  | AP          | 830                        | 50                 | 470                | Present(10)  | GA               | 540                       | 240                                  | 15.1                        | 2.7                              | 1                         | 6                         | 5                         | 370               | 100                | 118-55 | 16-0 | Inventive example |
| 61  | AQ          | 790                        | 130                | 510                | Present(20)  | GA               | 560                       | 160                                  | 19.8                        | 3.3                              | 1                         | 8                         | 5                         | 390               | 60                 | 119-53 | 15-9 | Inventive example |
| 62  | R           | 840                        | 160                | 490                | Present(60)  | GI               | -                         | 100                                  | 7.5                         | 3.0                              | 3                         | 7                         | 7                         | 490               | 40                 | 140-26 | 16-5 | Inventive example |

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(continued)

| No. | Steel grade | Annealing step             |                    | First cooling step | Holding step | Galvanizing step |                           | Second cooling step                  |                             |                                  |                           |                           |                           | Reheating cooling |                    |        | Note |                   |
|-----|-------------|----------------------------|--------------------|--------------------|--------------|------------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|---------------------------|---------------------------|-------------------|--------------------|--------|------|-------------------|
|     |             | Annealing temperature (°C) | Annealing time (s) |                    |              | Type             | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Temperature (°C)  | Tempering time (s) | CP (-) |      | k (-)             |
| 63  | R           | 830                        | 220                | 480                | Absent       | GA               | 530                       | 260                                  | 7.9                         | 2.9                              | 3                         | 4                         | 7                         | 420               | 260                | 134-05 | 16-4 | Inventive example |

1: Tension applied in the temperature range of 300 °C or more and 450 °C or less

\*2: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll

\*3: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for half the circumference of the roll

[Table 3-1]

| No. | Steel grade | Sheet thickness (mm) | Steel microstructure           |        |        |        |                                    |                        |                           |                           |   |   | Note                |
|-----|-------------|----------------------|--------------------------------|--------|--------|--------|------------------------------------|------------------------|---------------------------|---------------------------|---|---|---------------------|
|     |             |                      | Area fraction of each phase *1 |        |        |        | Microstructure of the remainder *1 |                        | C <sub>M</sub> *2 (mass%) | C <sub>γ</sub> *3 (mass%) | ρ <sub>c</sub> *4 (particles /μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) |                     |
|     |             |                      | BF (%)                         | TM (%) | RA (%) | FM (%) | Type                               | Area fraction of P (%) |                           |                           |   |   |                     |
| 1   | A           | 1.2                  | 5.6                            | 81.0   | 6.8    | 2.6    | F,θ                                | -                      | 0.082                     | 0.65                      | 1.70  | 0.30  | Inventive example   |
| 2   | B           | 1.6                  | 7.4                            | 64.1   | 3.8    | 6.5    | F,θ                                | -                      | 0.286                     | 0.89                      | 7.00  | 0.12  | Inventive example   |
| 3   | C           | 1.2                  | 10.3                           | 53.5   | 9.8    | 6.4    | F                                  | -                      | 0.389                     | 0.91                      | 5.20  | 0.21  | Inventive example   |
| 4   | D           | 1.2                  | 17.9                           | 61.5   | 6.8    | 6.7    | F,LB                               | -                      | 0.257                     | 1.09                      | 2.60  | 0.21  | Inventive example   |
| 5   | E           | 1.8                  | 8.7                            | 59.7   | 5.5    | 8.2    | F,LB                               | -                      | 0.251                     | 0.72                      | 3.80  | 0.09  | Inventive example   |
| 6   | F           | 1.2                  | 14.2                           | 54.9   | 10.0   | 5.7    | F,LB                               | -                      | 0.233                     | 0.77                      | 5.60  | 0.27  | Inventive example   |
| 7   | G           | 1.6                  | 9.6                            | 71.7   | 6.1    | 4.5    | F,LB                               | -                      | 0.335                     | 1.03                      | 7.30  | 0.15  | Inventive example   |
| 8   | H           | 1.8                  | 19.2                           | 43.8   | 5.6    | 11.8   | F,θ                                | -                      | 0.051                     | 0.58                      | 1.10  | 0.27  | Comparative example |
| 9   | I           | 1.8                  | 7.9                            | 61.0   | 9.5    | 7.6    | F,P,θ                              | 1.2                    | 0.482                     | 1.15                      | 6.70  | 0.05  | Comparative example |
| 10  | J           | 1.8                  | 9.3                            | 75.1   | 2.3    | 8.6    | F                                  | -                      | 0.299                     | 0.55                      | 9.10  | 0.09  | Comparative example |
| 11  | K           | 1.6                  | 5.9                            | 30.8   | 15.8   | 5.1    | F,LB                               | -                      | 0.398                     | 1.19                      | 0.80  | 0.16  | Comparative example |
| 12  | L           | 1.4                  | 16.7                           | 45.8   | 8.9    | 8.6    | F,LB                               | -                      | 0.197                     | 0.61                      | 4.40  | 0.16  | Comparative example |
| 13  | M           | 1.2                  | 13.3                           | 42.4   | 14.7   | 16.9   | F,θ                                | -                      | 0.300                     | 1.05                      | 3.00  | 0.27  | Comparative example |
| 14  | B           | 1.2                  | 3.5                            | 28.4   | 13.6   | 10.6   | F                                  | -                      | 0.458                     | 0.66                      | 6.60  | 0.22  | Comparative example |
| 15  | B           | 1.6                  | 4.6                            | 87.2   | 2.7    | 5.5    | -                                  | -                      | 0.257                     | 0.69                      | 4.50  | 0.29  | Comparative example |
| 16  | B           | 1.2                  | 13.2                           | 38.8   | 11.1   | 6.9    | F,θ                                | -                      | 0.362                     | 1.13                      | 4.20  | 0.28  | Comparative example |
| 17  | B           | 1.2                  | 26.5                           | 40.3   | 15.4   | 8.9    | F,LB                               | -                      | 0.274                     | 0.82                      | 6.10  | 0.08  | Comparative example |
| 18  | B           | 1.8                  | 5.4                            | 80.8   | 2.5    | 5.3    | P                                  | 6.0                    | 0.257                     | 0.98                      | 5.80  | 0.27  | Comparative example |
| 19  | E           | 1.6                  | 8.6                            | 75.2   | 2.3    | 1.4    | F,θ                                | -                      | 0.249                     | 0.86                      | 3.60  | 0.09  | Comparative example |
| 20  | E           | 1.6                  | 19.8                           | 1.5    | 12.6   | 38.7   | F,θ                                | -                      | 0.301                     | 0.79                      | 4.50  | 0.16  | Comparative example |
| 21  | E           | 1.4                  | 5.6                            | 88.3   | 2.9    | 3.2    | -                                  | -                      | 0.229                     | 0.73                      | 9.70  | 0.18  | Comparative example |
| 22  | E           | 1.8                  | 5.7                            | 7.3    | 1.2    | 85.8   | -                                  | -                      | 0.229                     | 0.55                      | 8.20  | 0.67  | Comparative example |

(continued)

| No. | Steel grade | Sheet thickness (mm) | Steel microstructure           |        |        |        |                                    |                        |                           |                           |   |   | Note                |
|-----|-------------|----------------------|--------------------------------|--------|--------|--------|------------------------------------|------------------------|---------------------------|---------------------------|---|---|---------------------|
|     |             |                      | Area fraction of each phase *1 |        |        |        | Microstructure of the remainder *1 |                        | C <sub>M</sub> *2 (mass%) | C <sub>γ</sub> *3 (mass%) | ρ <sub>C</sub> *4 (particles /μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) |                     |
|     |             |                      | BF (%)                         | TM (%) | RA (%) | FM (%) | Type                               | Area fraction of P (%) |                           |                           |   |   |                     |
| 23  | E           | 1.4                  | 13.2                           | 76.4   | 2.3    | 1.4    | 0, LB, P                           | 2.5                    | 0.229                     | 0.72                      | 2.60  | 0.28  | Comparative example |
| 24  | E           | 1.4                  | 4.0                            | 37.4   | 1.8    | 49.9   | F, LB                              | -                      | 0.238                     | 0.57                      | 6.40  | 0.72  | Comparative example |
| 25  | E           | 1.4                  | 30.8                           | 47.8   | 5.3    | 2.5    | 0, P                               | 0.5                    | 0.241                     | 1.20                      | 2.70  | 0.21  | Comparative example |
| 26  | E           | 1.8                  | 6.9                            | 40.2   | 2.2    | 17.8   | F, LB                              | -                      | 0.329                     | 0.98                      | 8.50  | 0.65  | Comparative example |
| 27  | E           | 1.2                  | 14.5                           | 75.7   | 2.1    | 1.5    | 0, LB, P                           | 2.8                    | 0.232                     | 0.77                      | 0.50  | 0.21  | Comparative example |
| 28  | F           | 1.8                  | 19.7                           | 43.4   | 8.6    | 13.1   | F                                  | -                      | 0.247                     | 1.09                      | 5.10  | 0.29  | Comparative example |
| 29  | F           | 1.4                  | 13.6                           | 40.5   | 8.4    | 14.9   | F                                  | -                      | 0.270                     | 0.96                      | 7.40  | 0.10  | Comparative example |
| 30  | F           | 1.6                  | 25.5                           | 46.6   | 9.7    | 10.4   | F, LB                              | -                      | 0.223                     | 0.81                      | 7.60  | 0.24  | Comparative example |
| 31  | F           | 1.8                  | 21.5                           | 53.0   | 8.2    | 14.3   | LB                                 | -                      | 0.209                     | 0.83                      | 5.90  | 0.26  | Comparative example |

\*1: BF; bainitic ferrite, TM; tempered martensite, RA; retained austenite, FM; fresh martensite, F; ferrite, LB; lower bainite, P; pearlite, 0; carbide

\*2: C<sub>M</sub>; the carbon concentration of martensite formed in the second cooling step

\*3: C<sub>γ</sub>; the concentration of carbon in retained austenite

\*4: ρ<sub>C</sub>; the density of carbides in tempered martensite

[Table 3-2]

| No. | Steel grade | Sheet thickness (mm) | Steel microstructure           |        |        |        |                                    |                        |                           |                           |  |   | Note |                   |
|-----|-------------|----------------------|--------------------------------|--------|--------|--------|------------------------------------|------------------------|---------------------------|---------------------------|--|---|------|-------------------|
|     |             |                      | Area fraction of each phase *1 |        |        |        | Microstructure of the remainder *1 |                        | C <sub>M</sub> *2 (mass%) | C <sub>γ</sub> *3 (mass%) | ρ <sub>c</sub> *4 (particles/μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) |      |                   |
|     |             |                      | BF (%)                         | TM (%) | RA (%) | FM (%) | Type                               | Area fraction of P (%) |                           |                           |  |   |      |                   |
| 32  | N           | 1.2                  | 5.8                            | 71.0   | 6.5    | 4.0    | 4.0                                | F, LB                  | -                         | 0.244                     | 0.85   | 4.80  | 0.19 | Inventive example |
| 33  | O           | 1.4                  | 10.3                           | 70.4   | 5.8    | 4.2    | 4.2                                | F, θ                   | -                         | 0.209                     | 1.13   | 3.30  | 0.21 | Inventive example |
| 34  | P           | 1.8                  | 15.8                           | 61.6   | 10.5   | 4.4    | 4.4                                | F                      | -                         | 0.189                     | 0.79   | 2.80  | 0.26 | Inventive example |
| 35  | Q           | 1.6                  | 9.8                            | 63.2   | 9.1    | 7.4    | 7.4                                | F, LB                  | -                         | 0.187                     | 0.90   | 3.80  | 0.30 | Inventive example |
| 36  | R           | 1.4                  | 7.3                            | 69.3   | 5.7    | 7.7    | 7.7                                | F, LB                  | -                         | 0.227                     | 0.96   | 4.30  | 0.05 | Inventive example |
| 37  | S           | 1.6                  | 13.3                           | 62.2   | 8.2    | 7.7    | 7.7                                | F, θ                   | -                         | 0.328                     | 0.89   | 6.50  | 0.20 | Inventive example |
| 38  | T           | 1.0                  | 11.5                           | 48.3   | 10.2   | 6.7    | 6.7                                | F, LB                  | -                         | 0.303                     | 1.04   | 7.60  | 0.29 | Inventive example |
| 39  | U           | 0.8                  | 4.2                            | 61.5   | 9.3    | 8.2    | 8.2                                | F                      | -                         | 0.358                     | 0.89   | 5.50  | 0.20 | Inventive example |
| 40  | V           | 1.8                  | 6.7                            | 62.3   | 6.8    | 5.6    | 5.6                                | F, θ                   | -                         | 0.221                     | 0.90   | 5.10  | 0.17 | Inventive example |
| 41  | W           | 1.8                  | 7.7                            | 61.8   | 7.8    | 9.8    | 9.8                                | F, LB, θ               | -                         | 0.181                     | 1.08   | 4.50  | 0.12 | Inventive example |
| 42  | X           | 1.6                  | 17.5                           | 47.2   | 12.2   | 5.0    | 5.0                                | F, LB                  | -                         | 0.344                     | 0.83   | 6.60  | 0.21 | Inventive example |
| 43  | Y           | 1.6                  | 7.4                            | 76.5   | 5.3    | 3.9    | 3.9                                | F                      | -                         | 0.244                     | 0.80   | 5.00  | 0.27 | Inventive example |
| 44  | Z           | 1.8                  | 12.6                           | 59.1   | 8.8    | 3.6    | 3.6                                | F                      | -                         | 0.207                     | 0.72   | 4.70  | 0.28 | Inventive example |
| 45  | AA          | 1.2                  | 6.9                            | 52.2   | 5.5    | 7.6    | 7.6                                | F, LB                  | -                         | 0.302                     | 0.74   | 6.20  | 0.13 | Inventive example |
| 46  | AB          | 1.8                  | 3.1                            | 66.2   | 6.4    | 5.6    | 5.6                                | F, LB                  | -                         | 0.310                     | 0.81   | 6.60  | 0.26 | Inventive example |
| 47  | AC          | 1.2                  | 10.1                           | 75.3   | 5.3    | 6.3    | 6.3                                | LB                     | -                         | 0.120                     | 0.68   | 5.60  | 0.14 | Inventive example |
| 48  | AD          | 1.4                  | 8.2                            | 73.1   | 6.7    | 3.6    | 3.6                                | F, LB                  | -                         | 0.249                     | 1.01   | 7.80  | 0.15 | Inventive example |
| 49  | AE          | 1.6                  | 8.6                            | 56.2   | 8.6    | 4.8    | 4.8                                | F                      | -                         | 0.254                     | 0.99   | 3.50  | 0.24 | Inventive example |
| 50  | AF          | 1.4                  | 19.1                           | 57.5   | 9.5    | 1.9    | 1.9                                | LB                     | -                         | 0.211                     | 0.77   | 7.30  | 0.20 | Inventive example |
| 51  | AG          | 1.2                  | 9.2                            | 49.7   | 8.3    | 6.3    | 6.3                                | F, θ                   | -                         | 0.339                     | 0.72   | 5.80  | 0.25 | Inventive example |
| 52  | AH          | 1.4                  | 10.5                           | 55.7   | 7.7    | 5.9    | 5.9                                | F, LB, θ               | -                         | 0.197                     | 0.93   | 5.40  | 0.22 | Inventive example |
| 53  | AI          | 1.6                  | 12.7                           | 57.8   | 6.3    | 4.1    | 4.1                                | F, θ                   | -                         | 0.182                     | 0.97   | 3.00  | 0.24 | Inventive example |

(continued)

| No. | Steel grade | Sheet thickness (mm) | Steel microstructure           |        |        |        |                                    |                        |                           |                           |  |   | Note |                   |
|-----|-------------|----------------------|--------------------------------|--------|--------|--------|------------------------------------|------------------------|---------------------------|---------------------------|--|---|------|-------------------|
|     |             |                      | Area fraction of each phase *1 |        |        |        | Microstructure of the remainder *1 |                        | C <sub>M</sub> *2 (mass%) | C <sub>γ</sub> *3 (mass%) | ρ <sub>C</sub> *4 (particles/μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) |      |                   |
|     |             |                      | BF (%)                         | TM (%) | RA (%) | FM (%) | Type                               | Area fraction of P (%) |                           |                           |  |   |      |                   |
| 54  | AJ          | 1.2                  | 9.4                            | 74.0   | 5.4    | 4.2    | 4.2                                | LB,θ                   | -                         | 0.282                     | 0.93   | 7.10  | 0.25 | Inventive example |
| 55  | AK          | 1.6                  | 5.1                            | 66.5   | 7.2    | 8.4    | 8.4                                | F,LB                   | -                         | 0.221                     | 0.88   | 6.10  | 0.24 | Inventive example |
| 56  | AL          | 1.4                  | 13.1                           | 60.9   | 6.5    | 5.2    | 5.2                                | F,LB                   | -                         | 0.270                     | 1.01   | 7.20  | 0.22 | Inventive example |
| 57  | AM          | 1.2                  | 17.2                           | 64.7   | 8.5    | 9.6    | 9.6                                |                        | -                         | 0.147                     | 0.87   | 4.90  | 0.07 | Inventive example |
| 58  | AN          | 1.2                  | 8.2                            | 62.7   | 5.9    | 7.0    | 7.0                                | F,LB                   | -                         | 0.257                     | 0.72   | 6.20  | 0.14 | Inventive example |
| 59  | AO          | 1.8                  | 10.0                           | 59.5   | 9.1    | 1.2    | 1.2                                | F,LB                   | -                         | 0.192                     | 0.99   | 5.80  | 0.24 | Inventive example |
| 60  | AP          | 1.4                  | 14.1                           | 64.0   | 8.6    | 6.9    | 6.9                                | F                      | -                         | 0.294                     | 0.66   | 6.70  | 0.10 | Inventive example |
| 61  | AQ          | 1.2                  | 5.7                            | 56.7   | 7.4    | 7.0    | 7.0                                | F                      | -                         | 0.318                     | 1.03   | 6.40  | 0.27 | Inventive example |
| 62  | R           | 2.6                  | 10.4                           | 64.8   | 7.2    | 2.3    | 2.3                                | F,θ                    | -                         | 0.223                     | 0.71   | 4.90  | 0.28 | Inventive example |
| 63  | R           | 3.2                  | 14.4                           | 63.9   | 8.7    | 3.7    | 3.7                                | F,θ                    | -                         | 0.226                     | 0.91   | 5.20  | 0.26 | Inventive example |

\*1: BF; bainitic ferrite, TM; tempered martensite, RA; retained austenite, FM; fresh martensite, F; ferrite, LB; lower bainite, P; pearlite, θ; carbide

\*2: C<sub>M</sub>; the carbon concentration of martensite formed in the second cooling step

\*3: C<sub>γ</sub>; the concentration of carbon in retained austenite

\*4: ρ<sub>C</sub>; the density of carbides in tempered martensite

EP 4 502 195 A1

[Table 4-1]

| No | Steel grade | YS (MPa)   | TS (MPa)    | EI (%)      | $\lambda$ (%) | $\alpha$ (°) | $S_{Fmax}$ (mm) | Crack length *1 ( $\mu$ m) | Change in grain size of BF *2 (-) | Axial compression | Note                |
|----|-------------|------------|-------------|-------------|---------------|--------------|-----------------|----------------------------|-----------------------------------|-------------------|---------------------|
| 1  | A           | 945        | 1310        | 13.2        | 74            | 102          | 29.1            | 87                         | 1.6                               | A                 | Inventive example   |
| 2  | B           | 1099       | 1220        | 14.7        | 59            | 81           | 27.7            | 128                        | 2.0                               | A                 | Inventive example   |
| 3  | C           | 955        | 1273        | 16.7        | 45            | 89           | 26.8            | 209                        | 3.1                               | B                 | Inventive example   |
| 4  | D           | 875        | 1189        | 14.4        | 76            | 92           | 28.7            | 91                         | 1.6                               | A                 | Inventive example   |
| 5  | E           | 1024       | 1187        | 14.5        | 61            | 85           | 27.5            | 138                        | 2.3                               | A                 | Inventive example   |
| 6  | F           | 968        | 1305        | 19.4        | 56            | 95           | 26.9            | 207                        | 2.9                               | B                 | Inventive example   |
| 7  | G           | 1151       | 1353        | 13.4        | 71            | 82           | 26.9            | 203                        | 2.9                               | A                 | Inventive example   |
| 8  | <u>H</u>    | <u>732</u> | <u>1090</u> | 14.7        | 40            | 81           | <u>25.5</u>     | 297                        | 4.3                               | <u>D</u>          | Comparative example |
| 9  | <u>I</u>    | 1105       | 1298        | 18.9        | <u>25</u>     | 86           | <u>24.7</u>     | 383                        | 4.8                               | <u>D</u>          | Comparative example |
| 10 | <u>J</u>    | 940        | 1268        | <u>10.5</u> | 75            | 88           | 28.7            | 97                         | 1.7                               | A                 | Comparative example |
| 11 | <u>K</u>    | <u>699</u> | <u>1120</u> | 22.8        | <u>22</u>     | 90           | <u>24.4</u>     | <u>401</u>                 | <u>5.1</u>                        | <u>D</u>          | Comparative example |
| 12 | <u>L</u>    | <u>721</u> | <u>1108</u> | 18.9        | 47            | 85           | 26.1            | 249                        | 3.7                               | C                 | Comparative example |
| 13 | <u>M</u>    | 1087       | 1310        | 19.4        | <u>13</u>     | 83           | <u>22.1</u>     | <u>472</u>                 | <u>5.3</u>                        | <u>D</u>          | Comparative example |
| 14 | B           | <u>608</u> | <u>975</u>  | 24.4        | <u>26</u>     | 93           | <u>25.6</u>     | 289                        | 4.2                               | <u>D</u>          | Comparative example |
| 15 | B           | 1085       | 1290        | <u>9.2</u>  | 85            | 86           | 28.6            | 98                         | 1.8                               | A                 | Comparative example |
| 16 | B           | <u>669</u> | <u>1052</u> | 19.1        | <u>29</u>     | 89           | <u>25.2</u>     | 316                        | 4.4                               | <u>D</u>          | Comparative example |
| 17 | B           | 816        | 1182        | 18.4        | <u>22</u>     | 91           | <u>24.9</u>     | 397                        | 4.8                               | <u>D</u>          | Comparative example |
| 18 | B           | 1068       | 1290        | <u>7.2</u>  | 87            | 90           | 29.5            | 66                         | 1.1                               | A                 | Comparative example |
| 19 | E           | 1097       | 1302        | <u>11.4</u> | 78            | 85           | 28.0            | 115                        | 2.0                               | A                 | Comparative example |
| 20 | E           | <u>655</u> | 1189        | 17.         | <u>15</u>     | 82           | <u>24.7</u>     | 381                        | 4.8                               | <u>D</u>          | Comparative         |
|    |             |            |             | 3           |               |              |                 |                            |                                   |                   | example             |
| 21 | E           | 1022       | 1280        | <u>6.1</u>  | 92            | 93           | 29.2            | 73                         | 1.5                               | A                 | Comparative example |

EP 4 502 195 A1

(continued)

| No | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | $S_{Fmax}$ (mm) | Crack length *1 ( $\mu$ m) | Change in grain size of BF *2 (-) | Axial compression | Note                |
|----|-------------|----------|----------|--------|---------------|--------------|-----------------|----------------------------|-----------------------------------|-------------------|---------------------|
| 22 | E           | 1254     | 1439     | 3.6    | 24            | 65           | 22.9            | 457                        | 6.5                               | D                 | Comparative example |
| 23 | E           | 769      | 1132     | 7.6    | 29            | 69           | 23.1            | 451                        | 5.3                               | D                 | Comparative example |
| 24 | E           | 1144     | 1334     | 5.9    | 26            | 62           | 22.6            | 466                        | 5.7                               | D                 | Comparative example |
| 25 | E           | 727      | 1099     | 11.9   | 41            | 81           | 26.2            | 248                        | 3.3                               | C                 | Comparative example |
| 26 | E           | 761      | 1190     | 15.5   | 25            | 70           | 23.3            | 404                        | 5.3                               | D                 | Comparative example |
| 27 | E           | 886      | 1105     | 9.8    | 10.3          | 72           | 29.9            | 56                         | 1.2                               | A                 | Comparative example |
| 28 | F           | 975      | 1303     | 17.7   | 26            | 83           | 25.8            | 268                        | 4.2                               | D                 | Comparative example |
| 29 | F           | 857      | 1210     | 19.5   | 22            | 91           | 24.7            | 359                        | 4.5                               | D                 | Comparative example |
| 30 | F           | 928      | 1297     | 14.6   | 32            | 78           | 25.9            | 267                        | 4.1                               | D                 | Comparative example |
| 31 | F           | 836      | 1222     | 12.8   | 29            | 76           | 25.5            | 293                        | 4.3                               | D                 | Comparative example |

\*1: The crack length ( $\mu$ m) in an L cross section in a V-VDA bending test performed to the maximum load point  
 \*2: In a region formed from each position on a starting line present from a starting point of a bending peak on the outside of a VDA bend to a position of 50  $\mu$ m in the thickness direction up to a position of 50  $\mu$ m on each side of the starting line perpendicular to the starting line, with respect to an average grain size of bainitic ferrite in the thickness direction, the ratio of the average grain size before processing to the average grain size after the processing

[Table 4-2]

| No. | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | $S_{Fmax}$ (mm) | Crack length *1 ( $\mu$ m) | Change in grain size of BF *2 (-) | Axial compression | Note              |
|-----|-------------|----------|----------|--------|---------------|--------------|-----------------|----------------------------|-----------------------------------|-------------------|-------------------|
| 32  | N           | 1030     | 1207     | 13.7   | 72            | 97           | 28.4            | 101                        | 1.9                               | A                 | Inventive example |
| 33  | O           | 815      | 1219     | 13.5   | 87            | 98           | 29.5            | 64                         | 1.2                               | A                 | Inventive example |
| 34  | P           | 757      | 1274     | 16.1   | 59            | 92           | 27.6            | 129                        | 2.2                               | A                 | Inventive example |
| 35  | Q           | 1039     | 1266     | 14.4   | 58            | 93           | 28.8            | 88                         | 1.6                               | A                 | Inventive example |
| 36  | R           | 1066     | 1295     | 14.0   | 55            | 86           | 28.6            | 97                         | 1.8                               | A                 | Inventive example |
| 37  | S           | 1162     | 1357     | 13.3   | 54            | 82           | 26.5            | 217                        | 3.2                               | A                 | Inventive example |

EP 4 502 195 A1

(continued)

| No. | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | $S_{Fmax}$ (mm) | Crack length *1 ( $\mu\text{m}$ ) | Change in grain size of BF *2 (-) | Axial compression | Note |                   |
|-----|-------------|----------|----------|--------|---------------|--------------|-----------------|-----------------------------------|-----------------------------------|-------------------|------|-------------------|
| 5   | 38          | T        | 757      | 1224   | 16.2          | 43           | 84              | 26.4                              | 219                               | 3.2               | C    | Inventive example |
| 10  | 39          | U        | 874      | 1206   | 16.9          | 39           | 82              | 26.0                              | 260                               | 3.9               | C    | Inventive example |
|     | 40          | V        | 1025     | 1262   | 15.7          | 48           | 86              | 27.2                              | 158                               | 2.5               | B    | Inventive example |
| 15  | 41          | W        | 786      | 1238   | 15.1          | 40           | 83              | 26.2                              | 244                               | 3.3               | C    | Inventive example |
|     | 42          | X        | 1063     | 1291   | 14.5          | 31           | 80              | 26.1                              | 249                               | 3.4               | C    | Inventive example |
| 20  | 43          | Y        | 1063     | 1209   | 14.6          | 53           | 94              | 26.9                              | 195                               | 2.5               | B    | Inventive example |
|     | 44          | Z        | 920      | 1286   | 18.6          | 35           | 90              | 26.0                              | 254                               | 3.9               | C    | Inventive example |
| 25  | 45          | AA       | 881      | 1294   | 19.0          | 59           | 95              | 27.7                              | 125                               | 2.0               | A    | Inventive example |
|     | 46          | AB       | 884      | 1294   | 16.3          | 46           | 91              | 26.9                              | 196                               | 2.8               | B    | Inventive example |
| 30  | 47          | AC       | 1037     | 1264   | 12.6          | 83           | 96              | 28.9                              | 88                                | 1.6               | A    | Inventive example |
|     | 48          | AD       | 772      | 1225   | 13.8          | 63           | 93              | 27.8                              | 124                               | 2.0               | A    | Inventive example |
| 35  | 49          | AE       | 860      | 1290   | 19.9          | 35           | 90              | 26.6                              | 212                               | 3.2               | C    | Inventive example |
|     | 50          | AF       | 819      | 1264   | 14.0          | 49           | 85              | 27.3                              | 148                               | 2.4               | B    | Inventive example |
| 40  | 51          | AG       | 838      | 1248   | 19.4          | 34           | 90              | 26.3                              | 223                               | 3.3               | C    | Inventive example |
|     | 52          | AH       | 796      | 1205   | 14.6          | 64           | 92              | 28.3                              | 105                               | 1.9               | A    | Inventive example |
| 45  | 53          | AI       | 827      | 1226   | 15.6          | 63           | 94              | 28.4                              | 101                               | 1.9               | A    | Inventive example |
|     | 54          | AJ       | 834      | 1220   | 12.6          | 86           | 89              | 29.2                              | 70                                | 1.3               | A    | Inventive example |
| 50  | 55          | AK       | 1013     | 1237   | 13.6          | 80           | 99              | 28.7                              | 95                                | 1.7               | A    | Inventive example |
|     | 56          | AL       | 773      | 1249   | 12.6          | 76           | 87              | 28.5                              | 100                               | 1.8               | A    | Inventive example |
| 55  | 57          | AM       | 852      | 1316   | 12.0          | 68           | 86              | 28.2                              | 106                               | 1.9               | A    | Inventive example |
|     | 58          | AN       | 869      | 1263   | 15.3          | 63           | 96              | 28.1                              | 108                               | 2.0               | A    | Inventive example |
|     | 59          | AO       | 983      | 1254   | 17.           | 45           | 10              | 27.0                              | 177                               | 2.5               | B    | Inventive         |

EP 4 502 195 A1

(continued)

| No. | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | $S_{Fmax}$ (mm) | Crack length *1 ( $\mu\text{m}$ ) | Change in grain size of BF *2 (-) | Axial compression | Note              |
|-----|-------------|----------|----------|--------|---------------|--------------|-----------------|-----------------------------------|-----------------------------------|-------------------|-------------------|
|     |             |          |          | 7      |               | 1            |                 |                                   |                                   |                   | example           |
| 60  | AP          | 976      | 1320     | 14.9   | 63            | 97           | 27.6            | 129                               | 2.1                               | A                 | Inventive example |
| 61  | AQ          | 875      | 1277     | 19.4   | 50            | 99           | 26.6            | 210                               | 3.1                               | B                 | Inventive example |
| 62  | R           | 944      | 1283     | 15.9   | 59            | 89           | 27.5            | 131                               | 2.2                               | A                 | Inventive example |
| 63  | R           | 763      | 1276     | 14.8   | 63            | 91           | 28.0            | 110                               | 2.0                               | A                 | Inventive example |

\*1: The crack length ( $\mu\text{m}$ ) in an L cross section in a V-VDA bending test performed to the maximum load point

\*2: In a region formed from each position on a starting line present from a starting point of a bending peak on the outside of a VDA bend to a position of 50  $\mu\text{m}$  in the thickness direction up to a position of 50  $\mu\text{m}$  on each side of the starting line perpendicular to the starting line, with respect to an average grain size of bainitic ferrite in the thickness direction, the ratio of the average grain size before processing to the average grain size after the processing

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[Table 5]

| No. | Steel grade | First coating step                                      | Annealing step                          |                                    |                                    | First cooling step                                   | Holding step  | Coating step                         |           | Second cooling step                                   |  |  |   |   |   | Reheating cooling                          |                            |            |           | Note                           |
|-----|-------------|---|---|------------------------------------|------------------------------------|--|---|--------------------------------------|-----------|---|--|--|---|---|---|--|----------------------------|------------|-----------|--------------------------------|
|     |             | Pre-<br>sence or<br>ab-<br>sence<br>(Coat-<br>ing type) | Anneal-<br>ing tem-<br>perature<br>(°C) | An-<br>neal-<br>ing<br>time<br>(s) | D-<br>ew<br>po-<br>int<br>(°<br>C) | First<br>cooling<br>stop<br>tem-<br>perature<br>(°C) | Pre-<br>sence or<br>ab-<br>sence of<br>holding<br>(holding<br>time) (s) | Alloying<br>tem-<br>perature<br>(°C) | Ty-<br>pe | Second<br>cooling<br>stop<br>tem-<br>perature<br>(°C) | Aver-<br>age<br>cool-<br>ing<br>rate<br>(°C/s) | Ten-<br>sion *1<br>(kgf/m-<br>m <sup>2</sup> ) | Appli-<br>cation<br>fre-<br>quency<br>(-) | Num-<br>ber of<br>pas-<br>ses 1<br>*2 (-) | Num-<br>ber of<br>pas-<br>ses 2<br>*3 (-) | Temper-<br>ing<br>tem-<br>perature<br>(°C) | Tem-<br>pering<br>time (s) | CP<br>(-)  | k<br>(-)  | Inven-<br>tive<br>exam-<br>ple |
| 64  | E           | Absent  | 830                                     | 70                                 | -15                                | 470  | Absent  | 510                                  | GA        | 240   | 5.6  | 3.0  | 3   | 6   | 2   | 390  | 50                         | 121-<br>69 | 16-<br>.3 | Inven-<br>tive<br>exam-<br>ple |
| 65  | E           | Absent  | 820                                     | 50                                 | 10                                 | 500  | Pre-<br>sent(20)  | -                                    | GI        | 220   | 5.4  | 3.3  | 3   | 4   | 3   | 360  | 20                         | 112-<br>85 | 16-<br>.3 | Inven-<br>tive<br>exam-<br>ple |
| 66  | E           | Pre-<br>sent(Fe)  | 820                                     | 60                                 | -15                                | 480  | Absent  | -                                    | GI        | 250   | 8.0  | 3.3  | 1   | 7   | 3   | 390  | 40                         | 120-<br>83 | 16-<br>.3 | Inven-<br>tive<br>exam-<br>ple |
| 67  | E           | Pre-<br>sent(Fe)  | 830                                     | 50                                 | 10                                 | 490  | Absent  | 520                                  | GA        | 240   | 8.4  | 2.9  | 1   | 5   | 4   | 380  | 50                         | 119-<br>78 | 16-<br>.3 | Inven-<br>tive<br>exam-<br>ple |
| 68  | E           | Present<br>(Ni)   | 810                                     | 90                                 | 10                                 | 490  | Present<br>(10)   | -                                    | GI        | 230   | 7.2  | 3.0  | 2   | 6   | 4   | 400  | 40                         | 122-<br>48 | 16-<br>.3 | Inven-<br>tive<br>exam-<br>ple |
| 69  | G           | Absent  | 800                                     | 50                                 | -12                                | 480  | Absent  | -                                    | GI        | 220   | 7.6  | 2.0  | 3   | 4   | 8   | 420  | 70                         | 124-<br>71 | 15-<br>.8 | Inven-<br>tive<br>exam-<br>ple |

(continued)

| No. | Steel grade | First coating step                 |                            | Annealing step     |                |                                     | First cooling step                                | Holding step | Coating step              |                                      | Second cooling step         |                                  |                           |                         |                         |                            | Reheating cooling  |        |       |                   | Note |
|-----|-------------|------------------------------------|----------------------------|--------------------|----------------|-------------------------------------|---|--------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|-------------------------|-------------------------|----------------------------|--------------------|--------|-------|-------------------|------|
|     |             | Presence or absence (Coating type) | Annealing temperature (°C) | Annealing time (s) | Dew point (°C) | First cooling stop temperature (°C) | Presence or absence of holding (holding time) (s) | Type         | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes *2 (-) | Number of passes *3 (-) | Tempering temperature (°C) | Tempering time (s) | CP (-) | k (-) |                   |      |
| 70  | G           | Absent                             | 790                        | 60                 | 13             | 520                                 | Present (10)                                      | GA           | 500                       | 190                                  | 8.9                         | 2.0                              | 2                         | 7                       | 4                       | 410                        | 30                 | 119-30 | 15-7  | Inventive example |      |
| 71  | G           | Present(Fe)                        | 810                        | 50                 | -12            | 500                                 | Present (10)                                      | GI           | -                         | 210                                  | 10.0                        | 2.0                              | 4                         | 6                       | 9                       | 430                        | 50                 | 125-46 | 15-8  | Inventive example |      |
| 72  | G           | Present(Fe)                        | 790                        | 80                 | 13             | 470                                 | Absent  | GA           | 510                       | 220                                  | 8.0                         | 22                               | 3                         | 5                       | 8                       | 410                        | 60                 | 121-93 | 15-7  | Inventive example |      |
| 73  | G           | Present (Ni)                       | 790                        | 50                 | 13             | 530                                 | Present(20)                                       | GA           | 500                       | 200                                  | 9.2                         | 2.3                              | 4                         | 4                       | 7                       | 430                        | 50                 | 124-46 | 15-7  | Inventive example |      |
| 74  | R           | Absent                             | 825                        | 70                 | -15            | 470                                 | Present (10)                                      | GA           | 520                       | 210                                  | 9.0                         | 2.5                              | 3                         | 9                       | 4                       | 420                        | 50                 | 128-08 | 16-4  | Inventive example |      |
| 75  | R           | Absent                             | 815                        | 60                 | 10             | 480                                 | Present(20)                                       | GA           | 500                       | 200                                  | 7.8                         | 2.9                              | 2                         | 4                       | 3                       | 430                        | 90                 | 131-80 | 16-4  | Inventive example |      |

(continued)

| No. | Steel grade | First coating step                 |                            | Annealing step     |                |                                     | First cooling step                                | Holding step | Coating step              |                                      | Second cooling step         |                                  |                           |                         |                         |                            | Reheating cooling  |        |       | Note              |
|-----|-------------|------------------------------------|----------------------------|--------------------|----------------|-------------------------------------|---|--------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|-------------------------|-------------------------|----------------------------|--------------------|--------|-------|-------------------|
|     |             | Presence or absence (Coating type) | Annealing temperature (°C) | Annealing time (s) | Dew point (°C) | First cooling stop temperature (°C) | Presence or absence of holding (holding time) (s) | Type         | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes *2 (-) | Number of passes *3 (-) | Tempering temperature (°C) | Tempering time (s) | CP (-) | k (-) |                   |
| 76  | R           | Present(Fe)                        | 825                        | 50                 | -15            | 490                                 | Absent  | GA           | 530                       | 180                                  | 10.7                        | 2.9                              | 2                         | 4                       | 7                       | 400                        | 60                 | 124-80 | 16-4  | Inventive example |
| 77  | R           | Present(Fe)                        | 835                        | 80                 | 10             | 500                                 | Present(30)                                       | GA           | 500                       | 220                                  | 11.3                        | 2.6                              | 1                         | 9                       | 3                       | 410                        | 60                 | 127-07 | 16-5  | Inventive example |
| 78  | R           | Present(Ni)                        | 815                        | 70                 | 10             | 470                                 | Absent  | GA           | 530                       | 210                                  | 7.7                         | 2.6                              | 1                         | 5                       | 7                       | 400                        | 50                 | 124-18 | 16-4  | Inventive example |
| 79  | R           | Absent                             | 820                        | 230                | -15            | 470                                 | Absent  | GA           | 510                       | 250                                  | 6.7                         | 3.1                              | 4                         | 4                       | 7                       | 410                        | 280                | 132-25 | 16-4  | Inventive example |
| 80  | R           | Absent                             | 850                        | 220                | 10             | 480                                 | Absent  | GA           | 550                       | 280                                  | 7.0                         | 2.8                              | 4                         | 9                       | 9                       | 430                        | 240                | 136-44 | 16-6  | Inventive example |
| 81  | R           | Present(Fe)                        | 830                        | 230                | -15            | 460                                 | Absent  | GA           | 520                       | 240                                  | 6.6                         | 2.9                              | 2                         | 7                       | 7                       | 420                        | 200                | 133-14 | 16-5  | Inventive example |

(continued)

| No. | Steel grade | First coating step                 |                            | Annealing step     |               |                                     | First cooling step                                | Holding step | Coating step              |                                      | Second cooling step         |                                  |                           |                         |                         |                  | Reheating cooling  |        |       | Note              |
|-----|-------------|------------------------------------|----------------------------|--------------------|---------------|-------------------------------------|---|--------------|---------------------------|--------------------------------------|-----------------------------|----------------------------------|---------------------------|-------------------------|-------------------------|------------------|--------------------|--------|-------|-------------------|
|     |             | Presence or absence (Coating type) | Annealing temperature (°C) | Annealing time (s) | Dewpoint (°C) | First cooling stop temperature (°C) | Presence or absence of holding (holding time) (s) | Type         | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/m <sup>2</sup> ) | Application frequency (-) | Number of passes *2 (-) | Number of passes *3 (-) | Temperature (°C) | Tempering time (s) | CP (-) | k (-) |                   |
| 82  | R           | Present(Fe)                        | 840                        | 210                | 10            | 480                                 | Absent  | GA           | 540                       | 270                                  | 8.8                         | 2.8                              | 3                         | 9                       | 7                       | 400              | 240                | 130-08 | 16.5  | Inventive example |
| 83  | R           | Present(Ni)                        | 820                        | 240                | 10            | 490                                 | Present (10)                                      | GI           | -                         | 250                                  | 6.6                         | 2.7                              | 2                         | 4                       | 7                       | 440              | 240                | 137-57 | 16.4  | Inventive example |

\*1: Tension applied in the temperature range of 300°C or more and 450°C or less

\*2: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll

\*3: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for half the circumference of the roll

[Table 6]

| No.    | Steel grade | Sheet thickness (mm) | Steel microstructure           |      |                        |     |                                    |   |                   |                           | Surface layer | Metal coating weight (g/m <sup>2</sup> ) | Nanohardness of sheet surface                  |   |                           | Note |                                   |
|--------|-------------|----------------------|--------------------------------|------|------------------------|-----|------------------------------------|---|-------------------|---------------------------|---------------|--|--|---|---------------------------|------|-----------------------------------|
|        |             |                      | Area fraction of each phase *1 |      |                        |     | Microstructure of the remainder *1 |   | C <sub>M</sub> *2 | C <sub>γ</sub> *3 (mass%) |               |  | ρ <sub>c</sub> *4 (particles/μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) | Soft layer thickness (μm) |      | Ratio of Hn of 7.0 GPa or more *5 |
| BF (%) | TM (%)      | RA (%)               | FM (%)                         | Type | Area fraction of P (%) |     |                                    |   |                   |                           |               |  |  |   |                           |      |                                   |
| 64     | E           | 1.8                  | 15.1                           | 56.4 | 7.6                    | 6.1 | F <sub>1</sub> LB                  | - | 0.247             | 0.80                      | 420           | 0.20                                     | 8  | 0.19  | 1.9                       | 2.3  | Inventive example                 |
| 65     | E           | 1.8                  | 9.9                            | 612  | 7.8                    | 5.5 | F <sub>1</sub> LB                  | - | 0.256             | 0.71                      | 4.50          | 0.24                                     | 35   | 0.06  | 1.5                       | 1.6  | Inventive example                 |
| 66     | E           | 1.8                  | 12.7                           | 55.6 | 7.1                    | 8.9 | F <sub>1</sub> LB                  | - | 0.250             | 0.71                      | 3.60          | 0.28                                     | 9  | 0.20  | 1.6                       | 2.0  | Inventive example                 |
| 67     | E           | 1.8                  | 15.7                           | 57.8 | 6.9                    | 5.7 | F <sub>1</sub> LB                  | - | 0.249             | 0.80                      | 4.80          | 0.18                                     | 33   | 0.01  | 0.7                       | 0.8  | Inventive example                 |
| 68     | E           | 1.8                  | 9.2                            | 66.9 | 6.4                    | 5.3 | F <sub>1</sub> LB                  | - | 0.254             | 0.78                      | 4.70          | 0.10                                     | 34   | 0.02  | 0.8                       | 1.0  | Inventive example                 |
| 69     | G           | 1.4                  | 14.6                           | 65.8 | 7.0                    | 5.6 | F <sub>1</sub> LB                  | - | 0.336             | 0.99                      | 6.30          | 0.15                                     | 9  | 0.22  | 2.1                       | 2.4  | Inventive example                 |
| 70     | G           | 1.4                  | 6.8                            | 72.3 | 5.9                    | 5.2 | F <sub>1</sub> LB                  | - | 0.351             | 0.97                      | 6.80          | 0.23                                     | 27   | 0.10  | 1.6                       | 2.0  | Inventive example                 |
| 71     | G           | 1.4                  | 9.8                            | 70.8 | 5.8                    | 6.7 | F <sub>1</sub> LB                  | - | 0.332             | 0.93                      | 7.10          | 0.14                                     | 10   | 0.24  | 1.7                       | 2.1  | Inventive example                 |
| 72     | G           | 1.4                  | 10.2                           | 66.6 | 6.4                    | 6.8 | F <sub>1</sub> LB                  | - | 0.347             | 1.03                      | 7.10          | 0.09                                     | 28   | 0.04  | 0.8                       | 1.2  | Inventive example                 |
| 73     | G           | 1.4                  | 8.3                            | 70.1 | 6.9                    | 5.4 | F <sub>1</sub> LB                  | - | 0.356             | 0.93                      | 8.00          | 0.24                                     | 26   | 0.04  | 0.9                       | 1.3  | Inventive example                 |
| 74     | R           | 1.4                  | 10.2                           | 65.7 | 7.2                    | 7.8 | F                                  | - | 0.226             | 0.96                      | 500           | 0.14                                     | 10   | 0.16  | 2.0                       | 2.4  | Inventive example                 |
| 75     | R           | 1.4                  | 9.5                            | 65.5 | 7.4                    | 6.0 | F                                  | - | 0.233             | 1.05                      | 4.50          | 0.11                                     | 48   | 0.05  | 1.3                       | 1.4  | Inventive example                 |

(continued)

| No.    | Steel grade | Sheet thickness (mm) | Steel microstructure           |      |                        |     |                                    |   |                   | Surface layer             |  | Nanohardness of sheet surface               |                           |  | Note |                                   |  |   |
|--------|-------------|----------------------|--------------------------------|------|------------------------|-----|------------------------------------|---|-------------------|---------------------------|--|---|---------------------------|--|------|-----------------------------------|--|---|
|        |             |                      | Area fraction of each phase *1 |      |                        |     | Microstructure of the remainder *1 |   | C <sub>M</sub> *2 | C <sub>γ</sub> *3 (mass%) | ρ <sub>c</sub> *4 (particles/μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) | Soft layer thickness (μm) | Metal coating weight (g/m <sup>2</sup> ) |      | Ratio of Hn of 7.0 GPa or more *5 | Standard deviation of Hn at quarter position (GPa)*6 | Standard deviation of Hn at half position (GPa)*7 |
| BF (%) | TM (%)      | RA (%)               | FM (%)                         | Type | Area fraction of P (%) |     |                                    |   |                   |                           |  |   |                           |  |      |                                   |  |   |
| 76     | R           | 1.4                  | 8.9                            | 67.2 | 6.1                    | 6.1 | F, LB                              | - | 0.232             | 0.96                      | 500  | 0.09  | 10                        | 10                                       | 0.18 | 1.6                               | 1.9  | Inventive example                                 |
| 77     | R           | 1.4                  | 13.3                           | 64.6 | 7.2                    | 7.0 | F                                  | - | 0.222             | 0.93                      | 4.30   | 0.12  | 45                        | 10                                       | 0.03 | 0.4                               | 0.6  | Inventive example                                 |
| 78     | R           | 1.4                  | 11.4                           | 63.8 | 6.3                    | 5.9 | F, LB                              | - | 0.231             | 0.90                      | 3.80   | 0.13  | 47                        | 10                                       | 0.03 | 0.7                               | 1.0  | Inventive example                                 |
| 79     | R           | 32                   | 13.3                           | 64.7 | 7.1                    | 5.1 | F, θ                               | - | 0.229             | 0.92                      | 5.80   | 0.31  | 9                         | -  | 0.15 | 1.9                               | 2.3  | Inventive example                                 |
| 80     | R           | 32                   | 19.9                           | 66.9 | 6.5                    | 5.7 | F, θ                               | - | 0.208             | 0.97                      | 420  | 0.31  | 46                        | -  | 0.05 | 1.3                               | 1.7  | Inventive example                                 |
| 81     | R           | 32                   | 12.0                           | 68.6 | 6.9                    | 4.2 | F, LB, θ                           | - | 0.225             | 0.83                      | 5.60   | 0.17  | 8                         | 10                                       | 0.17 | 1.7                               | 1.9  | Inventive example                                 |
| 82     | R           | 32                   | 16.4                           | 64.4 | 7.8                    | 4.6 | F, θ                               | - | 0.221             | 0.92                      | 520  | 0.17  | 50                        | 10                                       | 0.02 | 0.5                               | 0.8  | Inventive example                                 |
| 83     | R           | 32                   | 11.3                           | 65.5 | 7.9                    | 5.8 | F, θ                               | - | 0.227             | 0.84                      | 520  | 0.32  | 49                        | 10                                       | 0.04 | 0.7                               | 0.9  | Inventive example                                 |

\*1: BF; bainitic ferrite, TM; tempered martensite, RA; retained austenite, FM; fresh martensite, F; ferrite, LB; lower bainite, P; pearlite, θ; carbide

\*2: C<sub>M</sub>: the carbon concentration of martensite formed in the second cooling step

\*3: C<sub>γ</sub>: the concentration of carbon in retained austenite

\*4: ρ<sub>c</sub>: the density of carbides in tempered martensite

\*5: The ratio of the number of measurements with a nanohardness of 7.0 GPa or more to the total number of measurements of nanohardness at a quarter depth position in the thickness direction of a surface soft layer from the surface of a base steel sheet

\*6: The standard deviation of the nanohardness of a sheet surface at a quarter position in the thickness direction of a surface soft layer from the surface of a base steel sheet

\*7: The standard deviation of the nanohardness of a sheet surface at a half position in the thickness direction of a surface soft layer from the surface of a base steel sheet

EP 4 502 195 A1

[Table 7]

| No. | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | SFmax (mm) | Crack length *1 ( $\mu$ m) | Change in grain size of BF *2 (-) | Axial compression | Note |                   |
|-----|-------------|----------|----------|--------|---------------|--------------|------------|----------------------------|-----------------------------------|-------------------|------|-------------------|
| 5   | 64          | E        | 866      | 1253   | 13.8          | 62           | 85         | 27.5                       | 125                               | 2.9               | B    | Inventive example |
| 10  | 65          | E        | 849      | 1190   | 14.9          | 59           | 100        | 29.2                       | 109                               | 2.5               | A    | Inventive example |
|     | 66          | E        | 866      | 1253   | 13.3          | 62           | 90         | 27.9                       | 120                               | 2.7               | A    | Inventive example |
| 15  | 67          | E        | 883      | 1228   | 12.9          | 63           | 112        | 30.5                       | 95                                | 1.9               | A    | Inventive example |
|     | 68          | E        | 899      | 1242   | 12.6          | 62           | 110        | 30.1                       | 99                                | 2.1               | A    | Inventive example |
| 20  | 69          | G        | 962      | 1407   | 11.0          | 74           | 83         | 26.9                       | 195                               | 2.1               | B    | Inventive example |
|     | 70          | G        | 935      | 1326   | 10.5          | 66           | 94         | 28.6                       | 176                               | 1.6               | A    | Inventive example |
| 25  | 71          | G        | 974      | 1423   | 10.8          | 73           | 87         | 27.5                       | 189                               | 1.9               | A    | Inventive example |
|     | 72          | G        | 935      | 1323   | 11.0          | 72           | 99         | 29.7                       | 162                               | 1.2               | A    | Inventive example |
| 30  | 73          | G        | 932      | 1322   | 12.4          | 67           | 96         | 29.5                       | 167                               | 1.3               | A    | Inventive example |
|     | 74          | R        | 935      | 1358   | 13.5          | 50           | 86         | 28.6                       | 108                               | 2.3               | B    | Inventive example |
| 35  | 75          | R        | 901      | 1260   | 14.5          | 54           | 97         | 30.2                       | 86                                | 1.8               | A    | Inventive example |
|     | 76          | R        | 914      | 1334   | 12.4          | 60           | 89         | 29.1                       | 103                               | 2.1               | A    | Inventive example |
| 40  | 77          | R        | 949      | 1309   | 12.9          | 58           | 109        | 31.6                       | 72                                | 1.4               | A    | Inventive example |
|     | 78          | R        | 904      | 1262   | 12.7          | 53           | 106        | 31.1                       | 78                                | 1.6               | A    | Inventive example |
| 45  | 79          | R        | 925      | 1247   | 13.7          | 58           | 91         | 28.0                       | 129                               | 1.8               | B    | Inventive example |
|     | 80          | R        | 1035     | 1242   | 12.1          | 58           | 106        | 29.9                       | 107                               | 1.4               | A    | Inventive example |
| 50  | 81          | R        | 940      | 1264   | 12.8          | 66           | 98         | 28.3                       | 123                               | 1.6               | A    | Inventive example |
|     | 82          | R        | 952      | 1252   | 13.8          | 61           | 119        | 31.0                       | 91                                | 1.0               | A    | Inventive example |

55

EP 4 502 195 A1

(continued)

| No. | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | SFmax (mm) | Crack length *1 ( $\mu$ m) | Change in grain size of BF *2 (-) | Axial compression | Note              |
|-----|-------------|----------|----------|--------|---------------|--------------|------------|----------------------------|-----------------------------------|-------------------|-------------------|
| 83  | R           | 920      | 1216     | 14.6   | 67            | 11.7         | 30.7       | 96                         | 1.1                               | A                 | Inventive example |

\*1: The crack length ( $\mu$ m) in an L cross section in a V-VDA bending test performed to the maximum load point  
 \*2: In a region formed from each position on a starting line present from a starting point of a bending peak on the outside of a VDA bend to a position of 50  $\mu$ m in the thickness direction up to a position of 50  $\mu$ m on each side of the starting line perpendicular to the starting line, with respect to an average grain size of bainitic ferrite in the thickness direction, the ratio of the average grain size before processing to the average grain size after the processing

[Table 8]

| No. | Steel grade | First coating step                 | Annealing step             |                    |                | First cooling step                  | Holding step                                      | Coating step |                           | Second cooling step                  |                             |                                   |                           |                           | Reheating cooling         |                            |                    |        | Note |                   |
|-----|-------------|------------------------------------|----------------------------|--------------------|----------------|-------------------------------------|---|--------------|---------------------------|--------------------------------------|-----------------------------|-----------------------------------|---------------------------|---------------------------|---------------------------|----------------------------|--------------------|--------|------|-------------------|
|     |             | Presence or absence (Coating type) | Annealing temperature (°C) | Annealing time (s) | Dew point (°C) | First cooling stop temperature (°C) | Presence or absence of holding (holding time) (s) | Type         | Alloying temperature (°C) | Second cooling stop temperature (°C) | Average cooling rate (°C/s) | Tension *1 (kgf/mm <sup>2</sup> ) | Application frequency (-) | Number of passes 1 *2 (-) | Number of passes 2 *3 (-) | Tempering temperature (°C) | Tempering time (s) | CP (-) |      | k (-)             |
| 84  | E           | Absent                             | 810                        | 70                 | -15            | 460                                 | Present (10)                                      | CR           | -                         | 230                                  | 6.0                         | 3.0                               | 2                         | 9                         | 4                         | 360                        | 40                 | 11562  | 16.3 | Inventive example |
| 85  | E           | Absent                             | 830                        | 90                 | 10             | 510                                 | Present (10)                                      | CR           | -                         | 220                                  | 6.7                         | 2.9                               | 3                         | 5                         | 6                         | 450                        | 40                 | 13165  | 16.3 | Inventive example |
| 86  | E           | Present (Fe)                       | 820                        | 70                 | -15            | 490                                 | Absent  | CR           | -                         | 240                                  | 7.5                         | 3.2                               | 4                         | 7                         | 6                         | 410                        | 80                 | 12728  | 16.4 | Inventive example |
| 87  | E           | Present (Fe)                       | 820                        | 90                 | 10             | 460                                 | Absent  | CR           | -                         | 230                                  | 6.1                         | 2.1                               | 3                         | 7                         | 3                         | 450                        | 80                 | 13406  | 16.3 | Inventive example |
| 88  | E           | Present (Ni)                       | 810                        | 90                 | 10             | 490                                 | Present (30)                                      | CR           | -                         | 220                                  | 9.7                         | 2.7                               | 1                         | 6                         | 7                         | 450                        | 40                 | 13214  | 16.4 | Inventive example |
| 89  | G           | Absent                             | 790                        | 90                 | -12            | 480                                 | Present (20)                                      | CR           | -                         | 190                                  | 8.3                         | 2.5                               | 3                         | 7                         | 4                         | 400                        | 80                 | 11918  | 15.4 | Inventive example |
| 90  | G           | Absent                             | 790                        | 60                 | 13             | 460                                 | Present (30)                                      | CR           | -                         | 190                                  | 9.7                         | 3.0                               | 1                         | 8                         | 4                         | 420                        | 60                 | 12188  | 15.5 | Inventive example |
| 91  | G           | Present (Fe)                       | 800                        | 80                 | -12            | 480                                 | Present (30)                                      | CR           | -                         | 220                                  | 7.0                         | 3.3                               | 2                         | 5                         | 4                         | 370                        | 90                 | 11493  | 15.5 | Inventive example |
| 92  | G           | Present (Fe)                       | 800                        | 70                 | 13             | 470                                 | Absent  | CR           | -                         | 190                                  | 5.8                         | 2.8                               | 3                         | 7                         | 5                         | 440                        | 70                 | 12702  | 15.6 | Inventive example |
| 93  | G           | Present (Ni)                       | 810                        | 50                 | 13             | 510                                 | Present (10)                                      | CR           | -                         | 220                                  | 7.0                         | 2.4                               | 3                         | 8                         | 6                         | 380                        | 70                 | 11677  | 15.7 | Inventive example |
| 94  | R           | Absent                             | 830                        | 80                 | -15            | 520                                 | Absent  | CR           | -                         | 180                                  | 8.6                         | 2.7                               | 1                         | 5                         | 8                         | 450                        | 60                 | 13391  | 16.4 | Inventive example |
| 95  | R           | Absent                             | 810                        | 50                 | 10             | 480                                 | Present (20)                                      | CR           | -                         | 210                                  | 6.2                         | 2.2                               | 4                         | 7                         | 9                         | 450                        | 60                 | 13378  | 16.4 | Inventive example |
| 96  | R           | Present (Fe)                       | 810                        | 80                 | -15            | 520                                 | Absent  | CR           | -                         | 210                                  | 6.9                         | 2.4                               | 4                         | 5                         | 8                         | 450                        | 50                 | 13375  | 16.5 | Inventive example |
| 97  | R           | Present (Fe)                       | 820                        | 50                 | 10             | 470                                 | Present (10)                                      | CR           | -                         | 220                                  | 10.2                        | 2.2                               | 4                         | 9                         | 8                         | 390                        | 70                 | 12311  | 16.4 | Inventive example |
| 98  | R           | Present (Ni)                       | 830                        | 80                 | 10             | 490                                 | Present (30)                                      | CR           | -                         | 220                                  | 5.5                         | 2.2                               | 1                         | 6                         | 3                         | 410                        | 60                 | 12576  | 16.3 | Inventive example |
| 99  | R           | Absent                             | 830                        | 220                | -15            | 460                                 | Present (20)                                      | HR           | -                         | 240                                  | 8.9                         | 2.8                               | 2                         | 5                         | 6                         | 370                        | 270                | 12470  | 16.5 | Inventive example |
| 100 | R           | Absent                             | 830                        | 230                | 10             | 480                                 | Present (30)                                      | HR           | -                         | 270                                  | 8.8                         | 3.3                               | 3                         | 6                         | 8                         | 390                        | 240                | 12748  | 16.4 | Inventive example |
| 101 | R           | Present (Fe)                       | 850                        | 220                | -15            | 500                                 | Present (10)                                      | HR           | -                         | 240                                  | 9.4                         | 2.3                               | 4                         | 9                         | 7                         | 410                        | 210                | 13056  | 16.3 | Inventive example |
| 102 | R           | Present (Fe)                       | 840                        | 230                | 10             | 520                                 | Present (30)                                      | HR           | -                         | 270                                  | 5.7                         | 3.3                               | 1                         | 8                         | 7                         | 380                        | 280                | 12668  | 16.5 | Inventive example |
| 103 | R           | Present (Ni)                       | 840                        | 240                | 10             | 520                                 | Absent  | HR           | -                         | 270                                  | 9.1                         | 3.0                               | 1                         | 9                         | 6                         | 380                        | 270                | 12568  | 16.3 | Inventive example |
| 104 | AR          | Absent                             | 820                        | 50                 | -15            | 460                                 | Present (20)                                      | CR           | -                         | 210                                  | 8.3                         | 2.0                               | 4                         | 5                         | 6                         | 430                        | 40                 | 12983  | 16.5 | Inventive example |
| 105 | AR          | Absent                             | 840                        | 50                 | 10             | 490                                 | Present (30)                                      | CR           | -                         | 220                                  | 5.6                         | 2.3                               | 4                         | 7                         | 6                         | 410                        | 50                 | 12681  | 16.5 | Inventive example |
| 106 | AR          | Present (Fe)                       | 840                        | 80                 | -15            | 460                                 | Present (10)                                      | CR           | -                         | 180                                  | 8.4                         | 2.5                               | 2                         | 7                         | 9                         | 400                        | 70                 | 12614  | 16.5 | Inventive example |
| 107 | AR          | Present (Fe)                       | 830                        | 70                 | 10             | 460                                 | Absent  | CR           | -                         | 200                                  | 9.4                         | 3.1                               | 2                         | 9                         | 4                         | 370                        | 70                 | 12076  | 16.6 | Inventive example |
| 108 | AR          | Present (Ni)                       | 820                        | 60                 | 10             | 470                                 | Present (30)                                      | CR           | -                         | 190                                  | 6.0                         | 3.3                               | 4                         | 9                         | 3                         | 420                        | 40                 | 12754  | 16.5 | Inventive example |
| 109 | U           | Absent                             | 810                        | 40                 | -15            | 480                                 | Absent  | GA           | 530                       | 150                                  | 15.0                        | 3.5                               | 3                         | 7                         | 4                         | 380                        | 60                 | 11788  | 15.9 | Inventive example |

\*1: Tension applied in the temperature range of 300°C or more and 450°C or less

\*2: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll

\*3: The number of passes, each pass involving contact between a steel sheet and a roll with a diameter of 500 mm or more and 1500 mm or less for half the circumference of the roll

[Table 9]

| No.    | Steel grade | Sheet thickness (mm) | Steel microstructure           |      |                        |     |                                    |   |                   | Surface layer             |  |   | Nanohardness of sheet surface |  |                                   | Note |  |   |
|--------|-------------|----------------------|--------------------------------|------|------------------------|-----|------------------------------------|---|-------------------|---------------------------|--|---|-------------------------------|--|-----------------------------------|------|--|---|
|        |             |                      | Area fraction of each phase *1 |      |                        |     | Microstructure of the remainder *1 |   | C <sub>M</sub> *2 | C <sub>γ</sub> *3 (mass%) | ρ <sub>c</sub> *4 (particles/μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) | Soft layer thickness (μm)     | Metal coating weight (g/m <sup>2</sup> ) | Ratio of Hn of 7.0 GPa or more *5 |      | Standard deviation of Hn at quarter position (GPa)*6 | Standard deviation of Hn at half position (GPa)*7 |
| BF (%) | TM (%)      | RA (%)               | FM (%)                         | Type | Area fraction of P (%) |     |                                    |   |                   |                           |  |   |                               |  |                                   |      |  |   |
| 84     | E           | 1.8                  | 5.7                            | 58.2 | 5.9                    | 4.1 | F,θ                                | - | 0.243             | 1.01                      | 4.20   | 0.32  | 5                             | -  | 0.21                              | 2.0  | 2.4  | Inventive example                                 |
| 85     | E           | 1.8                  | 9.2                            | 69.1 | 7.8                    | 5.7 | F, LB                              | - | 0.252             | 0.95                      | 6.60   | 0.24  | 36                            | -  | 0.09                              | 1.6  | 2.2  | Inventive example                                 |
| 86     | E           | 1.8                  | 5.1                            | 67.8 | 7.2                    | 7.2 | F                                  | - | 0.241             | 10.0                      | 5.10   | 0.31  | 6                             | 10                                       | 0.20                              | 1.4  | 2.1  | Inventive example                                 |
| 87     | E           | 1.8                  | 10.9                           | 61.0 | 5.1                    | 4.0 | F                                  | - | 0.257             | 0.95                      | 4.90   | 0.25  | 38                            | 10                                       | 0.05                              | 0.3  | 1.3  | Inventive example                                 |
| 88     | E           | 1.8                  | 5.0                            | 63.0 | 6.7                    | 7.0 | F, LB                              | - | 0.241             | 0.95                      | 6.50   | 0.11  | 41                            | 10                                       | 0.06                              | 0.5  | 1.0  | Inventive example                                 |
| 89     | G           | 1.4                  | 16.1                           | 65.5 | 6.3                    | 7.4 | F, LB                              | - | 0.396             | 1.13                      | 7.30   | 0.10  | 5                             | -  | 0.21                              | 2.2  | 2.4  | Inventive example                                 |
| 90     | G           | 1.4                  | 15.1                           | 57.4 | 5.1                    | 6.5 | F, LB                              | - | 0.391             | 1.18                      | 5.40   | 0.13  | 40                            | -  | 0.11                              | 1.8  | 1.8  | Inventive example                                 |
| 91     | G           | 1.4                  | 12.3                           | 69.4 | 6.5                    | 6.6 | F                                  | - | 0.379             | 1.08                      | 5.30   | 0.26  | 8                             | 13                                       | 0.18                              | 1.7  | 1.9  | Inventive example                                 |
| 92     | G           | 1.4                  | 9.4                            | 57.8 | 6.8                    | 6.3 | F                                  | - | 0.366             | 1.15                      | 6.70   | 0.25  | 41                            | 13                                       | 0.04                              | 0.8  | 1.3  | Inventive example                                 |
| 93     | G           | 1.4                  | 6.6                            | 59.7 | 6.5                    | 6.9 | F, LB                              | - | 0.355             | 1.10                      | 7.80   | 0.14  | 35                            | 13                                       | 0.06                              | 0.3  | 0.7  | Inventive example                                 |
| 94     | R           | 1.4                  | 12.1                           | 63.4 | 6.6                    | 6.1 | F, LB                              | - | 0.235             | 1.05                      | 4.60   | 0.25  | 9                             | -  | 0.18                              | 2.2  | 2.4  | Inventive example                                 |

(continued)

| No.    | Steel grade | Sheet thickness (mm) | Steel microstructure           |      |                        |                                    |                   |                   |                           | Surface layer                                  |   | Nanohardness of sheet surface |  |                                   | Note |  |   |                   |
|--------|-------------|----------------------|--------------------------------|------|------------------------|------------------------------------|-------------------|-------------------|---------------------------|--|---|-------------------------------|--|-----------------------------------|------|--|---|-------------------|
|        |             |                      | Area fraction of each phase *1 |      |                        | Microstructure of the remainder *1 |                   | C <sub>M</sub> *2 | C <sub>γ</sub> *3 (mass%) | ρ <sub>c</sub> *4 (particles/μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) | Softlayer thickness (μm)      | Metal coating weight (g/m <sup>2</sup> ) | Ratio of Hn of 7.0 GPa or more *5 |      | Standard deviation of Hn at quarter position (GPa)*6 | Standard deviation of Hn at half position (GPa)*7 |                   |
| BF (%) | TM (%)      | RA (%)               | FM (%)                         | Type | Area fraction of P (%) |                                    |                   |                   |                           |  |   |                               |  |                                   |      |  |   |                   |
| 95     | R           | 1.4                  | 13.2                           | 66.1 | 7.1                    | 6.4                                | F <sub>1</sub> LB | -                 | 0.238                     | 0.96   | 6.60  | 0.15                          | 36                                       | -                                 | 0.12 | 1.4  | 1.7   | Inventive example |
| 96     | R           | 1.4                  | 7.3                            | 68.2 | 7.9                    | 4.1                                | F <sub>0</sub>    | -                 | 0.223                     | 0.99   | 4.40  | 0.23                          | 7  | 10                                | 0.21 | 1.5  | 2.1   | Inventive example |
| 97     | R           | 1.4                  | 14.1                           | 59.2 | 6.9                    | 6.9                                | F <sub>1</sub> LB | -                 | 0.241                     | 0.96   | 8.00  | 0.23                          | 35                                       | 10                                | 0.04 | 0.7  | 1.1   | Inventive example |
| 98     | R           | 1.4                  | 18.3                           | 64.3 | 6.2                    | 6.9                                | F <sub>0</sub>    | -                 | 0.253                     | 1.05   | 6.50  | 0.26                          | 45                                       | 10                                | 0.03 | 0.4  | 1.0   | Inventive example |
| 99     | R           | 3.2                  | 6.2                            | 61.9 | 5.3                    | 8.0                                | F <sub>1</sub> LB | -                 | 0.221                     | 0.97   | 6.60  | 0.11                          | 10                                       | -                                 | 0.18 | 1.9  | 2.3   | Inventive example |
| 100    | R           | 3.2                  | 13.1                           | 67.7 | 6.3                    | 6.5                                | F                 | -                 | 0.238                     | 1.05   | 4.40  | 0.13                          | 44                                       | -                                 | 0.08 | 1.5  | 1.6   | Inventive example |
| 101    | R           | 3.2                  | 15.4                           | 59.1 | 6.2                    | 6.1                                | F                 | -                 | 0.245                     | 0.95   | 8.00  | 0.21                          | 6  | 10                                | 0.18 | 1.4  | 2.1   | Inventive example |
| 102    | R           | 3.2                  | 7.1                            | 60.0 | 7.4                    | 6.0                                | F                 | -                 | 0.223                     | 0.99   | 7.80  | 0.19                          | 40                                       | 10                                | 0.07 | 0.6  | 0.7   | Inventive example |
| 103    | R           | 3.2                  | 15.6                           | 65.9 | 5.7                    | 5.6                                | F <sub>1</sub> LB | -                 | 0.245                     | 1.04   | 3.60  | 0.32                          | 40                                       | 10                                | 0.07 | 0.5  | 0.8   | Inventive example |
| 104    | AR          | 1.4                  | 9.1                            | 65.9 | 6.3                    | 4.8                                | F <sub>1</sub> LB | -                 | 0.209                     | 0.98   | 4.00  | 0.23                          | 6  | -                                 | 0.15 | 2.0  | 2.4   | Inventive example |
| 105    | AR          | 1.4                  | 10.4                           | 65.7 | 6.8                    | 4.3                                | F <sub>0</sub>    | -                 | 0.212                     | 0.98   | 6.20  | 0.22                          | 37                                       | -                                 | 0.10 | 1.7  | 1.7   | Inventive example |

(continued)

| No.    | Steel grade | Sheet thickness (mm) | Steel microstructure           |      |                        |     |                                    |   |                   | Surface layer             |  | Nanohardness of sheet surface               |                           |  | Note |                                   |  |   |
|--------|-------------|----------------------|--------------------------------|------|------------------------|-----|------------------------------------|---|-------------------|---------------------------|--|---|---------------------------|--|------|-----------------------------------|--|---|
|        |             |                      | Area fraction of each phase *1 |      |                        |     | Microstructure of the remainder *1 |   | C <sub>M</sub> *2 | C <sub>γ</sub> *3 (mass%) | ρ <sub>c</sub> *4 (particles/μm <sup>2</sup> ) | Amount of diffusible hydrogen (ppm by mass) | Soft layer thickness (μm) | Metal coating weight (g/m <sup>2</sup> ) |      | Ratio of Hn of 7.0 GPa or more *5 | Standard deviation of Hn at quarter position (GPa)*6 | Standard deviation of Hn at half position (GPa)*7 |
| BF (%) | TM (%)      | RA (%)               | FM (%)                         | Type | Area fraction of P (%) |     |                                    |   |                   |                           |  |   |                           |  |      |                                   |  |   |
| 10 6   | AR          | 1.4                  | 10.3                           | 55.3 | 5.6                    | 5.0 | F, LB                              | - | 0.21 2            | 1.02                      | 5.00   | 0.20  | 8                         | 10                                       | 0.21 | 1.6                               | 1.8  | Inventive example                                 |
| 10 7   | AR          | 1.4                  | 7.6                            | 58.7 | 6.1                    | 6.7 | F, LB                              | - | 0.20 6            | 1.01                      | 8.00   | 0.25  | 42                        | 10                                       | 0.04 | 0.5                               | 1.3  | Inventive example                                 |
| 10 8   | AR          | 1.4                  | 13.5                           | 70.0 | 7.1                    | 5.0 | F, LB                              | - | 0.22 0            | 0.90                      | 7.00   | 0.24  | 43                        | 10                                       | 0.04 | 0.9                               | 1.1  | Inventive example                                 |
| 10 9   | U           | 0.9                  | 5.0                            | 65.6 | 6.2                    | 4.1 | F, LB, θ                           | - | 0.31 4            | 1.15                      | 7.50   | 0.19  | 6                         | -  | 0.22 | 2.3                               | 2.5  | Inventive example                                 |

\*1: BF; bainitic ferrite, TM; tempered martensite, RA; retained austenite, FM; fresh martensite, F; ferrite, LB; lower bainite, P; pearlite, θ; carbide

\*2: C<sub>M</sub>; the carbon concentration of martensite formed in the second cooling step

\*3: C<sub>γ</sub>; the concentration of carbon in retained austenite

\*4: ρ<sub>c</sub>; the density of carbides in tempered martensite

\*5: The ratio of the number of measurements with a nanohardness of 7.0 GPa or more to the total number of measurements of nanohardness at a quarter depth position in the thickness direction of a surface soft layer from the surface of a base steel sheet

\*6: The standard deviation a of the nanohardness of a sheet surface at a quarter position in the thickness direction of a surface soft layer from the surface of a base steel sheet

\*7: The standard deviation a of the nanohardness of a sheet surface at a half position in the thickness direction of a surface soft layer from the surface of a base steel sheet

EP 4 502 195 A1

[Table 10]

| No. | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | SFmax (mm) | Crack length *1 ( $\mu$ m) | Change in grain size of BF *2 (-) | Axial compression | Note |                   |
|-----|-------------|----------|----------|--------|---------------|--------------|------------|----------------------------|-----------------------------------|-------------------|------|-------------------|
| 5   | 84          | E        | 888      | 1206   | 12.9          | 50           | 86         | 27.8                       | 163                               | 1.2               | B    | Inventive example |
| 10  | 85          | E        | 882      | 1239   | 13.7          | 50           | 95         | 28.6                       | 136                               | 1.5               | A    | Inventive example |
|     | 86          | E        | 850      | 1225   | 13.8          | 66           | 95         | 29.2                       | 140                               | 2.9               | A    | Inventive example |
| 15  | 87          | E        | 859      | 1203   | 15.0          | 62           | 103        | 31.2                       | 78                                | 2.1               | A    | Inventive example |
|     | 88          | E        | 898      | 1244   | 14.6          | 53           | 116        | 31.1                       | 79                                | 2.8               | A    | Inventive example |
| 20  | 89          | G        | 972      | 1324   | 11.6          | 71           | 90         | 28.4                       | 163                               | 2.3               | B    | Inventive example |
|     | 90          | G        | 933      | 1322   | 10.6          | 70           | 94         | 29.3                       | 112                               | 1.9               | A    | Inventive example |
| 25  | 91          | G        | 938      | 1338   | 11.1          | 66           | 95         | 29.2                       | 127                               | 1.3               | A    | Inventive example |
|     | 92          | G        | 952      | 1377   | 12.1          | 74           | 114        | 30.8                       | 75                                | 2.0               | A    | Inventive example |
| 30  | 93          | G        | 961      | 1361   | 12.3          | 70           | 116        | 30.7                       | 86                                | 1.5               | A    | Inventive example |
|     | 94          | R        | 932      | 1277   | 12.9          | 52           | 88         | 28.2                       | 188                               | 2.0               | B    | Inventive example |
| 35  | 95          | R        | 905      | 1315   | 12.1          | 67           | 90         | 29.0                       | 131                               | 1.3               | A    | Inventive example |
|     | 96          | R        | 912      | 1306   | 12.2          | 65           | 93         | 29.3                       | 101                               | 2.8               | A    | Inventive example |
| 40  | 97          | R        | 944      | 1262   | 13.0          | 54           | 117        | 31.1                       | 90                                | 1.3               | A    | Inventive example |
|     | 98          | R        | 900      | 1314   | 12.9          | 55           | 112        | 31.1                       | 72                                | 2.5               | A    | Inventive example |
| 45  | 99          | R        | 1005     | 1227   | 13.5          | 68           | 86         | 28.0                       | 152                               | 2.9               | B    | Inventive example |
|     | 100         | R        | 936      | 1254   | 12.8          | 66           | 95         | 28.5                       | 127                               | 2.1               | A    | Inventive example |
| 50  | 101         | R        | 1015     | 1228   | 14.7          | 59           | 92         | 28.9                       | 113                               | 1.7               | A    | Inventive example |
|     | 102         | R        | 963      | 1228   | 13.0          | 68           | 102        | 29.9                       | 72                                | 1.5               | A    | Inventive example |
| 55  | 103         | R        | 941      | 1255   | 14.3          | 58           | 115        | 29.5                       | 77                                | 2.1               | A    | Inventive example |
|     | 104         | AR       | 940      | 1223   | 13.4          | 68           | 87         | 28.3                       | 160                               | 2.5               | B    | Inventive example |
|     | 105         | AR       | 960      | 1260   | 14.6          | 65           | 93         | 29.1                       | 128                               | 2.1               | A    | Inventive example |

(continued)

| No.  | Steel grade | YS (MPa) | TS (MPa) | EI (%) | $\lambda$ (%) | $\alpha$ (°) | SFmax (mm) | Crack length *1 ( $\mu\text{m}$ ) | Change in grain size of BF *2 (-) | Axial compression | Note              |
|--|-------------|----------|----------|--------|---------------|--------------|------------|-----------------------------------|-----------------------------------|-------------------|-------------------|
| 10 6   | AR          | 960      | 1258     | 14.3   | 58            | 92           | 28.6       | 124                               | 1.5                               | A                 | Inventive example |
| 10 7   | AR          | 937      | 1255     | 13.6   | 67            | 105          | 29.6       | 90                                | 1.7                               | A                 | Inventive example |
| 10 8   | AR          | 1003     | 1233     | 14.1   | 52            | 118          | 30.3       | 79                                | 1.7                               | A                 | Inventive example |
| 10 9   | U           | 880      | 1223     | 15.2   | 40            | 85           | 26.3       | 201                               | 2.8                               | C                 | Inventive example |
| <p>*1: The crack length (<math>\mu\text{m}</math>) in an L cross section in a V-VDA bending test performed to the maximum load point</p> <p>*2: In a region formed from each position on a starting line present from a starting point of a bending peak on the outside of a VDA bend to a position of 50 <math>\mu\text{m}</math> in the thickness direction up to a position of 50 <math>\mu\text{m}</math> on each side of the starting line perpendicular to the starting line, with respect to an average grain size of bainitic ferrite in the thickness direction, the ratio of the average grain size before processing to the average grain size after the processing</p> |             |          |          |        |               |              |            |                                   |                                   |                   |                   |

**[0339]** In Tables 1 to 10, the underlined portions indicate values outside the appropriate range of the present invention.

**[0340]** As shown in Tables 4, 7, and 10, all the inventive examples passed all the tensile strength (TS), the yield stress (YS), the total elongation (EI), the limiting hole expansion ratio ( $\lambda$ ), the critical bending angle ( $\alpha$ ) in the VDA bending test, and the stroke at the maximum load ( $S_{Fmax}$ ) in the V-VDA bending test, and had no fracture in the axial compression test.

**[0341]** In contrast, the comparative examples were not satisfactory in at least one of the tensile strength (TS), the yield stress (YS), the total elongation (EI), the limiting hole expansion ratio ( $\lambda$ ), the critical bending angle ( $\alpha$ ) in the VDA bending test, the stroke at the maximum load ( $S_{Fmax}$ ) in the V-VDA bending test, and the presence or absence of fracture in the axial compression test.

**[0342]** In Tables 5 to 10, at a dew point of  $-30^{\circ}\text{C}$  or more and  $-5^{\circ}\text{C}$  or less, although there were some cases where the soft layer had a thickness of less than 11  $\mu\text{m}$  and the fracture (appearance crack) in the axial compression test was rated as "B" or "C", even when the soft layer had a thickness of less than 11  $\mu\text{m}$ , in the presence of the metal coated layer, the fracture (appearance crack) in the axial compression test was rated as "A".

**[0343]** It was also found that the members produced by forming or joining the steel sheets of the inventive examples had good characteristics of the present invention in all of the tensile strength (TS), the yield stress (YS), the total elongation (EI), the limiting hole expansion ratio ( $\lambda$ ), the critical bending angle ( $\alpha$ ) in the VDA bending test, and the stroke at the maximum load ( $S_{Fmax}$ ) in the V-VDA bending test, had no fracture in the axial compression test, and had good characteristics of the present invention.

Reference Signs List

**[0344]**

- 10 hat-shaped member
- 20 galvanized steel sheet
- 30 test member
- 40 spot weld
- 50 base plate
- 60 impactor
- A1 die
- A2 support roll
- B1 punch
- B2 punch
- D1 width (C) direction
- D2 rolling (L) direction
- D3 compression direction
- D4 thickness direction

T1 test specimen

T2 test specimen

P maximum load point

R a region with the load being 94.9% to 99.9% of the maximum load when the stroke is increased from the maximum load point

AB a region of 0 to 50 μm from the surface of a steel sheet on the outside of a VDA bend and 50 μm on the left and right sides of a bending peak of the VDA bend in an L cross section in an overlap region of a V-bending ridge line portion and a VDA bending ridge line portion

AL an L cross section in an overlap region of a V-bending ridge line portion and a VDA bending ridge line portion

F ferrite

BF bainitic ferrite

BF1 bainitic ferrite before deformation

BF2 bainitic ferrite after deformation

TM tempered martensite

θ carbide

HI hard second phase

X1 island-like second phase

## Claims

1. A steel sheet comprising a base steel sheet, wherein the base steel sheet has a chemical composition containing, on a mass percent basis,

C: 0.050% or more and 0.400% or less,  
 Si: more than 0.75% and 3.00% or less,  
 Mn: 2.00% or more and less than 3.50%,  
 P: 0.001% or more and 0.100% or less,  
 S: 0.0001% or more and 0.0200% or less,  
 Al: 0.010% or more and 2.000% or less, and  
 N: 0.0100% or less,

with the remainder being Fe and incidental impurities,

the base steel sheet has a steel microstructure in which

an area fraction of bainitic ferrite: 3.0% or more and 20.0% or less,

an area fraction of tempered martensite: 40.0% or more and 90.0% or less,

an area fraction of retained austenite: more than 3.0% and 15.0% or less,

a concentration of carbon in retained austenite: 0.60% by mass or more and 1.30% by mass or less,

an area fraction of fresh martensite: 10.0% or less, and

a density of carbides in tempered martensite: 8.0 particles/μm<sup>2</sup> or less,

an amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less,

a V-VDA bending test is performed to a maximum load point,

in an L cross section,

a crack has a length of 400 μm or less,

in a region formed from each position on a starting line present from a starting point of a bending peak on an

outside of a VDA bend to a position of 50 μm in a thickness direction up to a position of 50 μm on each side of the

starting line perpendicular to the starting line,

with respect to an average grain size of bainitic ferrite in the thickness direction, a ratio of the average grain size

before processing to the average grain size after the processing is 5.0 or less, and

the steel sheet has a tensile strength of 1180 MPa or more.

2. The steel sheet according to Claim 1, wherein the base steel sheet has a chemical composition further containing, on a mass percent basis, at least one selected from

Nb: 0.200% or less,

Ti: 0.200% or less,

V: 0.200% or less,

B: 0.0100% or less,

Cr: 1.000% or less,

Ni: 1.000% or less,  
 Mo: 1.000% or less,  
 Sb: 0.200% or less,  
 Sn: 0.200% or less,  
 5 Cu: 1.000% or less,  
 Ta: 0.100% or less,  
 W: 0.500% or less,  
 Mg: 0.0200% or less,  
 Zn: 0.0200% or less,  
 10 Co: 0.0200% or less,  
 Zr: 0.1000% or less,  
 Ca: 0.0200% or less,  
 Se: 0.0200% or less,  
 Te: 0.0200% or less,  
 15 Ge: 0.0200% or less,  
 As: 0.0500% or less,  
 Sr: 0.0200% or less,  
 Cs: 0.0200% or less,  
 Hf: 0.0200% or less,  
 20 Pb: 0.0200% or less,  
 Bi: 0.0200% or less, and  
 REM: 0.0200% or less.

3. The steel sheet according to claim 1 or 2, comprising a galvanized layer as an outermost surface layer on one or both  
 25 surfaces of the steel sheet.

4. The steel sheet according to any one of Claims 1 to 3, wherein

30 when a region of 200  $\mu\text{m}$  or less from a surface of the base steel sheet in the thickness direction is defined as a surface layer,  
 the base steel sheet has, in the surface layer, a surface soft layer with a Vickers hardness of 85% or less with respect to a Vickers hardness at a quarter thickness position, and  
 when nanohardness is measured at 300 points or more in a 50  $\mu\text{m}$   $\times$  50  $\mu\text{m}$  region on a sheet surface at a quarter  
 35 depth position in the thickness direction and at a half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet,  
 a ratio of a number of measurements with a nanohardness of 7.0 GPa or more on the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet to a total number of measurements at the quarter depth position in the thickness direction of the surface soft layer is 0.10 or less,  
 40 the nanohardness of the sheet surface at the quarter depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet has a standard deviation  $\sigma$  of 1.8 GPa or less, and  
 the nanohardness of the sheet surface at the half depth position in the thickness direction of the surface soft layer from the surface of the base steel sheet has a standard deviation  $\sigma$  of 2.2 GPa or less.

45 5. The steel sheet according to any one of Claims 1 to 4, comprising a metal coated layer formed on the base steel sheet on one or both surfaces of the steel sheet.

6. A member comprising the steel sheet according to any one of Claims 1 to 5.

50 7. A method for producing a steel sheet, comprising:

a hot rolling step of hot-rolling a steel slab with the chemical composition according to Claim 1 or 2 to produce a hot-rolled steel sheet;  
 a pickling step of pickling the hot-rolled steel sheet;  
 55 an annealing step of annealing the steel sheet after the pickling step at an annealing temperature of  $(Ac_1 + 0.4 \times (Ac_3 - Ac_1))$  °C or more and 900°C or less for an annealing time of 20 seconds or more;  
 a first cooling step of cooling the steel sheet after the annealing step to a first cooling stop temperature of 400°C or more and 600°C or less;

a second cooling step of cooling the steel sheet after the first cooling step to a second cooling stop temperature of 100°C or more and 300°C or less at an average cooling rate of 25.0°C/s or less, during the cooling, applying a tension of 2.0 kgf/mm<sup>2</sup> or more to the steel sheet once or more in a temperature range of 300°C or more and 450°C or less,

5 then  
 10 subjecting the steel sheet to four or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for a quarter circumference of the roll, and  
 15 subjecting the steel sheet to two or more passes, each pass involving contact with a roll with a diameter of 500 mm or more and 1500 mm or less for half a circumference of the roll;  
 20 a reheating step of performing a reheat treatment of heating the steel sheet after the second cooling step to a tempering temperature range of more than 300°C and 500°C or less, holding the steel sheet in the temperature range for a tempering time of 20 seconds or more and 900 seconds or less, and setting a carbide control parameter CP represented by the following formula (1) to 10,000 or more and 15,000 or less during the reheat treatment; and  
 25 optionally a cold rolling step of cold-rolling the steel sheet after the pickling step and before the annealing step to produce a cold-rolled steel sheet,

$$CP = (T + 273) \times (k + 1.2 \times \log t) \quad \text{formula (1)}$$

30 wherein T denotes the tempering temperature (°C), k denotes a material constant depending on a C content, and t denotes the tempering time (second),

$$k = -6 \times C_M + 17.8,$$

35 wherein C<sub>M</sub> denotes a carbon concentration (% by mass) of martensite formed in the second cooling step.

8. The method for producing a steel sheet according to Claim 7, comprising a galvanizing step of performing a galvanizing treatment on the steel sheet to form a galvanized layer on the steel sheet after the first cooling step and before the second cooling step.
9. The method for producing a steel sheet according to Claim 7 or 8, wherein the annealing in the annealing step is performed in an atmosphere with a dew point of -30°C or more.
10. The method for producing a steel sheet according to any one of Claims 7 to 9, comprising a metal coating step of performing metal coating on one or both surfaces of the steel sheet to form a metal coated layer after the pickling step and before the annealing step.
11. A method for producing a member, comprising a step of subjecting the steel sheet according to any one of Claims 1 to 5 to at least one of forming and joining to produce a member.

FIG. 1

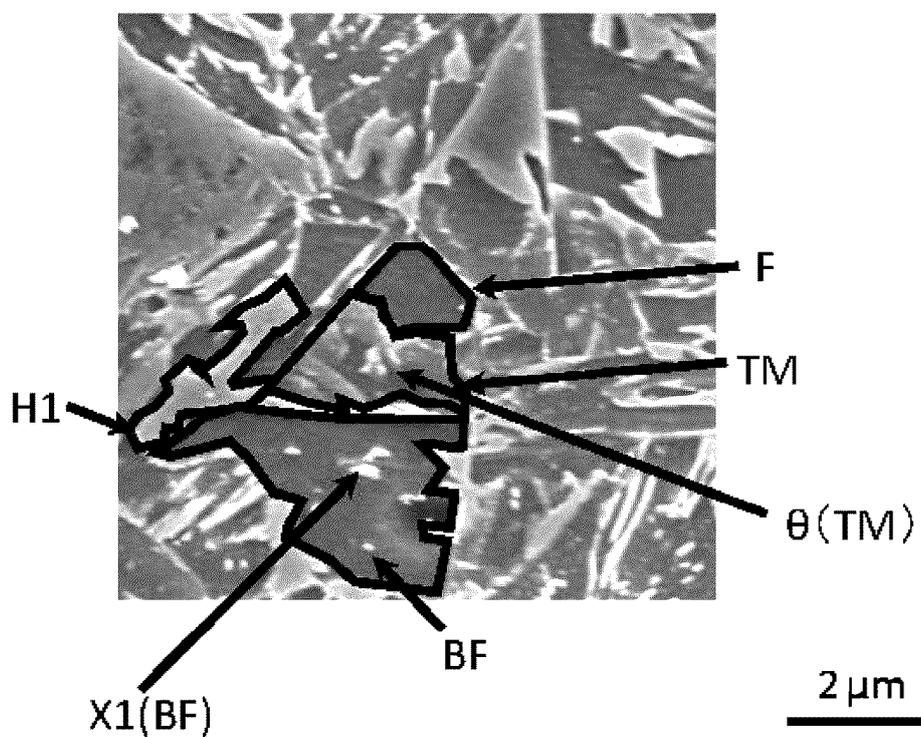
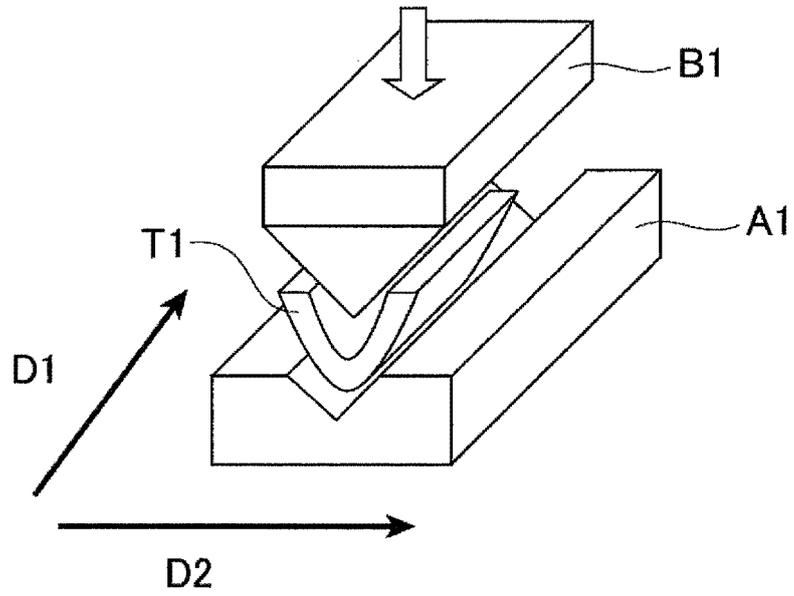


FIG. 2-1

(a)



(b)

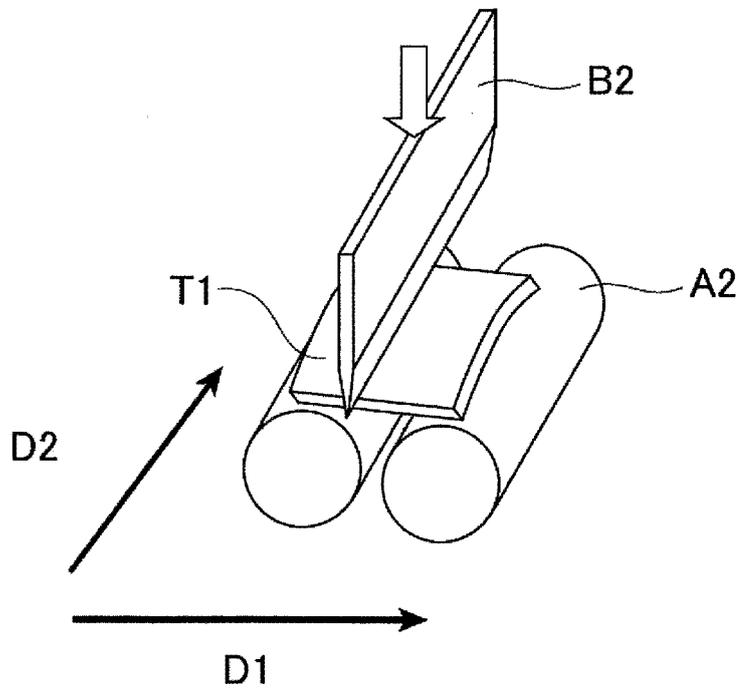


FIG. 2-2

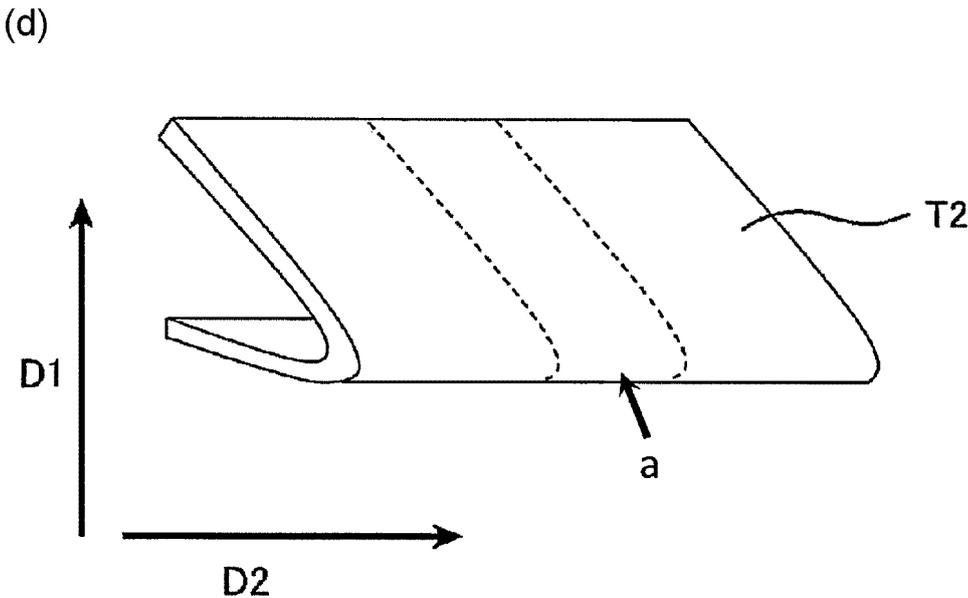
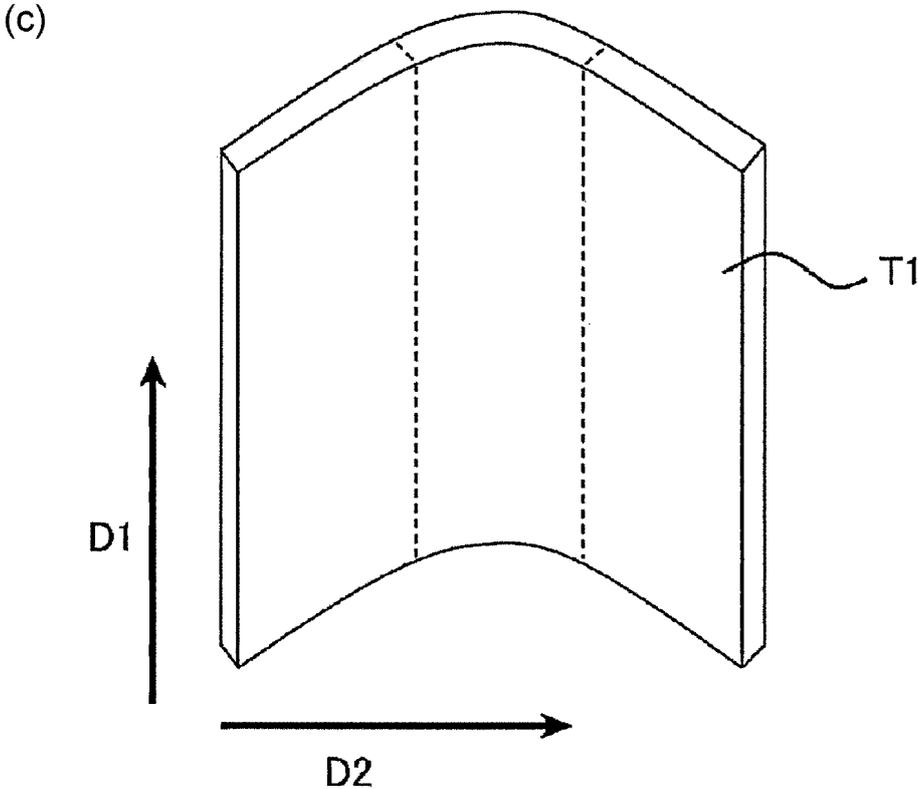


FIG. 2-3

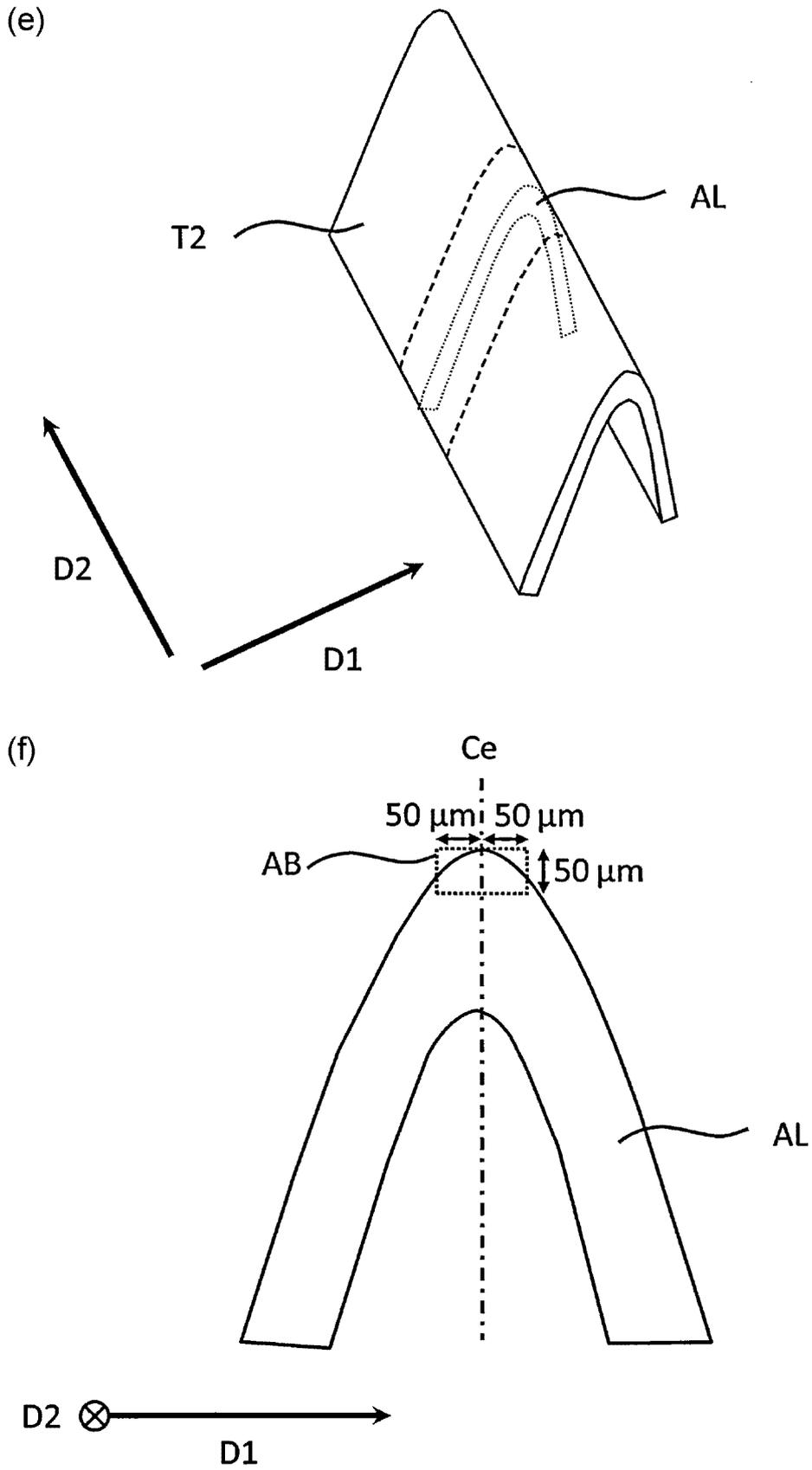


FIG. 2-4

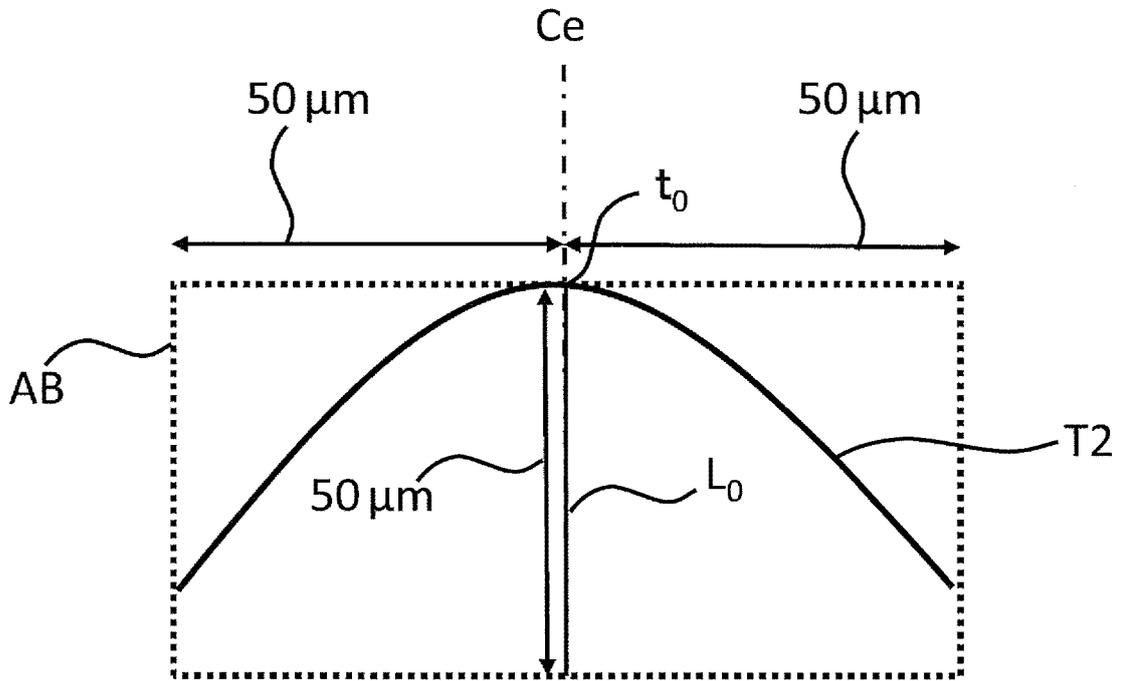


FIG. 3

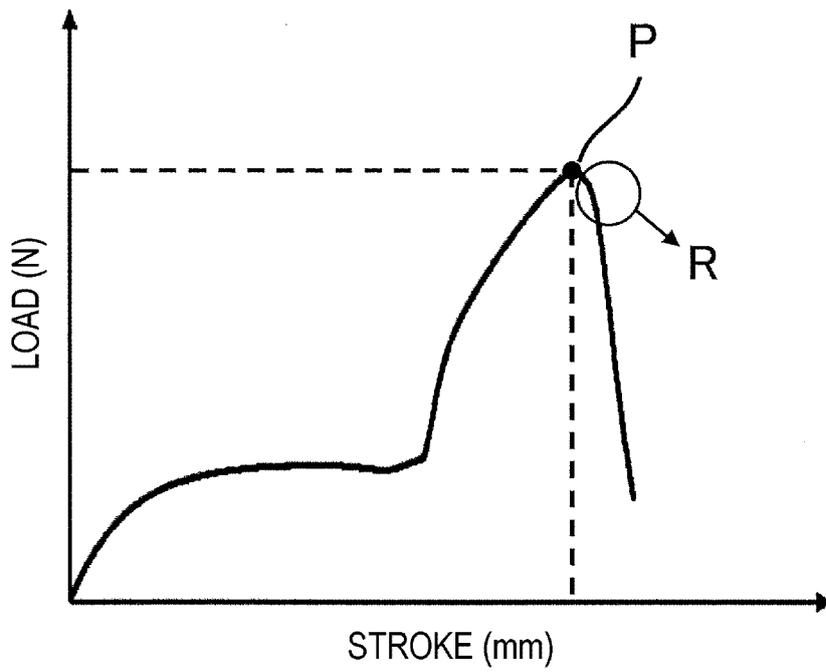


FIG. 4

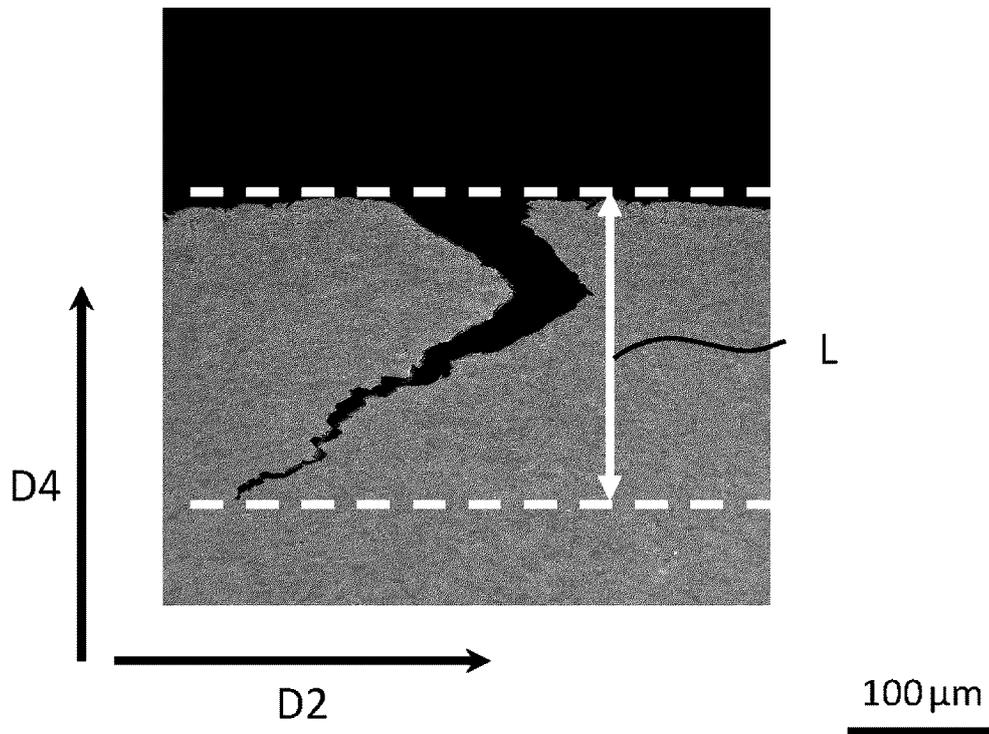
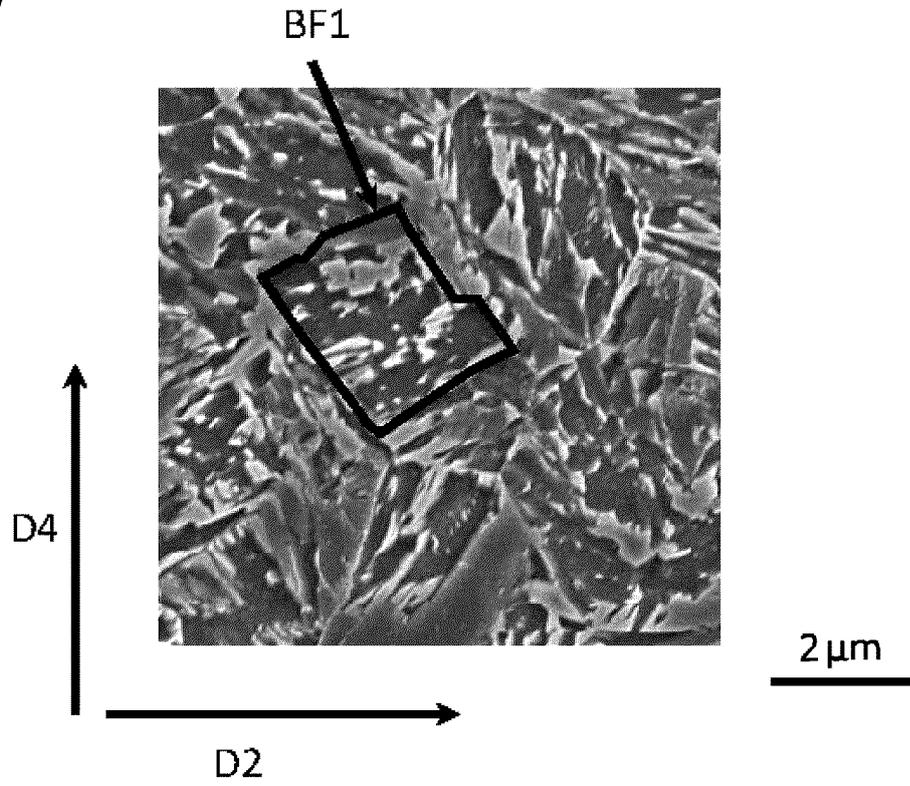


FIG. 5

(a)



(b)

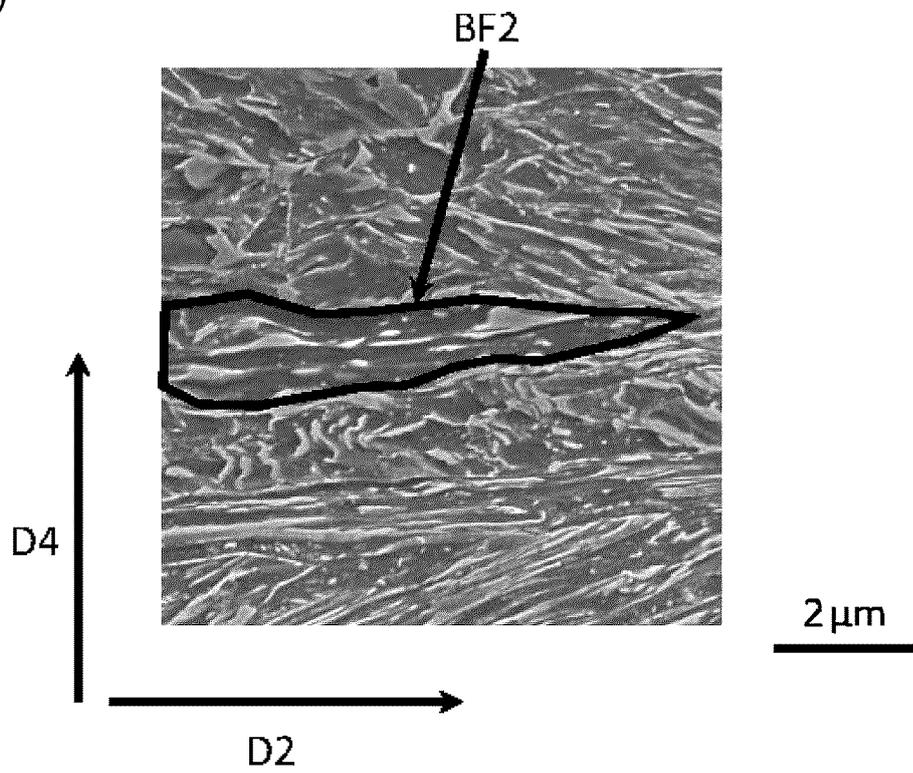
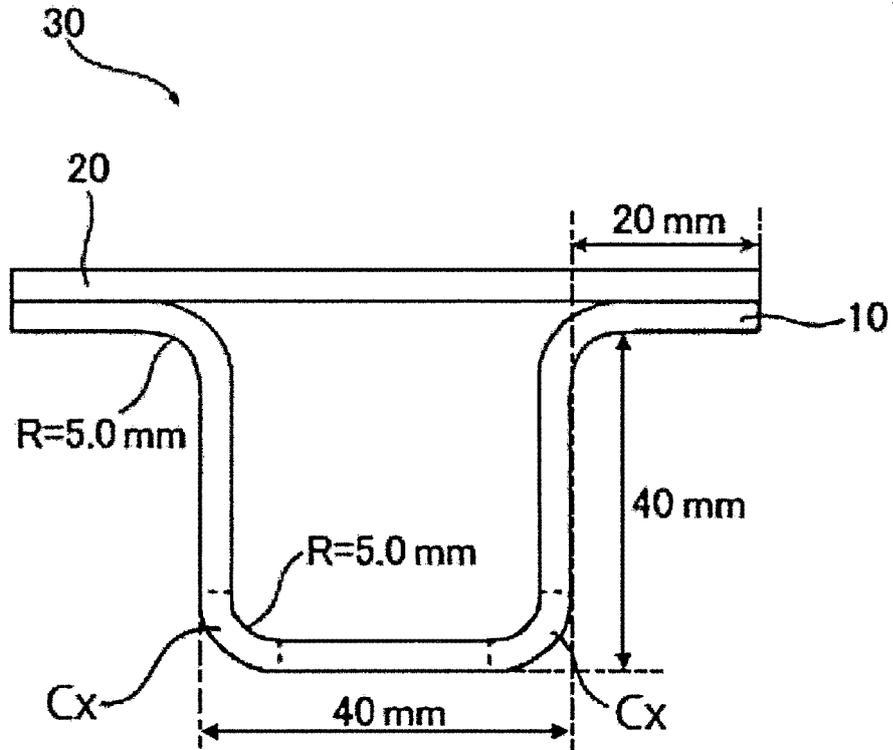


FIG. 6-1

(a)



(b)

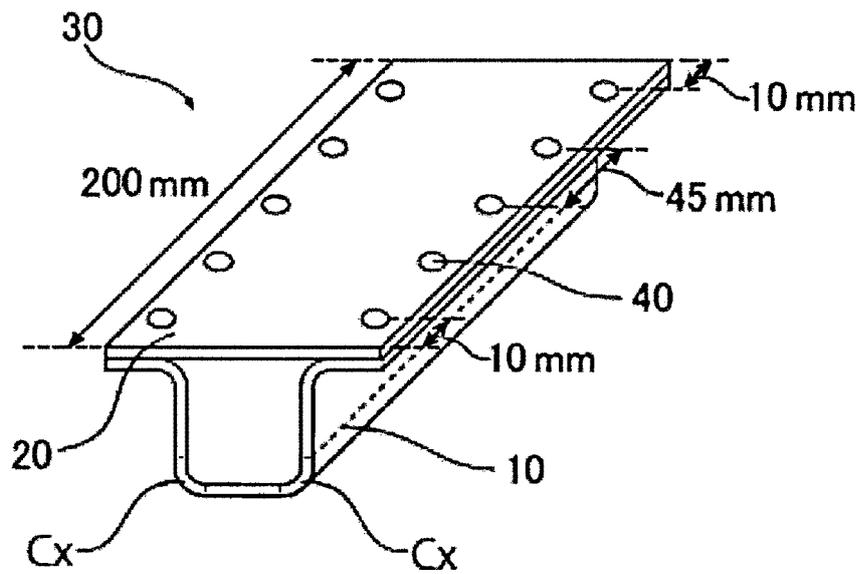
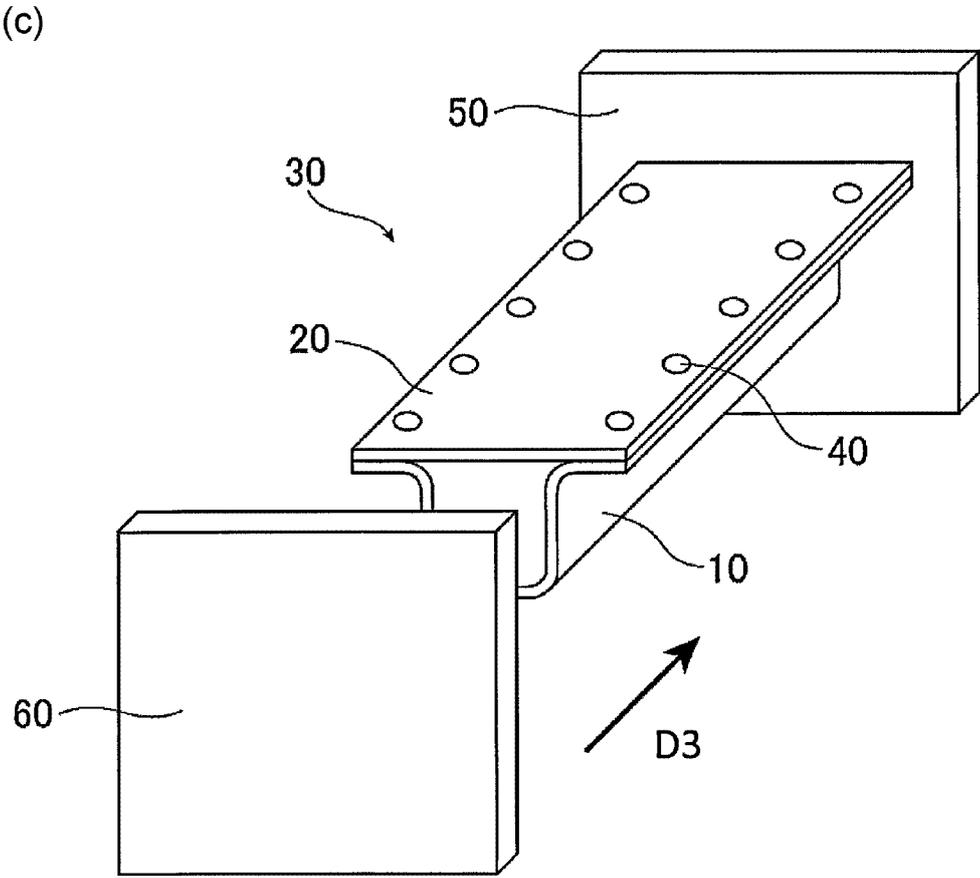


FIG. 6-2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/006926

|   |  |  |
|---|--|--|
| <b>A. CLASSIFICATION OF SUBJECT MATTER</b>  |  |  |
| <p><i>C21D 9/46</i>(2006.01); <i>C22C 38/00</i>(2006.01); <i>C22C 38/06</i>(2006.01); <i>C22C 38/60</i>(2006.01)j<br/>                 FI: C22C38/00 301T; C22C38/06; C22C38/60; C21D9/46 J; C22C38/00 301W; C22C38/00 301Z; C21D9/46 U</p> <p>According to International Patent Classification (IPC) or to both national classification and IPC</p>  |  |  |
| <b>B. FIELDS SEARCHED</b>   |  |  |
| <p>Minimum documentation searched (classification system followed by classification symbols)<br/>                 C21D9/46; C22C38/00-38/60</p> <p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched</p> <p>Published examined utility model applications of Japan 1922-1996<br/>                 Published unexamined utility model applications of Japan 1971-2023<br/>                 Registered utility model specifications of Japan 1996-2023<br/>                 Published registered utility model applications of Japan 1994-2023</p> <p>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)</p>  |  |  |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>   |  |  |
| Category*   | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No.                              |
| A   | WO 2021/200580 A1 (JFE STEEL CORP.) 07 October 2021 (2021-10-07)<br>entire text    | 1-11   |
| A   | WO 2021/153393 A1 (JFE STEEL CORP.) 05 August 2021 (2021-08-05)<br>entire text     | 1-11   |
| A   | WO 2013/051238 A1 (JFE STEEL CORP.) 11 April 2013 (2013-04-11)<br>entire text      | 1-11   |
| A   | WO 2022/079988 A1 (JFE STEEL CORP.) 21 April 2022 (2022-04-21)<br>entire text      | 1-11   |
| A   | WO 2020/136990 A1 (JFE STEEL CORP.) 02 July 2020 (2020-07-02)<br>entire text       | 1-11   |
| <input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.  |  |  |
| <p>* Special categories of cited documents:</p> <p>“A” document defining the general state of the art which is not considered to be of particular relevance</p> <p>“E” earlier application or patent but published on or after the international filing date</p> <p>“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>“O” document referring to an oral disclosure, use, exhibition or other means</p> <p>“P” document published prior to the international filing date but later than the priority date claimed</p> <p>“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>“&amp;” document member of the same patent family</p> |  |  |
| Date of the actual completion of the international search   |  | Date of mailing of the international search report |
| 19 April 2023   |  | 09 May 2023  |
| Name and mailing address of the ISA/JP  |  | Authorized officer                                 |
| Japan Patent Office (ISA/JP)<br>3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915<br>Japan   |  | Telephone No.                                      |

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INTERNATIONAL SEARCH REPORT  
Information on patent family members

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|---|
| International application No.<br><b>PCT/JP2023/006926</b> |
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| Patent document cited in search report | Publication date (day/month/year) | Patent family member(s)  | Publication date (day/month/year) |
|--|-----------------------------------|--|-----------------------------------|
| WO 2021/200580 A1                      | 07 October 2021                   | EP 4130324 A1<br>entire text<br>KR 10-2022-0145391 A<br>CN 115362279 A                       |                                   |
| WO 2021/153393 A1                      | 05 August 2021                    | EP 4067523 A1<br>entire text<br>KR 10-2022-0117922 A<br>CN 114981462 A                       |                                   |
| WO 2013/051238 A1                      | 11 April 2013                     | US 2014/0242416 A1<br>entire text<br>EP 2765212 A1<br>CN 103857819 A<br>KR 10-2014-0068207 A |                                   |
| WO 2022/079988 A1                      | 21 April 2022                     | JP 7078186 B1<br>entire text   |                                   |
| WO 2020/136990 A1                      | 02 July 2020                      | US 2022/0090223 A1<br>entire text<br>EP 3904554 A1<br>CN 113227430 A<br>KR 10-2021-0095190 A |                                   |

**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- JP 3887235 B [0007]
- JP 5953693 B [0007]
- JP 6052472 B [0007]