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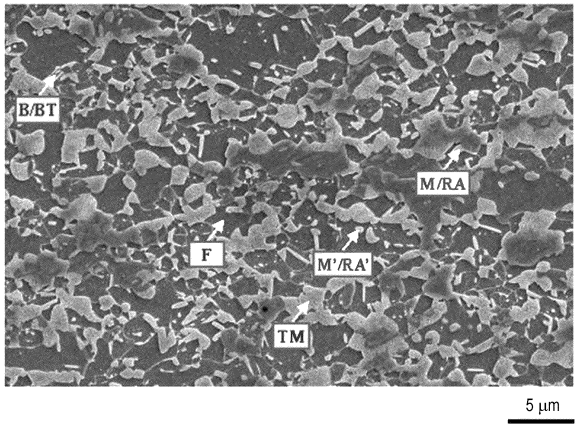
(54) **STEEL SHEET, MEMBER, AND METHOD FOR PRODUCING SAME**

(57) To achieve a TS of 780 MPa or more, high YS and YR, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) in case of a collision.

A base steel sheet has a specified chemical composition and has a steel microstructure at a quarter thickness position containing specified ranges of ferrite, fresh martensite, retained austenite, bainite, tempered bainite, and tempered martensite, the value obtained by dividing the total area fraction of isolated island-like fresh martensite and isolated island-like retained austenite by the sum of the area fraction of fresh martensite and the volume fraction of retained austenite in a ferrite grain is 0.65 or more, the isolated island-like fresh martensite and the isolated island-like retained austenite in the ferrite grain has an average grain size of 2.0 μm or less, and the amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less.

FIG. 1



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Description

Technical Field

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

Background Art

[0002] Automotive steel sheets have been reinforced to achieve both the reduction of CO_2 emissions due to an improvement of fuel efficiency by reducing the thickness and weight of steel sheets used in automobile bodies and an improvement of crash safety. Furthermore, new laws and regulations are continuously introduced. Thus, for the purpose of increasing the strength of an automobile body, high-strength steel sheets, particularly high-strength steel sheets with a tensile strength (hereinafter also referred to simply as TS) of 780 MPa or more, are increasingly applied to main structural members and reinforcing members (hereinafter also referred to as automobile frame structural members or the like) to be assembled to frames of automobile cabins. Furthermore, high-strength steel sheets used for frame structural members or the like of automobiles are required to have high member strength during press forming. To increase the strength of parts, for example, it is effective to increase the yield ratio (hereinafter also referred to simply as YR) obtained by dividing the yield stress (hereinafter also referred to simply as YS) of a steel sheet by TS. This increases the impact absorbed energy in case of a vehicle collision (hereinafter also referred to simply as impact absorbed energy). Furthermore, among frame structural members and the like of automobiles, for example, crash boxes and the like, have bent portions. From the perspective of press formability, therefore, a steel sheet with high bendability is preferably applies to such parts. Furthermore, from the perspective of anti-rust performance of an automobile body, a steel sheet serving as a material of an automobile body parts is often galvanized. Thus, the development of a hot-dip galvanized steel sheet with high press formability and enhanced crashworthiness in addition to high strength has been desired.

[0003] For example, Patent Literature 1 discloses, as such a steel sheet serving as a material of automobile body parts, 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 μm or less and an area fraction of 5% or more.

[0004] 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 μm or more and is precoated with 0.2 g/m^2 or more and 2.0 g/m^2 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 containing, 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 λ of 35000 MPa·% or more, wherein TS denotes tensile strength (MPa), EL denotes total elongation percentage (%), and λ 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 $Hv3/(-982.1 \times CM3^2 + 1676 \times CM3 + 189) \geq 0.80$.

[0005] 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 μm or less, the retained austenite phase having a C concentration of less than 0.7% by mass.

[0006] Patent Literature 4 discloses a hot-dip galvannealed steel sheet having a hot-dip galvannealed layer on the surface of the steel sheet, wherein the steel sheet has a chemical composition of, on a mass percent basis, C: 0.03% or

more and 0.35% or less, Si: 0.005% or more and 2.0% or less, Mn: 1.0% or more and 4.0% or less, P: 0.0004% or more and 0.1% or less, S: 0.02% or less, sol. Al: 0.0002% or more and 2.0% or less, and N: 0.01% or less, the remainder being Fe and impurities, the concentrated portion average interval is 1000 μm or less at a depth of 50 μm from the surface of the steel sheet, the concentrated portion average interval being an average interval in the direction perpendicular to the rolling direction of a concentrated portion in which Mn and/or Si spread in the rolling direction is concentrated, the number density of cracks with a depth of 3 μm or more and 10 μm or less on the surface of the steel sheet is 3 /mm or more and 1000 /mm or less, the steel sheet has a steel microstructure containing, on an area percent basis, bainite: 60% or more, retained austenite: 1% or more, martensite: 1% or more, and ferrite: 2% or more and less than 20%, and having a superhard phase average interval, which is the average closest distance of martensite and retained austenite, of 20 μm or less, and the hot-dip galvannealed steel sheet has mechanical characteristics with a tensile strength (TS) of 780 MPa or more.

Citation List

Patent Literature

[0007]

PTL 1: Japanese Patent No. 3887235
PTL 2: Japanese Patent No. 5953693
PTL 3: Japanese Patent No. 6052472
PTL 4: Japanese Patent No. 5699764

Summary of Invention

Technical Problem

[0008] Incidentally, although a steel sheet with a tensile strength TS (hereinafter also referred to simply as TS) of more than 590 MPa has been applied to a structural member of an automobile exemplified by a center pillar, only a steel sheet with a TS of 590 MPa is applied to an impact energy absorbing member of an automobile exemplified by a front side member or a rear side member.

[0009] Thus, to increase absorbed energy in case of a collision (hereinafter also referred to as impact absorbed energy), it is effective to improve the yield stress YS (hereinafter also referred to simply as YS) and the yield ratio YR (hereinafter also referred to simply as YR). However, a steel sheet with higher YS and YR typically has lower press formability and, in particular, lower ductility, flangeability, bendability, and the like. Thus, when 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 4 have a TS of 780 MPa or more, high YS and YR, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) in case of a collision.

[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 780 MPa or more, high yield stress YS and yield ratio YR, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) in case of a collision, and a method for producing the steel sheet.

[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 galvannealed steel sheet (hereinafter also referred to as GA).

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

[0015] The phrase "high yield stress YS and yield ratio YR" 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 780 MPa ≤ TS < 980 MPa, 500 MPa ≤ YS, and 0.64 ≤ YR
(B) For 980 MPa ≤ TS, 600 MPa ≤ YS, and 0.61 ≤ YR

[0016] The phrase "high ductility" means that the total elongation (El) 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 780 MPa ≤ TS < 980 MPa, 19.0% ≤ El
(B) For 980 MPa ≤ TS, 15.0% ≤ El

[0017] The phrase "high flangeability" refers to a limiting hole expansion ratio (λ) of 30% or more as measured in the hole expansion test according to JIS Z 2256 (2020).

[0018] The phrase "high bendability" means that R (critical bending radius)/t (thickness) measured in the V-bending test according to JIS Z 2248 (2014) satisfies the following formulae (A) or (B) depending on TS.

(A) For 780 MPa ≤ TS < 980 MPa, 2.0 ≥ R/t
(B) For 980 MPa ≤ TS, 2.5 ≥ R/t

[0019] The phrase "good axial compression characteristics" means that the critical spacer thickness (ST) in a U-bending + tight bending bending test satisfies the following formula (A) or (B) depending on TS.

(A) For 780 MPa ≤ TS < 980 MPa, 2.5 mm ≥ ST
(B) For 980 MPa ≤ TS, 4.0 mm ≥ ST

[0020] The phrase "good axial compression characteristics" means that the stroke at the maximum load (SFmax) measured in a V-bending + orthogonal VDA bending test satisfies the following formulae (A) or (B) depending on TS.

(A) For 780 MPa ≤ TS < 980 MPa, 28.0 mm ≤ SFmax
(B) For 980 MPa ≤ TS, 26.5 mm ≤ SFmax

[0021] The phrase "good axial compression characteristics" means that, after an axial compression test, fracture (appearance crack) occurs at one or less positions in the regions of R = 5.0 mm and 200 mm of lower two bending ridge line portions in Fig. 4(b) (see regions Cx in Figs. 4(a) and 4(b)).

[0022] The phrase "good bending fracture characteristics" means that the critical spacer thickness (ST) in the U-bending + tight bending bending test satisfies the formula (A) or (B) depending on TS, and the stroke at the maximum load (SFmax) measured in the V-bending + orthogonal VDA bending test satisfies the formula (A) or (B) depending on TS.

[0023] The El (ductility), λ (stretch flangeability), and R/t (bendability) are characteristics indicating the ease of forming a steel sheet during press forming (the degree of freedom of forming for press forming without cracking). On the other hand, the U-bending + tight bending test is a test simulating the deformation and fracture behavior of a vertical wall portion in a collision test, and the critical spacer thickness (ST) measured in the U-bending + tight bending test is a measure indicating the resistance to cracking of a steel sheet and a member of an automobile body in case of a collision (crashworthiness for absorbing impact energy without fracture).

[0024] The V-bending + orthogonal 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 (SFmax) measured in the V-bending + orthogonal VDA bending test is a measure indicating the resistance to cracking of an energy absorbing member. Solution to Problem

[0025] As a result of extensive studies to achieve the objects, the present inventors have found the following.

(1) A TS of 780 MPa or more can be ensured with specified components by controlling the area fraction of tempered martensite to 10.0% or more, decreasing an island-like hard second phase (martensite + retained austenite) in contact with a ferrite grain boundary, and increasing the ratio of an isolated fine island-like hard second phase (martensite + retained austenite) in a ferrite grain.
(2) High YS and YR can be ensured with specified components by controlling the area fraction of tempered martensite to 10.0% or more and decreasing an island-like hard second phase (martensite + retained austenite) in contact with a ferrite grain boundary.
(3) Ductility (correlated with stretch formability, which is one mode of press formability) can be improved with specified components by controlling the area fraction of ferrite to 20.0% or more.
(4) Flangeability correlated with stretch flangeability, which is one mode of press formability, can be improved with specified components by controlling the area fraction of fresh martensite to 15.0% or less, the area fraction of retained austenite to 3.0% or less, and the area fraction of tempered martensite to 10.0% or more, and increasing the ratio of an isolated fine island-like hard second phase (martensite + retained austenite) in a ferrite grain.
(5) Bendability, which is one mode of press formability, can be improved with specified components by controlling the area fraction of fresh martensite to 15.0% or less, the area fraction of retained austenite to 3.0% or less, and the area

fraction of tempered martensite to 10.0% or more, and increasing the ratio of an isolated fine island-like hard second phase (martensite + retained austenite) in a ferrite grain.
(6) The formation of hard fresh martensite by deformation-induced transformation of retained austenite during primary processing, such as punching or press forming, and the void formation and crack growth in a subsequent test can be suppressed at Si: 0.75% by mass or less and with specified components by controlling the area fraction of retained austenite to 3.0% or less. Furthermore, the critical spacer thickness (ST) measured in a U-bending + tight bending test simulating the deformation and fracture behavior of a vertical wall portion in a collision test, and the stroke at the maximum load (SFmax) measured in a V-bending + orthogonal VDA bending test simulating the deformation and fracture behavior of a bending ridge line portion in a collision test, which are measures of the crashworthiness of a steel sheet and a member of an automobile body in case of a collision, can be improved by controlling the area fraction of tempered martensite to 10.0% or more and increasing the ratio of an isolated fine island-like hard second phase (martensite + retained austenite) in a ferrite grain.

[0026] The present disclosure is based on these findings. The gist of the present disclosure is 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: 0.030% or more and 0.250% or less,
Si: 0.01% or more and 0.75% or less,
Mn: 2.00% or more and less than 3.50%,
P: 0.001% or more and 0.100% or less,
S: 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, and has a steel microstructure,
as a microstructure at a quarter thickness position of the base steel sheet,

in which

an area fraction of ferrite: 20.0% or more and 80.0% or less,
an area fraction of fresh martensite: 15.0% or less,
an area fraction of retained austenite: 3.0% or less,
a value obtained by dividing a total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by a sum of an area fraction of fresh martensite and an area fraction of retained austenite in the entire steel sheet: 0.65 or more,
an area fraction of bainite and tempered bainite: 10.0% or less,
an area fraction of tempered martensite: 10.0% or more and 70.0% or less, and
the island-like fresh martensite and the island-like retained austenite in the ferrite grain has an average grain size of 2.0 μm or less, and
an amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less, and the steel sheet has a tensile strength of 780 MPa or more.

[2] The steel sheet according to [1], wherein the chemical composition further contains, on a mass percent basis, at least one element 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.

[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

when a region of 200 μm 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 μm x 50 μm 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,
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 σ 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 σ of 2.2 GPa or less.

[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:

a hot rolling step of hot-rolling a steel slab with the chemical composition according to [1] or [2] under a condition of a finish rolling temperature of 820°C or more to produce a hot-rolled steel sheet;
a heating step of heating the steel sheet after the hot rolling step in a temperature range of 350°C or more and 600°C or less at an average heating rate of 7°C/s or more;
an annealing step of annealing under conditions of an annealing temperature: 750°C or more and 900°C or less and an annealing time: 20 seconds or more;
after the annealing step, a first cooling step of cooling under conditions of an average cooling rate of 7°C/s or more from (the annealing temperature - 30°C) to 650°C and an average cooling rate of 14°C/s or less from 650°C to 500°C;
after the first cooling step, a second cooling step of applying a tension of 2.0 kgf/mm^2 or more to the steel sheet in a temperature range of 300°C or more and 450°C or less, then subjecting the steel sheet to five 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 then cooling the steel sheet to a cooling stop temperature of 250°C or less;
a reheating step of reheating the steel sheet to a temperature range of the cooling stop temperature or more and 440°C or less and holding the steel sheet for 20 seconds or more after the second cooling step; and
optionally a cold rolling step of cold-rolling the steel sheet after the hot rolling step and before the heating step at a

rolling reduction of 20% or more and 80% or less to produce a cold-rolled steel sheet.

[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.

[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 before the annealing step.

[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

[0027] The present invention provides a steel sheet with a tensile strength TS of 780 MPa or more, high yield stress YS and yield ratio YR, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) in case of a collision.

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

Brief Description of Drawings

[0029]

[Fig. 1] Fig. 1 is an example of a SEM image of the present invention (Inventive Example No. 13 in Examples).

[Fig. 2] Fig. 2(a) is an explanatory view of U-bending (primary bending) in a U-bending + tight bending test in Examples. Fig. 2(b) is an explanatory view of tight bending (secondary bending) in a U-bending + tight bending test in Examples.

[Fig. 3] Fig. 3(a) is an explanatory view of V-bending (primary bending) in a V-bending + orthogonal VDA bending test in Examples. Fig. 3(b) is an explanatory view of orthogonal VDA bending (secondary bending) in a V-bending + orthogonal VDA bending test in Examples.

[Fig. 4] Fig. 4(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. 4(b) is a perspective view of the test member illustrated in Fig. 4(a). Fig. 4(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: 0.030% or more and 0.250% or less, Si: 0.01% or more and 0.75% or less, Mn: 2.00% or more and less than 3.50%, P: 0.001% or more and 0.100% or less, S: 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, and has a steel microstructure, as a microstructure at a quarter thickness position of the base steel sheet, in which the area fraction of ferrite: 20.0% or more and 80.0% or less, an area fraction of fresh martensite: 15.0% or less, an area fraction of retained austenite: 3.0% or less, a value obtained by dividing a total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by a sum of an area fraction of fresh martensite and an area fraction of retained austenite: 0.65 or more, an area fraction of bainite and tempered bainite: 10.0% or less, an area fraction of tempered martensite: 10.0% or more and 70.0% or less, and the island-like fresh martensite and the island-like retained austenite in the ferrite grain has an average grain size of 2.0 μm or less, and an amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less, and the steel sheet has a tensile strength of 780 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: 0.030% or more and 0.250% or less

[0034] C is an element effective in forming an appropriate amount of tempered martensite, bainite, tempered bainite, or the like to ensure a TS of 780 MPa or more and high YS and YR. A C content of less than 0.030% results in an increase in the area fraction of ferrite and makes it difficult to achieve a TS of 780 MPa or more. This also reduces YS and YR.

[0035] On the other hand, a C content of more than 0.250% results in an increase in the area fraction of fresh martensite, excessively high TS, and lower El. This also results in an increase in the area fraction of fresh martensite, lower bendability in a V-bending test, and undesired R/t (press formability). This also results in an increase in the area fraction of retained austenite, the formation of hard fresh martensite by deformation-induced transformation of retained austenite when a steel sheet is punched in a hole expansion test, is subjected to U-bending in a U-bending + tight bending test, or is subjected to V-bending in a V-bending + orthogonal VDA test, results in void formation and crack growth in a subsequent test, and results in undesired λ (press formability), ST (fracture resistance characteristics in case of a collision), and SFmax (fracture resistance characteristics in case of a collision). Thus, the C content is 0.030% or more and 0.250% or less. The C content is preferably 0.050% or more. The C content is preferably 0.130% or less.

Si: 0.01% or more and 0.75% or less

[0036] Si promotes ferrite transformation during annealing and in a cooling process after annealing. Thus, Si is an element that affects the area fraction of ferrite. A Si content of less than 0.01% results in a decrease in the area fraction of ferrite and lower ductility.

[0037] On the other hand, a Si content of more than 0.75% results in an increase in the volume fraction of retained austenite, the formation of hard fresh martensite by deformation-induced transformation of retained austenite when a steel sheet is punched in a hole expansion test, is subjected to U-bending in a U-bending + tight bending test, or is subjected to V-bending in a V-bending + orthogonal VDA test, results in void formation and crack growth in a subsequent test, and results in undesired λ, ST, and SFmax. Thus, the Si content is 0.01% or more and 0.75% or less. The Si content is preferably 0.10% or more. The Si content is preferably 0.70% or less.

Mn: 2.00% or more and less than 3.50%

[0038] Mn is an element that adjusts the area fraction of tempered martensite, bainite, tempered bainite, or the like. A Mn content of less than 2.00% results in an increase in the area fraction of ferrite and makes it difficult to achieve a TS of 780 MPa or more. This also reduces YS and YR.

[0039] On the other hand, a Mn content of 3.50% or more results in a decrease in martensite start temperature Ms (hereinafter also referred to simply as an Ms temperature or Ms) and a decrease in martensite formed in a first cooling step. This results in an increase in fresh martensite formed in the second cooling step, insufficient tempering of the fresh martensite in a subsequent reheating step, an increase in the area fraction of the fresh martensite, lower bendability in a V-bending test, and undesired R/t. Thus, the Mn content is 2.00% or more and less than 3.50%. The Mn content is preferably 2.20% or more. The Mn content is preferably 3.00% or less.

P: 0.001% or more and 0.100% or less

[0040] 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.

[0041] 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. This results in void formation and crack growth along the prior-austenite grain boundary and undesired R/t in a V-bending test. This also results in void formation and crack growth along the prior-austenite grain boundary when a steel sheet is punched in a hole expansion test, is subjected to U-bending in a U-bending + tight bending test, or is subjected to V-bending in a V-bending + orthogonal VDA test, and undesired λ, ST, and SFmax. Thus, the P content is 0.001% or more and 0.100% or less. The P content is preferably 0.030% or less.

S: 0.0200% or less

[0042] S is present as a sulfide in steel. In particular, a S content of more than 0.0200% results in void formation and crack growth from the sulfide as a starting point in a V-bending test and undesired R/t. This also results in void formation and crack growth from the sulfide as a starting point when a steel sheet is punched in a hole expansion test, is subjected to U-

bending in a U-bending + tight bending test, or is subjected to V-bending in a V-bending + orthogonal VDA test, and undesired λ, ST, and SFmax. Thus, the S content is 0.0200% or less. The S content is preferably 0.0080% or less.

[0043] The S content may have any lower limit but is preferably 0.0001% or more due to constraints on production technology.

Al: 0.010% or more and 2.000% or less

[0044] Al promotes ferrite transformation during annealing and in a cooling process after annealing. Thus, Al is an element that affects the area fraction of ferrite. An Al content of less than 0.010% results in a decrease in the area fraction of ferrite and lower ductility.

[0045] 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 780 MPa or more. This also reduces YS and YR. 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

[0046] N is present as a nitride in steel. In particular, a N content of more than 0.0100% results in void formation and crack growth from the nitride as a starting point in a V-bending test and undesired R/t. This also results in void formation and crack growth from the nitride as a starting point when a steel sheet is punched in a hole expansion test, is subjected to U-bending in a U-bending + tight bending test, or is subjected to V-bending in a V-bending + orthogonal VDA test, and undesired λ, ST, and SFmax. Thus, the N content is 0.0100% or less. The N content is preferably 0.0050% or less.

[0047] The N content may have any lower limit but is preferably 0.0005% or more due to constraints on production technology.

[0048] 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.

[0049] 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.

[0050] 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

[0051] Nb forms fine carbide, nitride, or carbonitride during hot rolling or annealing and thereby increases TS, YS, and YR. To produce such effects, the Nb content is preferably 0.001% or more. The Nb content is more preferably 0.005% or more.

[0052] 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 void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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

[0053] Like Nb, Ti forms fine carbide, nitride, or carbonitride during hot rolling or annealing and thereby increases TS, YS, and YR. To produce such effects, the Ti content is preferably 0.001% or more. The Ti content is more preferably 0.005% or more.

[0054] 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 void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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

[0055] 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, even further more preferably 0.030% or more.

[0056] 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 void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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

[0057] B is an element that segregates at an austenite grain boundary and enhances hardenability. B is also an element that controls 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.

[0058] The B content is even more preferably 0.0005% or more, even further more preferably 0.0007% or more.

[0059] On the other hand, a B content of more than 0.0100% may result in a crack in a steel sheet during hot rolling. The internal crack may act as a starting point of a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax may not be achieved. 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

[0060] Cr is an element that enhances hardenability, and the addition of Cr forms an appropriate amount of tempered martensite and increases TS, YS, and YR. To produce such effects, the Cr content is preferably 0.0005% or more. The Cr content is more preferably 0.010% or more.

[0061] Cr is even more preferably 0.030% or more, even further more preferably 0.050% or more.

[0062] On the other hand, a Cr content of more than 1.000% may result in an increase in the area fraction of fresh martensite, lower flangeability, lower bendability in a V-bending test, and undesired λ and R/t. 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

[0063] Ni is an element that enhances hardenability, and the addition of Ni forms a large amount of tempered martensite and increases TS, YS, and YR. 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, even further more preferably 0.060% or more.

[0064] On the other hand, a Ni content of more than 1.000% may result in an increase in the area fraction of fresh martensite, lower flangeability, lower bendability in a V-bending test, and undesired λ and R/t. Thus, when Ni is contained, the Ni content is preferably 1.000% or less. The Ni content is more preferably 0.800% or less.

[0065] The Ni content is even more preferably 0.600% or less, even further more preferably 0.400% or less.

Mo: 1.000% or less

[0066] Mo is an element that enhances hardenability, and the addition of Mo forms a large amount of tempered martensite and increases TS, YS, and YR. To produce such effects, the Mo content is preferably 0.010% or more. The Mo content is more preferably 0.030% or more.

[0067] On the other hand, a Mo content of more than 1.000% may result in an increase in the area fraction of fresh martensite, lower flangeability, lower bendability in a V-bending test, and undesired λ and R/t. 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, even further more preferably 0.400% or less. The Mo content is even more preferably 0.350% or less, even

further more preferably 0.300% or less.

Sb: 0.200% or less

[0068] 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 may make it difficult to achieve a TS of 780 MPa or more. This may also reduce YS. Thus, the Sb content is preferably 0.002% or more. The Sb content is more preferably 0.005% or more.

[0069] 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 λ, R/t, ST, and SFmax. 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

[0070] 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 may make it difficult to achieve a TS of 780 MPa or more. This may also reduce YS. Thus, the Sn content is preferably 0.002% or more. The Sn content is more preferably 0.005% or more.

[0071] 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 λ, R/t, ST, and SFmax. 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

[0072] Cu is an element that enhances hardenability, and the addition of Cu forms a large amount of tempered martensite and increases TS, YS, and YR. 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.

[0073] 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. Furthermore, a large number of coarse precipitates and inclusions may be formed. In such a case, excessively formed fresh martensite or a coarse precipitate or inclusion may act as a starting point of a void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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.

Ta: 0.100% or less

[0074] Like Ti, Nb, and V, Ta forms fine carbide, nitride, or carbonitride during hot rolling or annealing and increases TS, YS, and YR. 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.

[0075] 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, an excessively coarse precipitate or inclusion may act as a starting point of a void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax may not be achieved. Thus, when Ta is contained, the Ta content is preferably 0.100% or less.

[0076] The Ta content is more preferably 0.090% or less, even more preferably 0.080% or less.

W: 0.500% or less

[0077] W is an element that enhances hardenability, and the addition of W forms a large amount of tempered martensite and increases TS, YS, and YR. To produce such effects, the W content is preferably 0.001% or more. The W content is more preferably 0.030% or more.

[0078] On the other hand, a W content of more than 0.500% may result in an increase in the area fraction of fresh martensite, lower flangeability, lower bendability in a V-bending test, and undesired λ and R/t. 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

[0079] Mg is an element effective in spheroidizing the shape of an inclusion of sulfide, oxide, or the like and improving the flangeability and bendability 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.

[0080] 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, an excessively coarse precipitate or inclusion may act as a starting point of a void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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

[0081] Zn is an element effective in spheroidizing the shape of an inclusion and improving the flangeability and bendability 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.

[0082] 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, an excessively coarse precipitate or inclusion may act as a starting point of a void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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

[0083] Like Zn, Co is an element effective in spheroidizing the shape of an inclusion and improving the flangeability and bendability of a 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.

[0084] 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, an excessively coarse precipitate or inclusion may act as a starting point of a void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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

[0085] Like Zn and Co, Zr is an element effective in spheroidizing the shape of an inclusion and improving the flangeability and bendability of a steel sheet. To produce such effects, the Zr content is preferably 0.0010% or more. On the other hand, when the Zr content is more than 0.1000%, an excessively coarse precipitate or inclusion may act as a starting point of a void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, and a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax may not be achieved. Thus, when Zr is contained, the Zr content is preferably 0.1000% or less.

[0086] The Zr content is more preferably 0.0300% or less, even more preferably 0.0100% or less.

Ca: 0.0200% or less

[0087] 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, an excessively coarse precipitate or inclusion may act as a starting point of a void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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. The Ca content is more preferably 0.0019% or less, even more preferably 0.0018% or less. 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.

[0088] 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

[0089] Se, Te, Ge, As, Sr, Cs, Hf, Pb, Bi, and REM are elements effective in improving the flangeability and bendability 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.

[0090] 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 void and a crack in a hole expansion test, a V-bending test, a U-bending + tight bending test, or a V-bending + orthogonal VDA bending test, and desired λ, R/t, ST, and SFmax 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.

[0091] 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.

[0092] 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.

[0093] 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.

[0094] 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.

[0095] 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.

[0096] 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.

[0097] 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.

[0098] 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.

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

[0100] REM is more preferably 0.0005% or more, even more preferably 0.0008% or more. REM is more preferably 0.0180% or less, even more preferably 0.0150% or less.

[0101] 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.

[0102] REM is preferably, but not limited to, Sc, Y, Ce, or La.

Steel Microstructure

[0103] Next, the steel microstructure of a base steel sheet of a steel sheet according to an embodiment of the present invention is described.

Area fraction of ferrite: 20.0% or more and 80.0% or less

[0104] Soft ferrite is a phase that improves ductility. It is also a phase necessary to form isolated island-like fresh martensite or isolated island-like retained austenite in a grain and to suppress the connection of voids and crack growth. To achieve both desired ductility and good λ, R/t, ST, and SFmax, the area fraction of ferrite is 20.0% or more. On the other hand, an excessive increase in the area fraction of ferrite makes it difficult to achieve a TS of 780 MPa or more. This also reduces YS and YR. Thus, the area fraction of ferrite is 80.0% or less. The area fraction of ferrite is preferably 30.0% or more.

Area fraction of fresh martensite: 15.0% or less (including 0.0%)

[0105] In the present invention, fresh martensite with an excessively increased area fraction acts as a starting point of void formation in a hole expanding process in a hole expansion test or in a bending process in a V-bending test, and desired λ and R/t cannot be achieved. Thus, the area fraction of fresh martensite is 15.0% or less. The area fraction of fresh martensite is preferably 10.0% or less. The area fraction of fresh martensite may have any lower limit and may be 0.0%. The term "fresh martensite" refers to as-quenched (untempered) martensite. The fresh martensite includes (isolated) island-like fresh martensite in ferrite grains described later.

Area fraction of retained austenite: 3.0% or less (including 0.0%)

[0106] In the present invention, an excessive increase in the area fraction of retained austenite results in the formation of hard fresh martensite by deformation-induced transformation of retained austenite when a steel sheet is punched in a hole expansion test, is subjected to U-bending in a U-bending + tight bending test, or is subjected to V-bending in a V-bending +

orthogonal VDA test, results in void formation and crack growth in a subsequent test, and results in undesired λ, ST, and SFmax. Thus, the area fraction of retained austenite is 3.0% or less. The area fraction of retained austenite is preferably 2.5% or less, more preferably 2.0% or less. The lower limit of the area fraction of retained austenite is preferably, but not limited to, 0.1% or more, more preferably 0.2% or more.

[0107] The retained austenite includes (isolated) island-like retained austenite in ferrite grains described later.

[0108] In a second cooling step in a production method described later, the desired area fraction of tempered martensite can be ensured by applying a tension of 2.0 kgf/mm^2 or more to a steel sheet in the temperature range of 300°C or more and 450°C or less, then subjecting the steel sheet to five 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, to cause deformation-induced transformation of non-transformed austenite into fresh martensite, tempering the fresh martensite in a subsequent reheating step, and finally controlling the area fraction of fresh martensite to 15.0% or less and the volume fraction of retained austenite to 3.0% or less.

[0109] Value obtained by dividing total area fraction of island-like fresh martensite and island-like retained austenite in ferrite grain by sum of area fraction of fresh martensite and area fraction of retained austenite in entire steel sheet: 0.65 or more

[0110] In the present invention, as shown in Fig. 1, isolated island-like fresh martensite (M') and isolated island-like retained austenite (RA') in a ferrite (F) grain are finer than tempered martensite (TM) and hard second phase (fresh martensite (M) + retained austenite (RA)) present at a ferrite grain boundary, is a microstructure that may act as a void formation position but is less likely to be involved in the connection of voids or crack growth, and is a microstructure that is necessary to ensure a TS of 780 MPa or more and achieve desired λ, R/t, ST, and SFmax. Thus, the value ((M' + RA')/(M + RA)) obtained by dividing the total area fraction of isolated island-like fresh martensite and isolated island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite is 0.65 or more.

[0111] In the present invention, the value obtained by dividing the total area fraction of isolated island-like fresh martensite and isolated island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite can be a value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in the ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite in the entire steel sheet. Thus, in the present invention, the value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite in the entire steel sheet is 0.65 or more.

[0112] Furthermore, the value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite in the entire steel sheet is preferably 0.70 or more.

[0113] The upper limit of the value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the volume fraction of retained austenite in the entire steel sheet is preferably, but not limited to, 0.94 or less, more preferably 0.92 or less.

Area fraction of bainite and tempered bainite: 10.0% or less (including 0.0%)

[0114] An excessive increase in the area fraction of bainite formed in the first cooling step or tempered bainite formed by tempering the bainite formed in the reheating step results in tempered martensite with an undesired area fraction and makes it difficult to achieve a TS of 780 MPa or more. Thus, the area fraction of bainite and tempered bainite (B + BT) is 10.0% or less. The area fraction of bainite and tempered bainite is preferably 8.0% or less. The area fraction of bainite and tempered bainite may be 0.0%.

Area fraction of tempered martensite: 10.0% or more and 70.0% or less

[0115] A hard second phase (fresh martensite + retained austenite) present at a ferrite grain boundary is a microstructure that promotes void formation and crack growth during press forming and in case of a collision. On the other hand, tempered martensite is a microstructure mostly present at a ferrite grain boundary. The microstructure is formed by applying a tension of 2.0 kgf/mm^2 or more to a steel sheet in the temperature range of 300°C or more and 450°C or less in a second cooling step in a production method described later, then subjecting the steel sheet to five 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, to cause deformation-induced transformation of non-transformed austenite into fresh martensite, and tempering the fresh martensite in a subsequent reheating step. The tempered martensite is a microstructure necessary to achieve desired λ, R/t, ST, and SFmax. Thus, the area fraction of tempered martensite is 10.0% or more. The area fraction of tempered martensite is preferably 20.0% or more.

[0116] On the other hand, an excessive increase in the area fraction of tempered martensite results in ferrite with an

undesired area fraction, and desired ductility cannot be ensured. Thus, the area fraction of tempered martensite is 70.0% or less. The area fraction of tempered martensite is preferably 60.0% or less.

[0117] Average grain size of island-like fresh martensite and island-like retained austenite in ferrite grain: 2.0 μm or less

[0118] In the present invention, when island-like fresh martensite and island-like retained austenite in a ferrite grain have a small average grain size, it is possible to ensure a TS of 780 MPa or more, further suppress void formation, and achieve better A, R/t, ST, and SFmax. Thus, the average grain size of island-like fresh martensite and island-like retained austenite (M' + RA') in a ferrite grain is 2.0 μm or less. The average grain size of island-like fresh martensite and island-like retained austenite in a ferrite grain is preferably 1.0 μm or less.

[0119] Although the lower limit is not particularly limited, the average grain size of island-like fresh martensite and island-like retained austenite in a ferrite grain is preferably 0.1 μm or more, more preferably 0.2 μm or more.

[0120] The area fraction of the remaining microstructure other than the ferrite, fresh martensite, retained austenite, bainite, tempered bainite, and tempered martensite is preferably 10.0% or less. The area fraction of the remaining microstructure is more preferably 5.0% or less. The area fraction of the remaining microstructure may be 0.0%.

[0121] The remaining microstructure is, for example, but not limited to, pearlite, or carbide such as cementite, or unrecrystallized ferrite. The type of the remaining microstructure can be determined, for example, by scanning electron microscope (SEM) observation.

[0122] The area fractions of ferrite, bainite, tempered bainite, tempered martensite, and the hard second phase (fresh martensite + retained austenite) are measured at a quarter thickness position of a base steel sheet as described below.

[0123] A sample is cut out to form a thickness cross section (L cross section) parallel to the rolling direction of a steel sheet as an observation surface. The observation surface of the sample is then polished with a diamond paste and is then subjected to final polishing with alumina. The observation surface of the sample is then etched with 3% by volume nital to expose the microstructure. The steel sheet is then observed at a quarter thickness position using a SEM at a magnification of 3000 times in five visual fields. From a microstructure image thus taken, the area fraction is calculated by dividing the area of each constituent microstructure (ferrite, bainite, tempered bainite, tempered martensite, and the hard second phase (fresh martensite + retained austenite)) by the measurement area in five visual fields using Adobe Photoshop available from Adobe Systems, and the area fractions are averaged to determine the area fraction of each microstructure.

[0124] Ferrite: a massive black region. Almost no carbide is contained. The area fraction of ferrite does not include isolated island-like fresh martensite and isolated island-like retained austenite in a ferrite grain.

Bainite and tempered bainite: a black to dark gray region of a massive form, an indefinite form, or the like. A relatively small number of carbide particles are contained.
Tempered martensite: a gray region of an indefinite form. A relatively large number of carbide particles are contained.
Hard second phase (retained austenite + fresh martensite): a white to light gray region of an indefinite form. No carbide is contained.
Carbide: a dotted or linear white region. It is contained in bainite, tempered bainite, and tempered martensite.
Remaining microstructure: the pearlite, cementite, and the like of known forms.

[0125] From the SEM image used for the microstructure fraction measurement, the total area of isolated island-like fresh martensite and isolated island-like retained austenite in a ferrite grain is divided by the number of isolated island-like fresh martensite grains and isolated island-like retained austenite grains in the ferrite grain to obtain an average area, and the average area is divided by the circumference ratio π, and the square root thereof is multiplied by 2 to obtain an equivalent circular diameter as the average grain size.

[0126] For one isolated island-like fresh martensite or isolated island-like retained austenite grain in a ferrite grain, in a SEM image, an island-like region with the outer periphery surrounded by ferrite and integrally formed without interruption is regarded as one to be measured.

[0127] The area fraction of retained austenite is measured as described below.

[0128] 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 MoKα 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.

[0129] 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.

[Area fraction of fresh martensite (%)] = [area fraction (%) of hard second phase] - [area fraction (%) of retained austenite]

[0130] The area fraction of the remaining microstructure is determined by subtracting the area fraction of ferrite, the area fraction of bainite and tempered bainite, the area fraction of tempered martensite, and the area fraction of the hard second phase, which are determined as described above, from 100.0%.

[Area fraction of remaining microstructure (%)] = 100.0 - [area fraction of ferrite (%)] - [area fraction of bainite and tempered bainite (%)] - [area fraction of tempered martensite (%)] - [area fraction of hard second phase (%)]

Amount of diffusible hydrogen contained in base steel sheet (in steel): 0.50 ppm by mass or less

[0131] When the amount of diffusible hydrogen in a steel sheet is more than 0.50 ppm by mass, desired λ, R/t, ST, and SFmax cannot be achieved.

[0132] The amount of diffusible hydrogen in a steel sheet is preferably 0.25 ppm by mass or less. The amount of diffusible hydrogen in a steel sheet may have any lower limit and is preferably 0.01 ppm by mass or more due to constraints on production technology.

[0133] A base steel sheet in which the amount of diffusible hydrogen is measured may be, in addition to a high-strength steel sheet before coating treatment, a base steel sheet of a high-strength galvanized steel sheet after galvanizing treatment and before processing. It may also be a base steel sheet of a steel sheet subjected to processing, such as punching or stretch flange forming, after galvanizing treatment, or a base portion of a product produced by welding a steel sheet after processing.

[0134] The amount of diffusible hydrogen in a steel sheet is measured by the following method. A test specimen with a length of 30 mm and a width of 5 mm is taken and, when a galvanized layer is formed on the steel sheet, the hot-dip galvanized layer or hot-dip galvannealed 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 cumulative amount of hydrogen released from the test specimen from room temperature to 210°C is measured as the amount of diffusible hydrogen in the 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. 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.

Surface Soft Layer

[0135] 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.

[0136] 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 lower limit of the thickness of the surface soft layer is preferably, but not limited to, 8 μm or more, more preferably more than 17 μm. The surface soft layer is preferably 30 μm or more, more preferably 40 μm or more.

[0137] 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).

[0138] The Vickers hardness is measured at a load of 10 gf in accordance with JIS Z 2244-1 (2020).

Nanohardness of Surface Soft Layer

[0139] 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.

[0140] 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 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 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 and SFmax.

[0141] 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 σ 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 σ of 2.2 GPa or less.

[0142] 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 σ 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 σ 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 σ 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 σ 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 and in case of a collision, thus resulting in good R/t and SFmax.

[0143] 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 σ 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 σ of 1.3 GPa or less. The standard deviation σ 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.

[0144] 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 σ 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 σ of 1.7 GPa or less. The standard deviation σ 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.

[0145] 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.

[0146] When a coated layer is formed, after the coated layer is peeled off, mechanical polishing is performed to the quarter depth position - 5 μm 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.

[0147] The nanohardness is measured with Hysitron tribo-950 and a Berkovich diamond indenter under the conditions of a load of 500 μN, a measurement area of 50 μm × 50 μm, and a dot-to-dot distance of 2 μm.

[0148] Furthermore, mechanical polishing is performed to the half depth position in the thickness direction of the surface soft layer, buffing with diamond and alumina is performed, and colloidal silica polishing is further performed. The nanohardness is measured with Hysitron tribo-950 and a Berkovich diamond indenter under the conditions of a load of 500 μN, a measurement area of 50 μm × 50 μm, and a dot-to-dot distance of 2 μm.

[0149] 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.

[0150] For example, when the surface soft layer has a thickness of 100 μm, the quarter position is a position of 25 μm from the surface of the surface soft layer, and the half position is a position of 50 μm from the surface of the surface soft layer. The nanohardness is measured at 300 points or more at the position of 25 μm, and the nanohardness is also measured at 300 points or more at the position of 50 μm.

Metal Coated Layer (First Coated Layer)

[0151] A steel sheet according to an embodiment of the present invention preferably has a metal coated layer (first coated layer, precoated 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 galvannealed layer). The metal coated layer is preferably a metal electroplated layer, and the metal electroplated layer is described below as an example.

[0152] 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.

[0153] In the present invention, the dew point can be more than -20°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 - 20°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.

[0154] 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.

[0155] The coating weight of the Fe-based electroplated layer is more than 0 g/m^2, preferably 2.0 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 g/m^2 or less. The coating weight of the Fe-based electroplated layer is preferably 50 g/m^2 or less, more preferably 40 g/m^2 or less, even more preferably 30 g/m^2 or less.

[0156] The coating weight of the Fe-based electroplated layer is measured as described below. A sample with a size of 10 $\times$ 15 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 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.

[0157] 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.

[0158] Next, mechanical characteristics of a steel sheet according to an embodiment of the present invention are described.

Tensile strength (TS): 780 MPa or more

[0159] A steel sheet according to an embodiment of the present invention has a tensile strength of 780 MPa or more.

[0160] The reference values of the yield stress (YS), the yield ratio (YR), the total elongation (El), the limiting hole expansion ratio (λ), the critical spacer thickness (ST) in a U-bending + tight bending test and the stroke at the maximum load (SFmax) in a V-bending + orthogonal VDA bending test, and the presence or absence of fracture (appearance crack) in the axial compression test of a steel sheet according to an embodiment of the present invention are as described above.

[0161] The tensile strength (TS), the yield stress (YS), the yield ratio (YR), and the total elongation (El) are measured in the tensile test according to JIS Z 2241 (2011) described later in Examples. The limiting hole expansion ratio (A) is measured in the hole expansion test according to JIS Z 2256 (2020) described later in Examples. The critical spacer thickness (ST) is measured in a U-bending + tight bending test described later in Examples. The stroke at the maximum load (SFmax) in the V-bending + orthogonal VDA bending test is measured in a V-bending + orthogonal VDA bending test described later in Examples. The presence or absence of fracture (appearance crack) in the axial compression test is measured in an axial compression test described later in Examples.

Galvanized Layer (Second Coated Layer)

[0162] 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. A steel sheet with a galvanized layer may be a galvanized steel sheet.

[0163] Thus, a steel sheet according to the present invention may have a base steel sheet and a second coated layer (a galvanized layer, an aluminum coated layer, or the like) 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, an aluminum coated layer, or the like) sequentially formed on the base steel sheet.

[0164] 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 galvannealed layer.

[0165] 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.

[0166] A hot-dip galvannealed layer is preferably composed of, for example, 20% 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 galvannealed 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 galvannealed 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 galvannealed 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.

[0167] Furthermore, the coating weight per side of the galvanized layer is preferably, but not limited to, 20 g/m^2 or more. The coating weight per side of the galvanized layer is preferably 80 g/m^2 or less.

[0168] The coating weight of the galvanized layer is measured as described below. 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^2).

[0169] 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.

[0170] 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.

[0171] The steel sheet preferably has a thickness of 3.5 mm or less. The thickness is more preferably 2.3 mm or less.

[0172] 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]

[0173] Next, a method for producing a steel sheet according to an embodiment of the present invention is described.

[0174] A method for producing a steel sheet according to the present invention includes a hot rolling step of hot-rolling a steel slab with the chemical composition described above under a condition of a finish rolling temperature of 820°C or more to produce a hot-rolled steel sheet; a heating step of heating the steel sheet after the hot rolling step in the temperature range of 350°C or more and 600°C or less at an average heating rate of 7°C/s or more; an annealing step of annealing under conditions of an annealing temperature: 750°C or more and 900°C or less and an annealing time: 20 seconds or more; after the annealing step, a first cooling step of cooling under conditions of an average cooling rate of 7°C/s or more from (the annealing temperature - 30°C) to 650°C and an average cooling rate of 14°C/s or less from 650°C to 500°C; after the first cooling step, a second cooling step of applying a tension of 2.0 kgf/mm^2 or more to the steel sheet in the temperature range of 300°C or more and 450°C or less, then subjecting the steel sheet to five 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 then cooling the steel sheet to a cooling stop temperature of 250°C or less; a reheating step of reheating the steel sheet to the temperature range of the cooling stop temperature or more and 440°C or less and holding the steel sheet for 20 seconds or more after the second cooling step; and optionally a cold rolling step of cold-rolling the steel sheet after the hot rolling step and before the heating step at a rolling reduction of 20% or more and 80% or less to produce a cold-rolled steel sheet.

[0175] In the present invention, a steel material (steel slab) can be melted by any method, for example, by a known melting method using a converter, an electric arc furnace, or the like. To prevent macrosegregation, a steel slab (slab) is preferably produced by continuous casting but may also be produced by ingot casting, thin slab casting, or the like. After a steel slab is produced, the steel slab may be temporarily cooled to room temperature and then reheated by a known method. Alternatively, without being cooled to room temperature, a steel slab may be subjected without problems to an energy-saving process, such as hot charge rolling or hot direct rolling, in which a hot slab is charged directly into a furnace

or is immediately rolled after slight heat retention.

(Hot Rolling Step)

[0176] For heating a slab, the slab heating 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.

[0177] The slab heating temperature is the surface temperature of the slab. A slab is formed into a sheet bar by rough rolling under typical conditions. At a low heating temperature, from the perspective of avoiding a trouble during hot rolling, the sheet bar is preferably heated with a bar heater or the like before finish rolling.

Finish rolling temperature: 820°C or more

[0178] Finish rolling reduces the ductility, flangeability, and bendability of the final material as a result of an increase in rolling load or an increase in rolling reduction in an unrecrystallized state of austenite and development of an abnormal microstructure elongated in the rolling direction. Thus, the finish rolling temperature is 820°C or more. The finish rolling temperature is preferably 830°C or more, more preferably 850°C or more. The finish rolling temperature is preferably 1080°C or less, more preferably 1050°C or less.

[0179] The coiling temperature after hot rolling is not particularly limited, but it is necessary to consider the case where the ductility, flangeability, and bendability of the final material degrade. Thus, the coiling temperature after hot rolling is preferably 300°C or more. The coiling temperature after hot rolling is preferably 700°C or less.

[0180] Rough-rolled sheets may be joined together during hot rolling to continuously perform finish rolling. A rough-rolled sheet may be temporarily coiled. 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. The friction coefficient in the rolling with lubrication is preferably 0.25 or less.

(Pickling Step)

[0181] A hot-rolled steel sheet thus produced may be pickled. Pickling can remove an oxide from the surface of a steel sheet and can therefore be performed to ensure high chemical convertibility and quality of coating of a high-strength steel sheet of the final product. Pickling may be performed once or may be divided into a plurality of times.

(Cold Rolling Step)

[0182] A pickled sheet after hot rolling or a hot-rolled steel sheet thus produced is cold-rolled as required. For cold rolling, after hot rolling, a pickled sheet may be directly cold-rolled or may be cold-rolled after heat treatment. Optionally, a cold-rolled steel sheet after the cold rolling may be pickled.

[0183] The cold rolling is, for example, multi-pass rolling requiring two or more passes, such as tandem multi-stand rolling or reverse rolling.

Rolling reduction of optional cold rolling: 20% or more and 80% or less

[0184] For cold rolling, the rolling reduction (cumulative rolling reduction ratio) in the cold rolling is preferably, but not limited to, 20% or more and 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. Thus, the rolling reduction in the cold rolling is preferably 20% or more. 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. Thus, the rolling reduction in the cold rolling is preferably 80% or less.

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

[0185] An embodiment of the present invention may include a first coating step of performing metal coating on one or both surfaces of a steel sheet after the hot rolling step (after a cold rolling step when cold rolling is performed) and before a heating step to form a metal coated layer (first coated layer).

[0186] 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).

[0187] 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.

[0188] 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.

[0189] The 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. Although Fe-based electroplating is described below as an example, the following conditions for the Fe-based electroplating can also be applied to another metal electroplating.

[0190] 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 Fe^{2+}. When the Fe ion content of an Fe-based electroplating bath is 0.5 mol/L or more in terms of 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.

[0191] 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.

[0192] 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^2 or more from the perspective of productivity and is preferably 150 A/dm^2 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.

[0193] 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 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.

(Heating Step)

[0194] An embodiment of the present invention includes a heating step of heating a steel sheet in the temperature range of 350°C or more and 600°C or less at an average heating rate of 7°C/s or more after the hot rolling step (after a cold rolling step when cold rolling is performed, after a metal coating step when metal coating is performed to form a metal coated layer (first coated layer), or after a metal coating step when cold rolling and metal coating are performed).

Average heating rate in temperature range of 350°C or more and 600°C or less: 7°C/s or more

[0195] In the present invention, λ, R/t, ST, and SFmax can be improved by increasing the average heating rate in the temperature range of 350°C or more and 600°C or less to increase the ratio of an isolated fine island-like hard second phase (martensite + retained austenite) in a ferrite grain. Thus, the average heating rate in the temperature range of 350°C or more and 600°C or less is 7°C/s or more, preferably 9°C/s or more.

[0196] Although the upper limit is not particularly limited, the average heating rate in the temperature range of 350°C or more and 600°C or less is preferably 100°C/s or less, more preferably 90°C/s or less.

The average heating rate (°C/s) is calculated by (final heating temperature (°C) - initial heating temperature (°C))/ heating time (s).

(Annealing Step)

[0197] An embodiment of the present invention includes an annealing step of annealing under conditions of an annealing temperature: 750°C or more and 900°C or less and an annealing time: 20 seconds or more after the heating step.

Annealing temperature: 750°C or more and 900°C or less

[0198] An annealing temperature of less than 750°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 undesired TS, YS, and YR.

[0199] On the other hand, at an annealing temperature of more than 900°C, the area fraction of ferrite cannot be 20.0% or more, and the ductility decreases.

[0200] Thus, the annealing temperature is 750°C or more and 900°C or less. The annealing temperature is preferably 880°C or less. The annealing temperature is the highest temperature reached in the annealing step.

Annealing time: 20 seconds or more

[0201] 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 TS, YS, and YR cannot be obtained. Thus, the annealing time is 20 seconds or more. The annealing time is preferably 30 seconds or more, more preferably 50 seconds or more.

[0202] 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.

[0203] 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.

[0204] The number of annealing processes may be two or more but is preferably one from the perspective of energy efficiency.

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

[0205] In an embodiment of the present invention, the dew point of the atmosphere in the annealing step (annealing atmosphere) is preferably -30°C or more. 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 in the annealing atmosphere in the annealing step is more preferably -25°C or more, even more preferably more than - 20°C, even further more preferably -15°C or more, most preferably -5°C or more.

[0206] 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. The dew point in the annealing atmosphere in the annealing step is preferably 25°C or less, more preferably 20°C or less.

(First Cooling Step)

[0207] The present invention includes, after the annealing step, a first cooling step of cooling under conditions of an average cooling rate of 7°C/s or more from (the annealing temperature - 30°C) to 650°C and an average cooling rate of 14°C/s or less from 650°C to 500°C.

Average cooling rate from (annealing temperature - 30°C) to 650°C: 7°C/s or more

[0208] In the present invention, rapid cooling in a high-temperature region of 650°C or more results in fine austenite left in a ferrite grain boundary and finally an increase in the ratio of an isolated fine island-like hard second phase (martensite + retained austenite) in a ferrite grain. Thus, the average cooling rate from (annealing temperature - 30°C) to 650°C is 7°C/s or more. The average cooling rate from (annealing temperature - 30°C) to 650°C is preferably 9°C/s or more.

[0209] The average cooling rate from (annealing temperature - 30°C) to 650°C is preferably 80°C/s or less, more preferably 60°C/s or less. The average cooling rate is even more preferably 30°C/s or less, even further more preferably 18°C/s or less.

The average cooling rate (°C/s) is calculated by (annealing temperature (°C) - 30(°C) - 650(°C))/cooling time (s).

Average cooling rate from 650°C to 500°C: 14°C/s or less

[0210] In the present invention, slow cooling in an intermediate-temperature region of 650°C or less causes fine austenite at a ferrite grain boundary, after coalescence of adjacent ferrite with similar orientation resulting in one ferrite grain, to form isolated fine island-like austenite left in the ferrite grain, and finally an increase in the ratio of an isolated fine island-like hard second phase (martensite + retained austenite) in the ferrite grain. Thus, the average cooling rate from 650°C to 500°C (first cooling stop temperature) is 14°C/s or less, preferably 12°C/s or less. The average cooling rate from 650°C to 500°C is preferably 1°C/s or more, more preferably 2°C/s or more.

The average cooling rate (°C/s) is calculated by (650(°C) - 500(°C))/cooling time (s).

(Galvanizing Step (Second Coating Step))

[0211] In the present invention, after the first cooling step, the steel sheet may be subjected to a galvanizing treatment. A galvanized steel sheet can be produced by the galvanizing treatment.

[0212] The galvanizing treatment is, for example, a hot-dip galvanizing treatment or a galvannealing treatment.

[0213] 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.

[0214] In the galvannealing treatment, after the hot-dip galvanizing treatment performed in the manner described above, a hot-dip 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.

[0215] 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 and makes it difficult to achieve a TS of 780 MPa or more. The alloying temperature is more preferably 500°C or more, even more preferably 510°C or more. The alloying temperature is more preferably 570°C or less.

[0216] The coating weight of each of the hot-dip galvanized steel sheet (GI) and the hot-dip galvannealed steel sheet (GA) is preferably 20 g/m^2 or more per side. The coating weight per side of the galvanized layer is preferably 80 g/m^2 or less. The coating weight can be adjusted by gas wiping or the like.

(Second Cooling Step)

[0217] The present invention includes, after the first cooling step (after a galvanizing step when the galvanizing step is performed), a second cooling step of applying a tension of 2.0 kgf/mm^2 or more to a steel sheet in the temperature range of 300°C or more and 450°C or less, subjecting the steel sheet to five 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 then cooling the steel sheet to a cooling stop temperature (second cooling stop temperature) of 250°C or less.

Tension applied in the temperature range of 300°C or more and 450°C or less: 2.0 kgf/mm^2 or more

[0218] In the present invention, as described above, applying a tension of 2.0 kgf/mm^2 or more to a steel sheet once or more can transform most of austenite into martensite by deformation-induced transformation (stress-strain-induced transformation), and subsequent tempering in the reheating step can reduce the area fraction of fresh martensite in the final microstructure and ensure an appropriate amount of tempered martensite. This can also reduce the amount of austenite immediately after the second cooling step and reduce the volume fraction of retained austenite in the final microstructure. Consequently, desired λ, R/t, ST, and SFmax can be achieved.

[0219] 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) $\times$ sheet width (mm)) (mm^2). The load cells should be arranged parallel to the direction of the tension.

[0220] 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.

[0221] The tension is preferably 2.2 kgf/mm^2 or more, more preferably 2.4 kgf/mm^2 or more. The tension is preferably 15.0 kgf/mm^2 or less, more preferably 10.0 kgf/mm^2 or less. The tension is even more preferably 7.0 kgf/mm^2 or less, even further more preferably 4.0 kgf/mm^2 or less.

[0222] The number of passes to which a 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: five or more passes

[0223] In the present invention, subjecting a steel sheet to five 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, can transform most of austenite into martensite by deformation-induced transformation (stress-strain-induced transformation), and subsequent tempering in the reheating step can reduce the area fraction of fresh martensite in the final microstructure and ensure an appropriate amount of tempered martensite. This can also reduce the amount of austenite immediately after the second cooling step and reduce the volume fraction of retained austenite in the final microstructure. Consequently, desired λ, R/t, ST, and SFmax can be achieved.

[0224] The number of passes is preferably six or more passes, more preferably seven or more passes.

[0225] Although the upper limit is not particularly limited, the number of passes is preferably ten or less passes, more preferably nine or less passes.

Cooling stop temperature: 250°C or less

[0226] The cooling conditions in the second cooling step are 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. Setting the cooling stop temperature (second cooling stop temperature) to 250°C or less can transform an appropriate amount of austenite into martensite, and subsequent tempering in the reheating step can reduce the area fraction of fresh martensite in the final microstructure and ensure an appropriate amount of tempered martensite. This can also reduce the amount of austenite immediately after the second cooling step and reduce the volume fraction of retained austenite in the final microstructure. Consequently, desired λ, R/t, ST, and SFmax can be achieved. From the perspective of preventing surface oxidation, cooling is preferably performed to 200°C or less. The lower limit is preferably, but not limited to, room temperature (-5°C or more and 55°C or less). The average cooling rate is preferably, for example, 1°C/s or more. The average cooling rate is preferably 50°C/s or less. The average cooling rate (°C/s) is calculated by (cooling start temperature (°C) - cooling stop temperature (°C))/cooling time (s).

(Reheating Step)

[0227] After the second cooling step, as a reheating step, the steel sheet is reheated to the temperature range of the cooling stop temperature (second cooling stop temperature) or more and 440°C or less and is held for 20 seconds or more.

Reheating temperature: the temperature range of the cooling stop temperature (second cooling stop temperature) or more and 440°C or less

Reheating holding time: 20 seconds or more

[0228] In the present invention, reheating to the cooling stop temperature (second cooling stop temperature) or more and holding for 20 seconds or more release diffusible hydrogen from steel. These can also reduce the area fraction of fresh martensite in the final microstructure and ensure an appropriate amount of tempered martensite. This can also reduce the amount of austenite immediately after the second cooling step and reduce the volume fraction of retained austenite in the final microstructure. Consequently, desired λ, R/t, ST, and SFmax can be achieved.

[0229] On the other hand, at a reheating temperature of more than 440°C, when a galvanizing treatment is performed, a zinc coating is partially melted and adheres to a roll, and a uniformly galvanized hot-dip galvanized steel sheet cannot be produced. When the reheating holding time is less than 20 seconds, a desired amount of diffusible hydrogen in steel is not released.

[0230] Thus, in the present invention, reheating is performed to the temperature range of the second cooling stop temperature or more and 440°C or less, and holding is performed for 20 seconds or more.

[0231] The reheating temperature is preferably 40°C or more, more preferably 160°C or more.

[0232] The reheating temperature is preferably 420°C or less, more preferably 320°C or less.

[0233] The reheating holding time is preferably 25 seconds or more, more preferably 30 seconds or more.

[0234] The reheating holding time is preferably 300 seconds or less, more preferably 200 seconds or less.

[0235] 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.

[0236] Other conditions of the production method are not particularly limited and, from the perspective of productivity, a series of these treatments, such as annealing, hot-dip galvanizing, and an alloying treatment of a zinc coating, are preferably performed in a continuous galvanizing line (CGL), which is a hot-dip galvanizing line. After the hot-dip galvanizing, the coating weight can be adjusted by wiping. Conditions for coating and the like other than these conditions may be based on a usual method for hot-dip galvanizing.

[3. Member]

[0237] Next, a member according to an embodiment of the present invention is described.

[0238] 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.

[0239] The steel sheet has a TS of 780 MPa or more, high YS and YR, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) in case of a collision. 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]

[0240] Next, a method for producing a member according to an embodiment of the present invention is described.

[0241] 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.

[0242] The forming method is, for example, but not limited to, a typical processing method, such as press working. A 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

[0243] 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.

[0244] The steel slab was heated to 1200°C and was then subjected to rough rolling and hot rolling to produce a hot-rolled steel sheet. Hot-rolled steel sheets No. 1 to No. 56, No. 60 to No. 83, No. 92 to No. 106, and No. 112 to No. 117 thus produced were pickled and cold-rolled to produce cold-rolled steel sheets with thicknesses shown in Tables 3, 5, and 7. Hot-rolled steel sheets No. 57 to No. 59, No. 84 to No. 91, and No. 107 to No. 111 were pickled to produce hot-rolled steel sheets (pickled) with thicknesses shown in Tables 3, 5, and 7.

[0245] The cold-rolled steel sheets or hot-rolled steel sheets (pickled) were subjected to the treatments in the heating step, the annealing step, the first cooling step, the galvanizing step, the second cooling step, and the reheating step under the conditions shown in Table 2 to produce steel sheets (galvanized steel sheets).

[0246] Treatments in the heating step, the first coating step (metal coating step), the annealing step, the first cooling step, the second coating step (galvanizing step), the second cooling step, and the reheating step were performed under the conditions shown in Table 4 to produce steel sheets (galvanized steel sheets).

[0247] Treatments in the heating step, the first coating step (metal coating step), the annealing step, the first cooling step, the second cooling step, and the reheating step were performed under the conditions shown in Table 6 to produce steel sheets.

[0248] In the galvanizing step shown in Tables 2 and 4, 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 galvannealed steel sheet (hereinafter also referred to as GA). In Tables 2 and 4, the type in the coating step is also denoted by "GI" and "GA". In the GI steel sheets in Tables 2 and 4, no alloying treatment was performed, and the alloying temperature is indicated by "-". In Table 6, no galvanizing treatment was performed, and the results are indicated as CR (cold-rolled steel sheet (without coating)) or HR (hot-rolled steel sheet (without coating)).

[0249] The galvanizing bath temperature was 470°C in the production of GI and GA.

[0250] The galvanizing coating weight ranged from 45 to 72 g/m^2 per side to produce GI and was 45 g/m^2 per side to produce GA.

[0251] The composition of the galvanized layer of the final hot-dip 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.

[0252] In both cases, the galvanized layer was formed on both surfaces of the base steel sheet.

[0253] In the steel sheet thus produced, the steel microstructure of the base steel sheet was identified in the manner described above. Tables 3, 5, and 7 show the measurement results. In Tables 3, 5, and 7, F denotes ferrite, M denotes martensite, RA denotes retained austenite, M' and RA' denote isolated island-like fresh martensite and isolated island-like retained austenite, B and BT denote bainite and tempered bainite, TM denotes tempered martensite, P denotes pearlite, θ denotes carbide, and F' denotes unrecrystallized ferrite.

[0254] 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-μm position to a 100-μm position in the thickness direction from the surface of the steel sheet at intervals of 1 μm. Measurement was then performed at intervals of 20 μm 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.

[0255] In Tables 1 to 7, the underlined portions indicate values outside the appropriate range of the present invention.

[0256] A tensile test, a hole expansion test, a V-bending test, a U-bending + tight bending test, a V-bending + orthogonal VDA bending test, and an axial compression test were performed in the manner described below. The tensile strength (TS), the yield stress (YS), the yield ratio (YR), the total elongation (El), the limiting hole expansion ratio (λ), R/t in the V-bending test, the critical spacer thickness (ST) in the U-bending + tight bending bending test, the stroke at the maximum load (SFmax) measured in the V-bending + orthogonal VDA bending test, and the presence or absence of fracture (appearance crack) in the axial compression test were evaluated in accordance with the following criteria.

- TS

[0257]

Good (pass): 780 MPa or more
Poor (fail): less than 780 MPa

- YS

[0258]

Good (pass):

(A) For 780 MPa $\leq$ TS < 980 MPa, 500 MPa $\leq$ YS
(B) For 980 MPa $\leq$ TS, 600 MPa $\leq$ YS

Poor (fail):

(A) For 780 MPa $\leq$ TS < 980 MPa, 500 MPa > YS
(B) For 980 MPa $\leq$ TS, 600 MPa > YS

- YR

[0259]

Good (pass):

(A) For 780 MPa $\leq$ TS < 980 MPa, 0.64 $\leq$ YR
(B) For 980 MPa $\leq$ TS, 0.61 $\leq$ YR

Poor (fail):

(A) For 780 MPa $\leq$ TS < 980 MPa, 0.64>YR
(B) For 980 MPa $\leq$ TS, 0.61>YR

- El

[0260]

Good (pass):

(A) For 780 MPa ≤ TS < 980 MPa, 19.0% ≤ El
(B) For 980 MPa ≤ TS, 15.0% ≤ El

Poor (fail):

(A) For 780 MPa ≤ TS < 980 MPa, 19.0% > El
(B) For 980 MPa ≤ TS, 15.0% > El

- λ

[0261]

Good (pass): 30% or more
Poor (fail): less than 30%

- R/t

[0262]

Good (pass):

(A) For 780 MPa ≤ TS < 980 MPa, 2.0 ≥ R/t
(B) For 980 MPa ≤ TS, 2.5 ≥ R/t

Poor (fail):

(A) For 780 MPa ≤ TS < 980 MPa, 2.0 < R/t
(B) For 980 MPa ≤ TS, 2.5 < R/t

- ST

[0263]

Good (pass):

(A) For 780 MPa ≤ TS < 980 MPa, 2.5 mm ≥ ST
(B) For 980 MPa ≤ TS, 4.0 mm ≥ ST

Poor (fail):

(A) For 780 MPa ≤ TS < 980 MPa, 2.5 mm < ST
(B) For 980 MPa ≤ TS, 4.0 mm < ST

- SFmax

[0264]

Good (pass)

(A) For 780 MPa ≤ TS < 980 MPa, 28.0 mm ≤ SFmax
(B) For 980 MPa ≤ TS, 26.5 mm ≤ SFmax

Poor (fail):

(A) For 780 MPa ≤ TS < 980 MPa, 28.0 mm > SFmax
(B) For 980 MPa ≤ TS, 26.5 mm > SFmax

- Presence or absence of axial compression fracture (appearance crack)

[0265]

Excellent (pass): No appearance crack was observed in the sample after the axial compression test.
Good (pass): No more than one appearance crack was observed in the sample after the axial compression test.
Poor (fail): Two or more appearance cracks were observed in the sample after the axial compression test.

(1) Tensile Test

[0266] 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, YR, and El of the test specimen were measured at a crosshead speed of 10 mm/min in the tensile test. Tables 3, 5, and 7 show the results.

(2) Hole Expansion Test

[0267] 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 λ (%) was determined using the following formula. λ is a measure for evaluating stretch flangeability. Tables 3, 5, and 7 show the results.

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

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

(3) V-Bending Test

[0268] The V (90-degree) bending test was performed in accordance with JIS Z 2248 (2014).

[0269] A 100 mm x 35 mm test specimen was taken from the steel sheet by shearing and end grinding. The sides of 100 mm are parallel to the width (C) direction.

Bending radius R: change in 0.5 mm pitch
Test method: die support, punch pressing
Forming load: 10 ton
Test speed: 30 mm/min
Holding time: 5 s
Bending direction: direction (C) perpendicular to rolling direction

[0270] The evaluation was performed three times, and R/t was calculated by dividing the minimum bending radius (critical bending radius) R with no crack by the sheet thickness t. A cleavage with a length of 200 μm or more was determined as a crack using a stereomicroscope manufactured by Leica at a magnification of 25 times. At a TS of 780 MPa or more and less than 980 MPa, 2.0 ≥ R/t was determined to be good, and at a TS of 980 MPa or more, 2.5 ≥ R/t was determined to be good.

(4) U-bending + Tight Bending Test

[0271] The U-bending + tight bending test was performed as described below.

[0272] A 60 mm x 30 mm test specimen was taken from the steel sheet by shearing and end grinding. The sides of 60 mm are parallel to the width (C) direction. U-bending (primary bending) was performed at a radius of curvature/thickness ratio of 4.2 in the width (C) direction with respect to an axis extending in the rolling (L) direction to prepare a test specimen. In the U-bending (primary bending), as illustrated in Fig. 2(a), a punch B1 was pressed against a steel sheet on rolls A1 to prepare a test specimen T1. Next, as illustrated in Fig. 2(b), tight bending (secondary bending) was performed in which the test specimen T1 on a lower die A2 was crushed with an upper die B2. In Fig. 2(a), D1 denotes the width (C) direction, and D2 denotes the rolling (L) direction. A spacer S described later is inserted in the test specimen.

[0273] The conditions for U-bending in the U-bending + tight bending test are as follows:

Test method: roll support, punch pressing
Punch tip R: 5.0 mm
Clearance between roll and punch: sheet thickness + 0.1 mm
Stroke speed: 10 mm/min
Bending direction: direction (C) perpendicular to rolling direction

[0274] The conditions for tight bending in the U-bending + tight bending test are as follows:

Spacer thickness: change in 0.5 mm pitch
Test method: die support, punch pressing
Forming load: 10 ton
Test speed: 10 mm/min
Holding time: 5 s
Bending direction: direction (C) perpendicular to rolling direction

[0275] The U-bending + tight bending test was performed three times, and the critical spacer thickness (ST) without cracking in any of the three tests was determined. A cleavage with a length of 200 μm or more was determined as a crack using a stereomicroscope manufactured by Leica at a magnification of 25 times. ST is a measure for evaluating fracture resistance characteristics (fracture resistance characteristics of a vertical wall portion in the axial compression test) in case of a collision. Tables 3, 5, and 7 show the results.

(5) V-bending + Orthogonal VDA Bending Test

[0276] The V-bending + orthogonal VDA bending test is performed as described below.

[0277] A 60 mm × 65 mm test specimen was taken from the steel sheet by shearing and end grinding. 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. 3(a), a punch B3 was pressed against a steel sheet on a die A3 with a V-groove to prepare a test specimen T1. Next, as illustrated in Fig. 3(b), the test specimen T1 on support rolls A4 was subjected to orthogonal bending (secondary bending) by pressing a punch B4 against the test specimen T1 in the direction perpendicular to the rolling direction. In Figs. 3(a) and 3(b), D1 denotes the width (C) direction, and D2 denotes the rolling (L) direction.

[0278] The V-bending conditions in the V-bending + orthogonal VDA bending test are as follows:

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

[0279] The VDA bending conditions in the V-bending + orthogonal VDA bending test are as follows:

Test method: roll support, punch pressing
Roll diameter: φ30 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 × 60 mm
Bending direction: direction (C) perpendicular to rolling direction

[0280] The stroke at the maximum load was determined in a stroke-load curve of the VDA bending. The average value of the stroke at the maximum load when the V-bending + orthogonal VDA bending test was performed three times was defined as SFmax (mm). SFmax is a measure for evaluating fracture resistance characteristics (fracture resistance characteristics of a bending ridge line portion in the axial compression test) in case of a collision. Tables 3, 5, and 7 show the results.

(6) Axial Compression Test

[0281] A 160 mm × 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. 4(a) and 4(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 × 100 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. 4(a) and 4(b). Fig. 4(a) is a front view of the test member 30 produced by spot-welding the hat-shaped member 10 and the steel sheet 20. Fig. 4(b) is a perspective view of the test member 30. As illustrated in Fig. 4(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. 4(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. 4(c), the compression direction D3 was a direction parallel to the longitudinal direction of the test member 30. Tables 3, 5, and 7 show the results.

[0282] The U-bending + tight bending test, the V-bending + orthogonal 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.

[0283] Since grinding may affect the bendability of the surface of a steel sheet, the ground surface in the U-bending + tight bending bending test was the inside of the bend (valley side), and the ground surface in the V-bending + orthogonal VDA bending test was the outside of the bend (mountain side) in the V-bending test and was the inside of the bend (valley side) in the subsequent VDA bending test. On the other hand, in the U-bending + tight bending test, the V-bending + orthogonal 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.

<Nanohardness Measurement>

[0284] 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 × 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 SFmax.

[0285] In the present example, when coating was performed, peeling the coating 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 × 50 μm, and
Dot-to-dot distance: 2 μm.

[0286] 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 × 50 μm, and
Dot-to-dot distance: 2 μm.

[Table 1-1]

Steel grade	Chemical composition (mass%)								Note
	C	Si	Mn	P	S	Al	N	Others	
A	0.115	0.65	2.85	0.009	0.0008	0.038	0.0031	-	Conforming steel
B	0.120	0.55	2.80	0.010	0.0009	0.580	0.0038	-	Conforming steel
C	0.085	0.15	2.45	0.012	0.0012	0.035	0.0032	-	Conforming steel
D	0.350	0.50	2.50	0.015	0.0013	0.035	0.0038	-	Comparative steel
E	0.010	0.45	2.75	0.009	0.0012	0.029	0.0048	-	Comparative steel
F	0.110	1.25	2.80	0.011	0.0018	0.030	0.0035	-	Comparative steel
G	0.100	0.50	3.85	0.016	0.0009	0.025	0.0034	-	Comparative steel
H	0.110	0.55	1.50	0.014	0.0018	0.028	0.0035	-	Comparative steel
I	0.100	0.70	2.70	0.009	0.0010	0.042	0.0028	Nb:0.035	Conforming steel
J	0.105	0.65	2.75	0.010	0.0009	0.028	0.0022	Ti:0.035	Conforming steel
K	0.095	0.65	2.60	0.008	0.0009	0.030	0.0034	Ti:0.025, B:0.0025	Conforming steel
L	0.090	0.55	2.65	0.012	0.0015	0.042	0.0037	Nb:0.015, Ti:0.025, B:0.0015	Conforming steel
M	0.070	0.15	2.25	0.014	0.0033	0.025	0.0028	Nb:0.015, Ti:0.025, B:0.0020, Cr:0.550	Conforming steel
N	0.090	0.55	2.75	0.013	0.0056	0.022	0.0026	Nb:0.015, Ti:0.025, B:0.0020	Conforming steel
O	0.135	0.55	2.70	0.010	0.0008	0.035	0.0025	Nb:0.020, Ti:0.015, B:0.0015	Conforming steel
P	0.045	0.60	2.65	0.015	0.0013	0.037	0.0046	Nb:0.015, Ti:0.020, B:0.0020	Conforming steel
Q	0.090	0.72	2.60	0.018	0.0028	0.032	0.0037	Nb:0.015, Ti:0.020, B:0.0015	Conforming steel

(continued)

Steel grade	Chemical composition (mass%)								Note
	C	Si	Mn	P	S	Al	N	Others	
R	0.085	0.08	2.70	0.010	0.0041	0.055	0.0030	Nb:0.020, Ti:0.020, B:0.0020	Conforming steel
S	0.090	0.55	3.15	0.001	0.0015	0.038	0.0026	Nb:0.015, Ti:0.025, B:0.0025	Conforming steel
T	0.085	0.60	2.10	0.011	0.0022	0.041	0.0026	Nb:0.025, Ti:0.015, B:0.0020	Conforming steel
U	0.085	0.65	2.65	0.012	0.0018	0.030	0.0031	V:0.045	Conforming steel
V	0.090	0.55	2.70	0.008	0.0016	0.042	0.0036	Cu:0.180	Conforming steel
W	0.095	0.50	2.55	0.007	0.0010	0.033	0.0025	Cr:0.090	Conforming steel
X	0.075	0.45	2.65	0.008	0.0008	0.055	0.0026	Ni:0.120	Conforming steel
Y	0.065	0.55	2.85	0.007	0.0020	0.045	0.0030	Mo:0.200	Conforming steel
Z	0.120	0.60	2.90	0.006	0.0007	0.035	0.0030	Sb:0.009	Conforming steel
- The remainder other than these is Fe and incidental impurities.									

[Table 1-2]

Steel grade	Chemical composition (mass%)								Note
	C	Si	Mn	P	S	Al	N	Others	
AA	0.085	0.45	2.70	0.009	0.0008	0.040	0.0036	Sn:0.018	Conforming steel
AB	0.115	0.50	2.25	0.007	0.0010	0.033	0.0025	Nb:0.035, Ta:0.008	Conforming steel
AC	0.080	0.55	2.70	0.008	0.0008	0.055	0.0026	Ta:0.007	Conforming steel
AD	0.075	0.45	2.35	0.012	0.0028	0.045	0.0022	W:0.040	Conforming steel
AE	0.065	0.50	2.65	0.004	0.0022	0.031	0.0052	Mg:0.0055	Conforming steel
AF	0.085	0.60	2.85	0.008	0.0010	0.035	0.0034	Zn:0.0070	Conforming steel
AG	0.070	0.55	2.55	0.010	0.0012	0.039	0.0030	Co:0.0090	Conforming steel
AH	0.080	0.50	2.70	0.013	0.0015	0.029	0.0025	Zr:0.0030	Conforming steel
AI	0.100	0.55	2.45	0.026	0.0019	0.052	0.0048	Ca:0.0017	Conforming steel

(continued)

Steel grade	Chemical composition (mass%)								Note
	C	Si	Mn	P	S	Al	N	Others	
AJ	0.085	0.45	2.65	0.013	0.0005	0.031	0.0042	Se:0.0080	Conforming steel
AK	0.090	0.50	2.80	0.012	0.0024	0.031	0.0062	Te:0.0150	Conforming steel
AL	0.080	0.55	2.55	0.030	0.0008	0.036	0.0032	Ge:0.0050	Conforming steel
AM	0.100	0.40	2.35	0.010	0.0036	0.033	0.0076	As:0.0230	Conforming steel
AN	0.090	0.60	2.25	0.045	0.0019	0.033	0.0045	Sr:0.0060	Conforming steel
AO	0.085	0.55	2.65	0.008	0.0023	0.035	0.0032	Cs:0.0110	Conforming steel
AP	0.125	0.25	2.50	0.010	0.0032	0.032	0.0033	Hf:0.0080	Conforming steel
AQ	0.070	0.35	2.75	0.023	0.0025	0.042	0.0035	Pb:0.0110	Conforming steel
AR	0.080	0.50	2.70	0.011	0.0014	0.045	0.0038	Bi:0.0040	Conforming steel
AS	0.095	0.45	2.60	0.045	0.0019	0.033	0.0045	REM:0.0025	Conforming steel
AT	0.065	0.12	2.21	0.012	0.0038	0.029	0.0035	Nb:0.190, Ti:0.190, V:0.180, B:0.0085, Cr:0.950, Ni:0.960, Mo:0.950, Sb:0.190, Sn:0.180, Cu:0.900, Ta:0.095, W:0.450, Mg:0.0170, Zn:0.0180, Co:0.0180, Zr:0.0930, Ca:0.0180, Se:0.0190, Te:0.0185, Ge:0.0190, As:0.0400, Sr:0.0180, Cs:0.0185, Hf:0.0185, Pb:0.0190, Bi:0.0190, REM:0.0190	Conforming steel
- The remainder other than these is Fe and incidental impurities.									

[Table 2-1]

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
1	A	890	51.7	11	810	120	13	8	GA	530	2.8	9	50	200	60	Inventive example
2	B	870	64.7	10	820	150	12	7	GA	520	2.4	8	30	210	80	Inventive example
3	C	900	50.0	14	810	200	14	9	GA	530	2.6	7	50	200	100	Inventive example
4	D	860	53.8	13	820	100	15	7	GA	510	3.0	10	50	200	60	Comparative example
5	E	870	50.0	9	810	90	10	5	GA	520	2.2	7	40	180	50	Comparative example
6	F	900	50.0	15	800	150	13	6	GA	530	2.4	6	50	240	80	Comparative example
7	Q	920	51.7	14	800	60	12	7	GI	-	2.2	8	30	220	100	Comparative example
8	H	860	53.8	16	810	150	14	8	GA	500	2.8	7	50	200	60	Comparative example
9	I	890	41.7	12	830	200	13	9	GA	520	2.6	10	80	300	200	Inventive example
10	J	920	37.9	13	820	50	12	8	GA	510	2.9	9	70	250	100	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
11	K	900	529	14	800	250	14	7	GI	-	2.6	7	30	200	80	Inventive example
12	L	870	56.3	10	790	150	15	8	GA	540	3.0	6	50	250	100	Inventive example
13	M	880	53.8	15	810	120	10	5	GA	520	2.5	8	40	200	60	Inventive example
14	N	890	57.1	13	800	200	13	7	GA	530	2.6	7	30	200	60	Inventive example
15	N	700	56.3	12	810	100	12	6	GA	520	2.9	9	50	250	100	Comparative example
16	N	870	58.6	3	790	150	14	7	GA	540	3.2	8	30	200	80	Comparative example
17	N	890	46.2	13	700	150	13	5	GI	-	2.6	7	40	200	60	Comparative example
18	N	920	57.1	14	800	5	15	8	GA	530	3.0	6	50	200	40	Comparative example
19	N	900	440	14	820	140	2	6	GA	510	2.6	8	60	250	100	Comparative example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
20	N	880	53.8	12	810	100	14	20	GI	-	2.9	9	50	250	150	Comparative example
21	N	870	35.7	13	810	120	16	6	GA	520	0.8	9	30	170	40	Comparative example
22	N	890	56.5	16	820	200	13	9	GA	530	2.1	3	40	180	30	Comparative example
23	N	890	56.5	17	790	120	14	9	GA	530	3.4	6	350	210	100	Comparative example
24	N	900	53.8	13	800	120	13	6	GA	530	2.5	7	30	500	60	Comparative example
25	N	890	57.1	11	820	300	13	5	GA	530	2.9	7	50	200	5	Comparative example
26	O	870	50.0	12	810	150	11	8	GA	520	2.8	10	30	180	80	Inventive example
27	P	890	58.6	14	800	120	13	7	GA	540	2.4	9	40	230	100	Inventive example
28	Q	860	440	13	810	100	12	9	GI	-	2.6	6	50	190	60	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
29	R	890	48.4	16	860	150	14	7	GA	540	2.5	8	70	240	80	Inventive example

(*1) Average heating rate: average heating rate between 350°C and 600°C
(*2) Average cooling rate (1): average cooling rate between (annealing temperature - 30°C) and 650°C
(*3) Average cooling rate (2): average cooling rate between 650°C and 500°C

[Table 2-2]

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
30	S	870	56.3	12	820	80	13	5	GA	500	2.9	12	60	190	40	Inventive example
31	T	880	53.8	13	810	100	13	8	GA	500	3.2	9	220	420	60	Inventive example
32	U	900	429	11	800	60	12	7	GA	520	2.9	6	40	180	120	Inventive example
33	V	890	62.5	12	810	120	14	11	GA	530	2.8	8	50	240	100	Inventive example
34	W	860	37.9	14	820	300	12	4	GA	510	2.4	9	30	180	50	Inventive example
35	X	900	50.0	13	810	180	11	7	GA	520	2.6	6	150	350	60	Inventive example
36	Y	850	23.1	10	800	400	12	4	GA	490	3.4	7	50	200	90	Inventive example
37	Z	870	429	14	810	200	13	7	GA	520	3.8	11	30	250	100	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
38	AA	900	41.7	12	860	200	12	6	GI	-	2.8	9	60	200	100	Inventive example
39	AB	840	50.0	11	850	70	14	8	GA	540	3.6	7	40	220	900	Inventive example
40	AC	890	43.8	17	800	100	13	4	GA	510	3.2	9	30	230	600	Inventive example
41	AD	880	61.5	13	820	150	12	7	GA	520	3.1	8	50	200	180	Inventive example
42	AE	830	50.0	11	880	40	14	6	GA	580	2.6	9	80	250	80	Inventive example
43	AF	950	62.5	14	800	90	12	12	GA	520	3.0	6	70	200	70	Inventive example
44	AG	870	51.7	13	820	200	14	8	GI	-	2.2	8	40	220	100	Inventive example
45	AH	930	38.5	13	810	150	13	6	GA	510	2.4	7	50	240	80	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
46	AI	910	71.4	20	820	180	17	12	GA	540	2.6	8	30	190	60	Inventive example
47	AJ	890	56.3	12	760	120	14	10	GA	520	3.0	10	100	200	180	Inventive example
48	AK	900	53.8	12	810	90	11	7	GA	530	3.8	10	60	250	60	Inventive example
49	AL	880	429	14	820	150	13	6	GA	500	3.0	7	50	200	50	Inventive example
50	AM	920	62.5	13	890	100	14	10	GA	540	2.6	8	40	240	150	Inventive example
51	AN	870	44.8	11	800	200	12	8	GA	520	2.2	7	50	220	60	Inventive example
52	AO	860	53.8	14	810	250	13	7	GA	500	2.4	9	30	250	180	Inventive example
53	AP	890	56.3	12	870	100	14	6	GA	550	2.6	7	50	200	100	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	Heating step	Annealing step		First cooling step		Galvanizing step		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
54	AQ	900	53.8	13	810	90	15	8	GA	520	3.8	9	40	190	30	Inventive example
55	AR	890	60.0	11	800	150	14	8	GA	530	2.6	8	40	240	50	Inventive example
56	AS	860	46.2	14	840	100	13	7	GI	-	3.0	7	30	200	100	Inventive example
57	N	850	-	11	790	200	11	5	GA	510	2.6	8	50	200	60	Inventive example
58	N	870	-	10	790	220	10	5	GA	530	3.2	10	40	250	60	Inventive example
59	N	900	-	9	770	250	9	4	GA	520	3.6	9	30	200	60	Inventive example

(*1) Average heating rate: average heating rate between 350°C and 600°C
(*2) Average cooling rate (1): average cooling rate between (annealing temperature - 30°C) and 650°C
(*3) Average cooling rate (2): average cooling rate between 650°C and 500°C

[Table 3-1]

No.	Steel grade	Sheet thickness (mm)	Steel microstructure							Amount of diffusible hydrogen in steel (ppm by mass)	YS (MPa)	TS (MPa)	YR (-)	El (%)	λ (%)	R/t	U-bending+ tight bending ST (mm)	V-bending+ VDA bending SFmax (mm)	Axial compression characteristics (appearance crack)	Type	Note
			Area fraction of each phase(*1)						Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)											
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)														
1	A	1.4	55.4	3.2	1.4	0.82	1.8	37.2	θ	0.32	0.10	695	1055	0.66	18.0	42	1.07	3.5	27.4	Excellent	GA	Inventive example
2	B	1.2	54.3	3.8	1.0	0.81	1.9	38.1	θ	0.31	0.08	674	1033	0.65	17.1	40	1.25	3.0	28.4	Excellent	GA	Inventive example
3	C	1.6	68.9	4.5	2.1	0.91	1.0	22.4	θ	0.23	0.06	568	835	0.68	22.4	48	0.63	2.0	29.2	Excellent	GA	Inventive example
4	D	1.2	28.6	23.8	9.5	0.67	0.6	36.3	θ	1.83	0.09	1021	1382	0.74	10.8	12	4.17	8.5	24.6	Poor	GA	Comparative example
5	E	1.4	84.2	6.3	0.2	0.71	0.4	7.9	θ	0.09	0.15	393	698	0.56	25.4	62	1.07	1.0	30.1	Good	GA	Comparative example
6	F	1.6	42.6	8.9	10.8	0.70	2.4	34.2	θ,P	0.34	0.06	725	1065	0.68	16.5	18	1.88	5.5	25.9	Poor	GA	Comparative example
7	G	1.4	47.8	25.8	2.8	0.71	0.4	22.8	θ	0.59	0.09	924	1492	0.62	10.4	31	3.21	9.0	24.9	Poor	GI	Comparative example
8	H	1.2	81.9	4.8	0.5	0.89	11.2	1.4	θ	0.05	0.10	378	658	0.57	26.3	61	0.42	1.0	30.3	Good	GA	Comparative example
9	I	1.4	54.2	3.5	1.8	0.81	1.6	38.6	θ	0.33	0.12	695	1062	0.65	17.7	38	1.43	3.5	27.3	Excellent	GA	Inventive example
10	J	1.8	55.1	3.1	2.0	0.87	2.1	37.4	θ	0.27	0.15	695	1028	0.68	17.2	43	0.83	2.5	28.5	Excellent	GA	Inventive example
11	K	1.6	52.9	4.0	1.6	0.89	1.4	38.9	θ	0.25	0.09	695	1059	0.66	18.2	45	0.63	3.0	27.9	Excellent	GI	Inventive example
12	L	1.4	54.2	4.2	1.9	0.85	1.9	37.5	θ	0.29	0.07	695	1044	0.67	17.9	45	1.07	2.5	28.6	Excellent	GA	Inventive example
13	M	1.2	68.2	4.3	2.2	0.93	0.8	23.4	θ	0.20	0.09	573	815	0.70	23.4	48	0.42	1.5	29.7	Excellent	GA	Inventive example
14	N	1.2	54.8	2.8	1.8	0.85	1.3	38.8	θ	0.28	0.08	700	1070	0.65	18.2	44	0.83	2.5	28.7	Excellent	GA	Inventive example
15	N	1.4	32.4	16.8	4.8	0.54	4.3	16.7	θ,F'	1.65	0.07	1021	1124	0.91	15.2	21	3.21	7.5	25.6	Poor	GA	Comparative example
16	N	1.2	51.8	3.4	1.6	0.39	1.6	36.2	θ,F'	2.11	0.08	635	1020	0.62	17.2	22	2.92	6.5	24.6	Poor	GA	Comparative example
17	N	1.4	81.2	2.1	1.3	0.71	0.4	8.5	θ,F'	0.05	0.09	385	667	0.58	24.2	54	0.71	1.0	30.3	Good	GI	Comparative example
18	N	1.2	82.4	2.0	1.1	0.72	0.2	7.1	θ,F'	0.03	0.12	412	693	0.59	23.8	52	0.83	1.5	30.5	Good	GA	Comparative example
19	N	1.4	56.7	8.6	2.0	0.38	1.1	30.4	θ	1.82	0.07	712	1058	0.67	17.8	28	2.86	4.5	26.1	Poor	GA	Comparative example
20	N	1.2	55.8	8.8	1.8	0.35	1.4	30.9	θ	2.18	0.06	724	1074	0.67	17.4	25	2.92	5.0	25.8	Poor	GI	Comparative example
21	N	1.8	65.2	17.2	4.5	0.74	3.2	9.2	θ	0.78	0.05	615	991	0.62	17.9	27	2.78	4.5	26.2	Poor	GA	Comparative example
22	N	1.0	66.2	16.3	4.7	0.73	2.7	9.1	θ	0.85	0.09	620	989	0.63	17.5	26	3.00	5.0	25.6	Poor	GA	Comparative example
23	N	1.0	66.2	17.1	4.3	0.77	2.4	9.3	θ	0.82	0.13	613	992	0.62	17.3	28	3.00	4.5	26.1	Poor	GA	Comparative example
24	N	1.2	64.8	17.2	4.8	0.72	3.1	9.7	θ	0.69	0.65	629	1021	0.62	16.7	15	4.58	6.5	24.6	Poor	GA	Comparative example
25	N	1.2	65.1	16.5	4.9	0.75	2.9	9.5	θ	0.72	0.68	625	1007	0.62	16.9	13	4.58	7.0	24.9	Poor	GA	Comparative example
26	O	1.6	49.1	12.1	2.3	0.81	2.0	32.8	θ	0.82	0.24	720	1124	0.64	16.1	36	2.19	3.5	26.7	Good	GA	Inventive example
27	P	1.2	72.9	6.3	0.2	0.73	0.4	18.8	θ	0.03	0.08	512	791	0.65	24.9	52	0.83	2.0	28.5	Excellent	GA	Inventive example
28	Q	1.4	52.6	8.9	2.8	0.79	2.7	31.2	θ,P	0.22	0.28	667	1049	0.64	17.4	33	2.14	3.5	26.8	Good	GI	Inventive example
29	R	1.6	29.4	6.6	1.0	0.81	2.2	59.5	θ	0.28	0.07	745	1124	0.66	15.9	35	1.88	3.0	27.1	Excellent	GA	Inventive example

(*1) F: ferrite, M: fresh martensite, RA: retained austenite, M': island-like fresh martensite, RA': island-like retained austenite, B: bainite, BT: tempered bainite, TM: tempered martensite, P: pearlite, θ: carbide, F': unrecrystallized ferrite

(*2) (M'+RA')/(M+RA): the value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite in the entire steel sheet

(*3) The average grain size of M' and RA': the average grain size of island-like fresh martensite and island-like retained austenite in a ferrite grain

[Table 3-2]

No.	Steel grade	Sheet thickness (mm)	Steel microstructure							Amount of diffusible hydrogen in steel (ppm by mass)	YS (MPa)	TS (MPa)	YR (-)	El (%)	λ (%)	R/t	U-bending+ tight bending ST (mm)	V-bending+ VDA bending SFmax (mm)	Axial compression characteristics (appearance crack)	Type	Note
			Area fraction of each phase(*1)						Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)											
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)														
30	S	1.4	49.1	13.7	2.0	0.72	1.2	33.3	θ	0.81	0.25	712	1089	0.65	17.4	37	2.50	3.5	26.7	Good	GA	Inventive example
31	T	1.2	73.2	5.2	1.2	0.75	3.2	12.2	θ	0.12	0.03	523	789	0.66	24.9	48	0.83	2.0	28.7	Excellent	GA	Inventive example
32	U	1.6	60.2	2.5	0.8	0.85	1.0	34.6	θ	0.29	0.21	668	998	0.67	18.9	39	0.94	3.0	27.2	Excellent	GA	Inventive example
33	V	1.2	50.1	5.2	1.0	0.82	0.8	42.4	θ	0.45	0.08	675	1028	0.66	17.8	43	1.25	2.5	28.2	Excellent	GA	Inventive example
34	W	1.8	52.2	4.0	1.2	0.81	1.4	40.4	θ	0.38	0.38	694	1053	0.66	17.2	38	0.83	3.0	27.1	Excellent	GA	Inventive example
35	X	1.6	54.8	2.9	2.0	0.82	1.9	37.5	θ	0.21	0.04	702	1061	0.66	17.7	39	0.94	3.5	27.3	Excellent	GA	Inventive example
36	Y	2.0	54.2	3.5	1.7	0.86	1.2	38.6	θ	0.53	0.12	687	1008	0.68	17.5	50	0.75	2.5	28.5	Excellent	GA	Inventive example
37	Z	1.6	54.8	3.8	2.1	0.83	2.1	35.8	θ	0.38	0.09	688	1059	0.65	18.2	42	0.94	3.0	27.2	Excellent	GA	Inventive example
38	AA	1.4	52.4	5.8	2.2	0.90	1.5	37.4	θ	0.31	0.11	667	1033	0.65	17.4	40	0.71	3.5	28.2	Excellent	GI	Inventive example
39	AB	1.6	56.1	2.9	1.0	0.87	0.9	38.6	θ	0.27	0.09	695	1022	0.68	17.8	45	0.94	2.5	27.1	Excellent	GA	Inventive example
40	AC	1.8	56.9	4.3	1.5	0.89	1.2	35.7	θ	0.29	0.10	702	1034	0.68	17.3	40	0.83	3.0	27.9	Excellent	GA	Inventive example
41	AD	1.0	52.2	3.9	1.4	0.84	0.8	40.6	θ	0.39	0.08	654	1062	0.62	18.1	41	1.00	3.5	27.3	Excellent	GA	Inventive example
42	AE	1.4	54.2	2.7	1.0	0.91	1.4	39.2	θ	0.20	0.06	700	1055	0.66	17.2	42	1.07	3.0	28.0	Excellent	GA	Inventive example
43	AF	1.2	54.9	3.7	1.8	0.94	1.2	37.9	θ	0.28	0.09	639	999	0.64	18.7	52	1.25	3.0	27.8	Excellent	GA	Inventive example
44	AG	1.4	53.5	2.9	1.2	0.78	1.6	38.6	θ	0.31	0.15	677	1012	0.67	17.7	42	1.07	3.5	27.3	Excellent	GI	Inventive example
45	AH	1.6	52.1	4.8	2.0	0.85	1.5	37.2	θ	0.47	0.09	695	1029	0.68	17.5	43	0.94	2.5	28.3	Excellent	GA	Inventive example
46	AI	0.8	51.9	3.4	1.6	0.89	0.7	38.5	θ	0.55	0.24	691	1051	0.66	17.6	38	1.25	3.0	27.9	Excellent	GA	Inventive example
47	AJ	1.4	64.2	9.1	1.8	0.82	0.4	23.5	θ	0.19	0.10	685	982	0.70	18.9	52	1.07	3.5	27.1	Excellent	GA	Inventive example
48	AK	1.2	51.2	2.6	1.0	0.93	1.5	42.6	θ	0.20	0.11	698	1027	0.68	17.2	48	1.25	2.5	28.2	Excellent	GA	Inventive example
49	AL	1.6	55.8	3.9	1.5	0.88	0.6	37.4	θ	0.28	0.14	710	1033	0.69	18.2	41	0.94	3.0	27.2	Excellent	GA	Inventive example
50	AM	1.2	35.2	2.8	1.0	0.83	6.2	53.7	θ	0.37	0.07	712	1098	0.65	16.8	36	1.25	3.5	27.3	Excellent	GA	Inventive example
51	AN	1.6	55.5	3.1	1.2	0.87	0.9	35.9	θ	0.17	0.08	695	1025	0.68	18.2	43	0.94	3.0	28.4	Excellent	GA	Inventive example
52	AO	1.2	52.9	2.7	1.8	0.82	1.3	38.1	θ	0.29	0.07	690	1047	0.66	17.3	41	1.25	3.0	27.6	Excellent	GA	Inventive example
53	AP	1.4	43.2	5.2	2.0	0.85	1.4	47.4	θ	0.19	0.10	720	1091	0.66	16.4	35	1.07	3.5	27.3	Excellent	GA	Inventive example
54	AQ	1.2	54.2	3.5	1.6	0.90	0.7	38.2	θ	0.20	0.32	685	1029	0.67	17.2	41	0.83	2.5	28.1	Excellent	GA	Inventive example
55	AR	1.6	55.1	3.1	1.2	0.92	1.0	37.1	θ	0.32	0.09	666	1045	0.64	17.6	42	0.94	3.0	27.9	Excellent	GA	Inventive example
56	AS	1.4	56.9	2.8	1.5	0.85	0.6	36.6	θ	0.26	0.10	684	1023	0.67	17.7	44	1.07	3.5	27.2	Excellent	GI	Inventive example
57	N	2.6	54.2	3.7	1.9	0.80	1.0	37.2	θ	0.42	0.11	684	1025	0.67	17.5	41	0.58	2.5	27.3	Excellent	GA	Inventive example
58	N	2.9	51.2	3.9	2.0	0.78	1.2	38.9	θ	0.48	0.10	697	1012	0.69	17.8	43	0.52	3.0	27.5	Excellent	GA	Inventive example
59	N	3.2	52.8	4.2	2.2	0.75	1.4	38.9	θ	0.56	0.11	696	1005	0.69	18.2	45	0.47	3.0	27.8	Excellent	GA	Inventive example

(*1) F: ferrite, M: fresh martensite, RA: retained austenite, M': island-like fresh martensite, RA': island-like retained austenite, B: bainite, BT: tempered bainite, TM: tempered martensite, P: pearlite, θ: carbide, F': unrecrystallized ferrite

(*2) (M'+RA')/(M+RA): the value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite in the entire steel sheet

(*3) The average grain size of M' and RA': the average grain size of island-like fresh martensite and island-like retained austenite in a ferrite grain

[Table 4]

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/m-m^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
60	A	888	51.7	Absent	12	833	98	-28	17	4	GA	530	2.5	6	40	208	59	Inventive example
61	A	892	51.7	Absent	18	827	124	9	16	5	GA	500	3.8	9	53	202	58	Inventive example
62	A	899	51.7	Present (Fe)	11	820	196	-28	11	10	GA	540	3.5	6	34	201	28	Inventive example
63	A	915	51.7	Present (Fe)	11	826	139	9	18	4	GA	490	3.3	7	51	200	29	Inventive example
64	A	888	51.7	Present (Ni)	13	837	136	9	11	5	GA	500	2.6	8	41	199	63	Inventive example
65	A	863	51.7	Absent	15	806	138	9	18	9	GI	-	3.3	6	34	206	59	Inventive example
66	A	867	51.7	Present (Fe)	16	808	127	-28	14	5	GI	-	2.9	6	39	204	46	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/m-m^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
67	A	915	51.7	Present (Fe)	10	818	132	9	12	8	GI	-	2.7	6	38	193	26	Inventive example
68	M	860	53.8	Absent	16	810	154	-25	12	5	GA	520	2.5	8	35	208	52	Inventive example
69	M	925	53.8	Absent	17	827	200	5	10	10	GA	500	3.5	6	30	192	43	Inventive example
70	M	903	53.8	Present (Fe)	18	800	177	-25	15	7	GA	530	2.9	10	46	201	54	Inventive example
71	M	915	53.8	Present (Fe)	14	804	151	5	18	7	GA	500	3.3	10	38	198	63	Inventive example
72	M	876	53.8	Present (Ni)	17	834	194	5	12	9	GA	490	4.0	6	33	197	64	Inventive example
73	M	916	53.8	Absent	12	813	165	5	12	5	GI	-	2.3	7	54	197	58	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
74	M	892	53.8	Present (Fe)	10	800	92	-25	18	10	GI	-	3.1	9	53	199	67	Inventive example
75	M	864	53.8	Present (Fe)	14	817	128	5	10	5	GI	-	3.0	7	50	201	60	Inventive example
76	N	912	57.1	Absent	18	800	140	-20	18	9	GA	530	3.2	10	55	198	51	Inventive example
77	N	876	57.1	Absent	18	806	190	10	19	10	GA	510	2.0	7	55	201	62	Inventive example
78	N	922	57.1	Present (Fe)	17	807	142	-20	13	9	GA	540	3.9	8	35	210	65	Inventive example
79	N	921	57.1	Present (Fe)	13	839	179	10	18	6	GA	500	3.0	8	32	205	47	Inventive example
80	N	899	57.1	Present (Ni)	10	840	159	10	17	8	GA	510	4.0	9	37	199	63	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
81	N	900	57.1	Absent	16	826	109	10	19	10	GI	-	2.0	6	48	194	36	Inventive example
82	N	874	57.1	Present (Fe)	14	839	127	-20	15	9	GI	-	2.5	7	46	193	58	Inventive example
83	N	888	57.1	Present (Fe)	13	832	198	10	14	10	GI	-	2.8	7	39	190	44	Inventive example
84	N	907	-	Absent	9	798	167	-20	12	7	GA	520	3.0	10	55	206	63	Inventive example
85	N	895	-	Absent	10	805	213	10	9	5	GA	490	3.0	7	49	209	44	Inventive example
86	N	886	-	Present (Fe)	9	810	173	-20	10	7	GA	530	3.2	9	40	206	35	Inventive example
87	N	920	-	Present (Fe)	13	805	246	10	11	4	GA	500	3.8	10	43	190	43	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/m-m^2)	Number of passes (-)	Second cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
88	N	873	-	Present (Ni)	9	798	239	10	12	3	GA	510	3.4	6	43	192	26	Inventive example
89	N	878	-	Absent	11	813	216	10	11	6	GI	-	3.9	9	42	192	42	Inventive example
90	N	890	-	Present (Fe)	11	794	200	-20	10	5	GI	-	3.9	7	35	201	35	Inventive example
91	N	904	-	Present (Fe)	10	808	204	10	12	6	GI	-	3.2	9	50	207	67	Inventive example

(*1) Average heating rate: average heating rate between 350°C and 600°C
(*2) Average cooling rate (1): average cooling rate between (annealing temperature - 30°C) and 650°C
(*3) Average cooling rate (2): average cooling rate between 650°C and 500°C

[Table 5-1]

No.	Steel grade	Sheet thickness (mm)	Steel microstructure								Amount of diffusible hydrogen in steel (ppm by mass)	Surface layer		Nanohardness of sheet surface			Type	Note
			Area fraction of each phase(*1)						Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)		Soft layer thickness (μm)	Metal coating weight (g/m^2) (*4)	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)		
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)										
60	A	1.4	64.7	2.5	2.4	0.85	1.3	28.1	θ	0.38	0.08	11	-	0.17	2.0	2.4	GA	Inventive example
61	A	1.4	56.7	3.3	1.9	0.81	1.2	35.7	θ	0.43	0.14	38	-	0.05	1.4	1.6	GA	Inventive example
62	A	1.4	58.3	3.9	2.2	0.77	3.1	32.3	θ	0.37	0.16	14	9.0	0.19	1.6	2.0	GA	Inventive example
63	A	1.4	56.4	5.0	1.5	0.86	0.1	33.3	θ	0.39	0.22	48	9.0	0.02	0.6	0.7	GA	Inventive example
64	A	1.4	52.9	4.6	0.4	0.86	0.7	28.7	θ	0.48	0.12	47	9.0	0.03	0.7	0.9	GA	Inventive example
65	A	1.4	64.0	3.5	1.3	0.86	3.0	28.1	θ	0.46	0.05	37	-	0.06	1.5	1.5	GI	Inventive example
66	A	1.4	58.1	3.4	0.6	0.88	2.5	34.6	θ	0.36	0.12	15	9.0	0.18	1.6	1.9	GI	Inventive example
67	A	1.4	60.7	4.1	1.6	0.76	1.9	29.5	θ	0.35	0.19	50	9.0	0.01	0.5	0.7	GI	Inventive example
68	M	1.2	72.1	3.2	1.3	0.79	0.4	22.0	θ	0.24	0.19	9	-	0.16	2.0	2.4	GA	Inventive example
69	M	1.2	71.9	4.8	1.0	0.80	1.5	20.6	θ	0.24	0.07	36	-	0.05	1.3	1.4	GA	Inventive example
70	M	1.2	71.4	3.4	1.2	0.93	2.9	20.8	θ	0.23	0.13	12	14.0	0.18	1.7	1.9	GA	Inventive example
71	M	1.2	70.5	2.6	2.2	0.81	2.2	19.8	θ	0.19	0.08	44	14.0	0.03	0.4	0.6	GA	Inventive example

(continued)

No.	Steel grade	Sheet thickness (mm)	Steel microstructure							Amount of diffusible hydrogen in steel (ppm by mass)	Surface layer		Nanohardness of sheet surface			Type	Note
			Area fraction of each phase(*1)					Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)		Soft layer thickness (μm)	Metal coating weight (g/m^2) (*4)	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)		
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)									
72	M	1.2	71.0	3.3	0.9	0.94	3.0	21.0	θ	0.21	0.10	43	14.0	0.03	0.7	1.0	GA	Inventive example
73	M	1.2	66.8	2.8	0.8	0.88	2.7	24.9	θ	0.18	0.21	35	-	0.04	1.2	1.3	GI	Inventive example
74	M	1.2	71.6	3.7	1.7	0.78	2.4	20.3	θ	0.26	0.11	15	14.0	0.17	1.6	1.8	GI	Inventive example
75	M	1.2	73.5	4.9	1.0	0.85	1.9	18.4	θ	0.22	0.08	51	14.0	0.02	0.3	0.5	GI	Inventive example
76	N	1.2	57.4	3.2	2.0	0.85	1.7	30.6	θ	0.37	0.22	8	-	0.19	1.9	2.3	GA	Inventive example
77	N	1.2	64.3	2.9	1.8	0.80	1.4	29.3	θ	0.28	0.18	35	-	0.06	1.5	1.6	GA	Inventive example
78	N	1.2	52.6	3.5	0.8	0.76	2.6	36.9	θ	0.34	0.10	11	12.0	0.20	1.7	2.0	GA	Inventive example
79	N	1.2	59.3	2.5	1.0	0.78	3.2	29.4	θ	0.50	0.17	46	12.0	0.01	0.7	0.8	GA	Inventive example
80	N	1.2	62.2	4.8	2.2	0.77	1.1	29.0	θ	0.38	0.16	44	12.0	0.02	0.8	1.0	GA	Inventive example
81	N	1.2	53.7	2.5	1.3	0.81	3.2	38.0	θ	0.30	0.14	36	-	0.05	1.4	1.5	GI	Inventive example
82	N	1.2	60.1	3.7	2.2	0.76	3.4	30.4	θ	0.28	0.12	13	12.0	0.19	1.6	1.9	GI	Inventive example
83	N	1.2	59.0	4.7	1.4	0.79	0.3	33.6	θ	0.34	0.17	49	12.0	0.01	0.6	0.7	GI	Inventive example

(continued)

No.	Steel grade	Sheet thickness (mm)	Steel microstructure								Amount of diffusible hydrogen in steel (ppm by mass)	Surface layer		Nanohardness of sheet surface			Type	Note
			Area fraction of each phase(*1)						Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)		Soft layer thickness (μm)	Metal coating weight (g/m^2) (*4)	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)		
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)										
84	N	3.2	59.2	3.0	0.8	0.87	0.1	34.2	θ	0.30	0.22	8	-	0.18	1.9	2.4	GA	Inventive example
85	N	3.2	59.9	3.5	1.2	0.83	0.6	31.5	θ	0.45	0.09	37	-	0.08	1.4	1.6	GA	Inventive example
86	N	3.2	56.4	4.2	2.1	0.84	1.2	36.0	θ	0.43	0.07	15	12.0	0.20	1.8	1.9	GA	Inventive example
87	N	3.2	54.9	2.5	1.6	0.81	0.1	39.7	θ	0.48	0.17	49	12.0	0.03	0.7	0.8	GA	Inventive example
88	N	3.2	58.8	3.3	1.5	0.94	1.8	33.9	θ	0.38	0.06	50	12.0	0.04	0.7	0.9	GA	Inventive example
89	N	3.2	53.6	3.2	2.4	0.91	3.4	35.3	θ	0.39	0.09	35	-	0.07	1.4	1.5	GI	Inventive example
90	N	3.2	61.9	3.9	1.1	0.82	3.1	29.8	θ	0.49	0.20	17	12.0	0.18	1.5	1.8	GI	Inventive example

(continued)

No.	Steel grade	Sheet thickness (mm)	Steel microstructure								Amount of diffusible hydrogen in steel (ppm by mass)	Surface layer		Nanohardness of sheet surface			Type	Note
			Area fraction of each phase(*1)						Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)		Soft layer thickness (μm)	Metal coating weight (g/m^2) (*4)	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)		
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)										
91	N	3.2	58.5	2.8	0.6	0.92	2.5	35.0	θ	0.49	0.08	48	12.0	0.01	0.6	0.7	GI	Inventive example

(*1) F: ferrite, M: fresh martensite, RA: retained austenite, M ':island-like fresh martensite, RA ':island-like retained austenite, B: bainite, BT: tempered bainite, TM: tempered martensite, θ: carbide

(*2) (M'+RA')/(M+RA): the value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite in the entire steel sheet

(*3) The average grain size of M' and RA': the average grain size of island-like fresh martensite and island-like retained austenite in a ferrite grain

(*4) Metal coating weight (g/m^2): first coating weight (g/m^2)

(*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 σ (GPa) 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 σ (Gpa) 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

[Table 5-2]

No.	YS (MPa)	TS (MPa)	YR	El (%)	λ (%)	R/t	U-bending+ tight bending ST (mm)	V-bending+ VDA bending SFmax (mm)	Axial compression characteristics (appearance crack)	Type	Note
60	659	1026	0.64	17.6	30	1.43	3.5	27.4	Good	GA	Inventive example
61	688	1056	0.65	19.0	39	0.71	2.5	28.3	Excellent	GA	Inventive example
62	654	1029	0.64	17.3	32	1.07	3.0	27.9	Excellent	GA	Inventive example
63	689	1001	0.69	17.9	37	0.00	1.5	29.0	Excellent	GA	Inventive example
64	661	1013	0.65	17.7	33	0.00	2.0	28.8	Excellent	GA	Inventive example
65	643	1011	0.64	18.7	38	0.71	2.5	28.1	Excellent	GI	Inventive example
66	664	1018	0.65	17.3	42	1.07	3.0	27.8	Excellent	GI	Inventive example
67	706	1047	0.67	17.1	35	0.00	1.5	28.9	Excellent	GI	Inventive example
68	550	794	0.69	22.9	37	0.83	2.0	29.0	Good	GA	Inventive example
69	590	792	0.74	21.4	43	0.42	1.0	29.8	Excellent	GA	Inventive example
70	549	839	0.65	20.3	43	0.42	1.5	29.5	Excellent	GA	Inventive example
71	598	853	0.70	21.3	37	0.00	0.0	30.3	Excellent	GA	Inventive example
72	565	842	0.67	20.9	42	0.00	0.0	30.1	Excellent	GA	Inventive example
73	565	849	0.67	21.4	43	0.42	1.0	29.7	Excellent	GI	Inventive example
74	560	854	0.66	20.7	34	0.42	1.5	29.5	Excellent	GI	Inventive example
75	585	794	0.74	20.3	34	0.00	0.0	30.1	Excellent	GI	Inventive example
76	720	1049	0.69	17.5	38	1.67	3.0	27.6	Good	GA	Inventive example
77	707	1067	0.66	18.7	40	0.83	2.0	28.4	Excellent	GA	Inventive example
78	686	1002	0.68	19.0	42	1.25	2.5	28.0	Excellent	GA	Inventive example
79	705	1031	0.68	17.4	45	0.00	1.0	29.2	Excellent	GA	Inventive example
80	681	1056	0.64	18.8	32	0.00	1.0	29.0	Excellent	GA	Inventive example

(continued)

No.	YS (MPa)	TS (MPa)	YR	El (%)	λ (%)	R/t	U-bending+ tight bending ST (mm)	V-bending+ VDA bending SFmax (mm)	Axial compression characteristics (appearance crack)	Type	Note
81	713	1033	0.69	18.5	36	0.83	2.0	28.3	Excellent	GI	Inventive example
82	702	1028	0.68	17.6	43	1.25	2.5	28.0	Excellent	GI	Inventive example
83	681	1038	0.66	18.6	40	0.00	1.0	29.3	Excellent	GI	Inventive example
84	660	1049	0.63	17.7	39	1.41	4.0	26.7	Good	GA	Inventive example
85	702	1023	0.69	18.8	43	0.94	3.5	27.5	Excellent	GA	Inventive example
86	640	1024	0.63	17.3	36	1.09	4.0	27.1	Excellent	GA	Inventive example
87	701	1045	0.67	17.3	36	0.31	2.0	28.2	Excellent	GA	Inventive example
88	681	1062	0.64	18.0	30	0.31	2.0	28.1	Excellent	GA	Inventive example
89	710	1047	0.68	17.4	36	0.94	3.5	27.4	Excellent	GI	Inventive example
90	700	1005	0.70	18.8	42	1.09	4.0	27.1	Excellent	GI	Inventive example
91	665	1023	0.65	17.5	31	0.31	2.0	28.1	Excellent	GI	Inventive example

[Table 6]

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/m-m^2)	Number of passes (-)	cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
92	A	876	53.8	Absent	12	785	90	-18	13	6	CR	-	2.8	6	30	182	48	Inventive example
93	A	882	53.8	Absent	13	788	84	10	12	5	CR	-	3.5	6	32	185	45	Inventive example
94	A	872	53.8	Present (Fe)	15	784	92	-18	13	6	CR	-	3.4	9	34	189	50	Inventive example
95	A	888	53.8	Present (Fe)	12	786	88	10	12	6	CR	-	3.3	8	33	181	46	Inventive example
96	A	870	53.8	Present (Ni)	14	788	80	10	12	5	CR	-	2.9	7	35	183	47	Inventive example
97	M	876	53.8	Absent	13	806	103	-10	11	7	CR	-	2.8	10	37	202	55	Inventive example
98	M	890	53.8	Absent	13	808	109	15	10	8	CR	-	3.7	6	38	204	56	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/m-m^2)	Number of passes (-)	cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
99	M	892	53.8	Present (Fe)	15	810	100	-10	10	7	CR	-	2.9	8	39	203	53	Inventive example
100	M	890	53.8	Present (Fe)	12	807	110	15	11	8	CR	-	3.8	6	38	200	57	Inventive example
101	M	885	53.8	Present (Ni)	11	805	107	15	10	7	CR	-	4.1	7	36	205	58	Inventive example
102	N	879	53.8	Absent	12	800	124	-20	12	6	CR	-	3.2	9	40	210	64	Inventive example
103	N	884	53.8	Absent	13	799	120	5	13	5	CR	-	2.8	9	41	211	67	Inventive example
104	N	890	53.8	Present (Fe)	12	802	128	-20	12	5	CR	-	3.8	9	39	209	63	Inventive example
105	N	882	53.8	Present (Fe)	14	801	130	5	12	6	CR	-	3.6	9	42	210	68	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/m-m^2)	Number of passes (-)	cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
10-6	N	884	53.8	Present (Ni)	15	798	122	5	13	5	CR	-	4.0	10	40	212	62	Inventive example
10-7	N	892	-	Absent	9	802	202	-15	9	5	HR	-	3.2	7	32	195	48	Inventive example
10-8	N	883	-	Absent	10	808	216	10	10	6	HR	-	3.4	7	31	190	44	Inventive example
10-9	N	886	-	Present (Fe)	9	810	208	-15	9	5	HR	-	3.1	8	29	189	41	Inventive example
11-0	N	894	-	Present (Fe)	9	803	222	10	9	5	HR	-	3.5	10	34	187	43	Inventive example
11-1	N	889	-	Present (Ni)	9	799	228	10	10	6	HR	-	3.3	10	32	192	49	Inventive example
11-2	Al	893	65.4	Absent	15	815	160	5	17	11	CR	-	2.9	9	30	180	50	Inventive example

(continued)

No.	Steel grade	Hot rolling step	Cold rolling step	First coating step (Metal Coating step)	Heating step	Annealing step			First cooling step		Second coating step (Galvanizing step)		Second cooling step			Reheating cooling		Note
		Finish rolling temperature (°C)	Rolling reduction (%)	Presence or absence (Coating type)	Average heating rate (*1) (°C/s)	Annealing temperature (°C)	Annealing time (s)	Dew point (°C)	Average cooling rate (1) (*2) (°C/s)	Average cooling rate (2) (*3) (°C/s)	Type	Alloying temperature (°C)	Tension (kgf/mm^2)	Number of passes (-)	cooling stop temperature (°C)	Reheating temperature (°C)	Holding time (s)	
11-3	AT	854	47.8	Absent	11	800	82	-12	10	7	CR	-	3.3	8	35	183	55	Inventive example
11-4	AT	862	47.8	Absent	12	796	80	8	11	7	CR	-	3.1	7	32	189	53	Inventive example
11-5	AT	848	47.8	Present (Fe)	11	805	85	-12	10	8	CR	-	2.9	9	36	185	52	Inventive example
11-6	AT	860	47.8	Present (Fe)	11	803	87	8	10	7	CR	-	3.2	8	34	180	56	Inventive example
11-7	AT	855	47.8	Present (Ni)	12	799	81	8	10	8	CR	-	3.4	9	30	182	51	Inventive example

(*1) Average heating rate: average heating rate between 350°C and 600°C
(*2) Average cooling rate (1): average cooling rate between (annealing temperature - 30°C) and 650°C
(*3) Average cooling rate (2): average cooling rate between 650°C and 500°C

[Table 7-1]

No.	Steel grade	Sheet thickness (mm)	Steel microstructure								Amount of diffusible hydrogen in steel (ppm by mass)	Surface layer		Nanohardness of sheet surface			Type	Note
			Area fraction of each phase(*1)						Microstruc-tu re of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)		Soft layer thickness (μm)	Metal coating weight (g/m^2) (*4)	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)		
			F (%)	M (%)	RA (%)	(M'+RA') /(M+RA) (*2) (-)	B+BT (%)	TM (%)										
92	A	1.2	63.2	2.9	2.8	0.84	1.5	28.3	θ	0.35	0.09	13	-	0.15	1.9	2.3	CR	Inventive example
93	A	1.2	56.3	3.1	1.8	0.82	1.3	35.5	θ	0.41	0.13	36	-	0.06	1.4	1.7	CR	Inventive example
94	A	1.2	57.7	3.2	2.3	0.76	3.3	32.5	θ	0.36	0.12	15	10.0	0.17	1.6	1.9	CR	Inventive example
95	A	1.2	57.3	4.5	1.9	0.84	0.7	34.8	θ	0.33	0.17	45	10.0	0.02	0.6	0.7	CR	Inventive example
96	A	1.2	56.9	4.3	0.8	0.83	0.9	35.7	θ	0.45	0.13	47	10.0	0.03	0.6	0.8	CR	Inventive example
97	M	1.2	72.0	3.5	1.1	0.77	0.7	22.2	θ	0.23	0.17	8	-	0.16	1.9	2.4	CR	Inventive example
98	M	1.2	71.5	4.3	1.0	0.79	1.5	20.6	θ	0.24	0.08	37	-	0.06	1.3	1.5	CR	Inventive example
99	M	1.2	71.4	3.4	1.5	0.90	2.6	20.5	θ	0.28	0.12	15	14.0	0.17	1.7	2.0	CR	Inventive example
100	M	1.2	71.8	2.6	2.3	0.83	2.1	19.6	θ	0.18	0.08	47	14.0	0.04	0.4	0.7	CR	Inventive example
101	M	1.2	71.2	3.1	0.9	0.94	3.2	21.0	θ	0.24	0.11	48	14.0	0.03	0.6	0.9	CR	Inventive example
102	N	1.2	60.4	3.3	2.2	0.85	1.7	30.8	θ	0.31	0.20	7	-	0.18	1.9	2.3	CR	Inventive example
103	N	1.2	63.1	2.9	1.9	0.80	1.5	29.2	θ	0.28	0.13	33	-	0.07	1.5	1.7	CR	Inventive example

(continued)

No.	Steel grade	Sheet thickness (mm)	Steel microstructure								Amount of diffusible hydrogen in steel (ppm by mass)	Surface layer		Nanohardness of sheet surface			Type	Note
			Area fraction of each phase(*1)						Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)		Soft layer thickness (μm)	Metal coating weight (g/m^2) (*4)	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)		
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)										
104	N	1.2	54.6	3.4	0.8	0.75	2.5	36.9	θ	0.32	0.10	12	12.0	0.17	1.6	2.0	CR	Inventive example
105	N	1.2	59.8	3.6	1.0	0.78	3.3	29.8	θ	0.47	0.12	45	12.0	0.02	0.6	0.8	CR	Inventive example
106	N	1.2	61.2	4.5	2.1	0.79	1.2	29.2	θ	0.39	0.15	44	12.0	0.02	0.7	0.9	CR	Inventive example
107	N	3.2	58.8	3.5	0.9	0.89	0.6	34.4	θ	0.31	0.22	9	-	0.19	2.0	2.4	HR	Inventive example
108	N	3.2	59.3	3.8	1.9	0.86	0.8	33.1	θ	0.43	0.08	39	-	0.08	1.4	1.7	HR	Inventive example
109	N	3.2	56.1	4.1	2.0	0.84	1.2	35.5	θ	0.41	0.09	16	12.0	0.18	1.8	1.9	HR	Inventive example
110	N	3.2	54.7	2.4	1.8	0.87	0.3	39.5	θ	0.45	0.13	50	12.0	0.04	0.7	0.9	HR	Inventive example
111	N	3.2	58.2	3.5	1.7	0.92	1.6	33.8	θ	0.39	0.07	52	12.0	0.03	0.6	0.9	HR	Inventive example
112	Al	0.9	52.5	3.1	1.8	0.88	0.9	39.9	θ	0.52	0.18	49	-	0.07	1.2	1.5	CR	Inventive example
113	AT	1.2	57.6	4.9	2.2	0.82	1.9	32.5	θ	0.33	0.12	6	-	0.17	2.0	2.3	CR	Inventive example
114	AT	1.2	60.1	3.8	2.1	0.83	1.4	31.3	θ	0.29	0.10	28	-	0.07	1.6	1.8	CR	Inventive example
115	AT	1.2	58.3	3.9	0.8	0.76	2.3	32.9	θ	0.32	0.09	10	10.0	0.14	1.6	2.0	CR	Inventive example

(continued)

No.	Steel grade	Sheet thickness (mm)	Steel microstructure								Amount of diffusible hydrogen in steel (ppm by mass)	Surface layer		Nanohardness of sheet surface			Type	Note
			Area fraction of each phase(*1)						Microstructure of the remainder (*1)	Average grain size of M' and RA' (*3) (μm)		Soft layer thickness (μm)	Metal coating weight (g/m^2) (*4)	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)		
			F (%)	M (%)	RA (%)	(M'+RA')/(M+RA) (*2) (-)	B+BT (%)	TM (%)										
116	AT	1.2	58.8	4.2	1.0	0.79	2.7	31.8	θ	0.43	0.11	40	10.0	0.04	0.8	1.0	CR	Inventive example
117	AT	1.2	60.2	4.7	2.1	0.80	2.2	29.2	θ	0.37	0.12	41	10.0	0.03	0.7	0.9	CR	Inventive example

(*1) F: ferrite, M: fresh martensite, RA: retained austenite, M ':island-like fresh martensite, RA ':island-like retained austenite, B: bainite, BT: tempered bainite, TM: tempered martensite, θ: carbide
(*2) (M'+RA')/(M+RA): the value obtained by dividing the total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by the sum of the area fraction of fresh martensite and the area fraction of retained austenite in the entire steel sheet
(*3) The average grain size of M' and RA': the average grain size of island-like fresh martensite and island-like retained austenite in a ferrite grain
(*4) Metal coating weight (g/m^2): first coating weight (g/m^2)
(*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 σ (GPa) 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 σ (Gpa) 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

[Table 7-2]

No.	YS (MPa)	TS (MPa)	YR (-)	El (%)	λ (%)	R/t	U-bending+ tight bending ST (mm)	V-bending+ VDA bending SFmax (mm)	Axial compression characteristics (appearance crack)	Type	Note
92	654	1038	0.63	17.2	32	1.67	3.5	27.1	Good	CR	Inventive example
93	692	1061	0.65	18.1	37	0.83	2.5	28.4	Excellent	CR	Inventive example
94	646	1028	0.63	17.4	33	1.25	3.0	28.1	Excellent	CR	Inventive example
95	682	1003	0.68	17.5	36	0.00	1.5	29.2	Excellent	CR	Inventive example
96	666	1015	0.66	17.8	32	0.00	1.5	28.9	Excellent	CR	Inventive example
97	552	796	0.69	22.8	38	0.83	2.0	29.0	Good	CR	Inventive example
98	578	793	0.73	21.3	41	0.42	1.0	29.9	Excellent	CR	Inventive example
99	565	834	0.68	21.1	42	0.42	1.5	29.6	Excellent	CR	Inventive example
100	595	833	0.71	21.4	39	0.00	0.0	30.5	Excellent	CR	Inventive example
101	563	841	0.67	20.9	42	0.00	0.0	30.3	Excellent	CR	Inventive example
102	712	1040	0.68	17.6	35	1.67	3.0	27.7	Good	CR	Inventive example
103	708	1062	0.67	16.9	43	0.83	2.0	28.3	Excellent	CR	Inventive example
104	691	1012	0.68	17.0	44	1.25	2.5	27.9	Excellent	CR	Inventive example
105	702	1021	0.69	17.4	46	0.00	1.0	29.1	Excellent	CR	Inventive example
106	689	1053	0.65	16.8	33	0.00	1.0	29.0	Excellent	CR	Inventive example
107	660	1038	0.64	19.2	42	1.41	4.0	26.8	Good	HR	Inventive example
108	672	1028	0.65	18.9	44	0.94	3.5	27.6	Excellent	HR	Inventive example
109	682	1024	0.67	19.4	38	1.09	4.0	27.2	Excellent	HR	Inventive example
110	700	1034	0.68	19.2	39	0.31	2.0	28.3	Excellent	HR	Inventive example
111	684	1039	0.66	19.1	36	0.31	2.0	28.2	Excellent	HR	Inventive example
112	694	1046	0.66	19.2	37	0.56	2.5	27.8	Excellent	CR	Inventive example

(continued)

No.	YS (MPa)	TS (MPa)	YR (-)	El (%)	λ (%)	R/t	U-bending+ tight bending ST (mm)	V-bending+ VDA bending SFmax (mm)	Axial compression characteristics (appearance crack)	Type	Note
113	682	1033	0.66	16.5	34	1.67	3.0	27.5	Good	CR	Inventive example
114	674	1018	0.66	16.4	41	0.83	2.0	28.1	Excellent	CR	Inventive example
115	679	1028	0.66	16.8	38	1.25	2.5	27.7	Excellent	CR	Inventive example
116	683	1010	0.68	17.0	45	0.00	1.0	29.3	Excellent	CR	Inventive example
117	680	1009	0.67	16.8	37	0.00	1.0	29.1	Excellent	CR	Inventive example

[0287] As shown in Tables 3, 5, and 7, all the inventive examples passed all the tensile strength (TS), the yield stress (YS), the yield ratio (YR), the total elongation (El), the limiting hole expansion ratio (λ), R/t in the V-bending test, the critical spacer thickness (ST) in the U-bending + tight bending bending test, and the stroke at the maximum load (SFmax) measured in the V-bending + orthogonal VDA bending test, and had no fracture (appearance crack) in the axial compression test.

[0288] In contrast, the comparative examples were not satisfactory in at least one of the tensile strength (TS), the yield stress (YS), the yield ratio (YR), the total elongation (El), the limiting hole expansion ratio (λ), R/t in the V-bending test, the critical spacer thickness (ST) in the U-bending + tight bending bending test, the stroke at the maximum load (SFmax) measured in the V-bending + orthogonal VDA bending test, and the presence or absence of fracture (appearance crack) in the axial compression test. In Tables 5 and 7, at a dew point of -30°C or more and -5°C or less, although the surface layer has a soft layer thickness of 17 μm or less and the fracture (appearance crack) in the axial compression test is rated as "Good", even when the surface layer has a soft layer thickness of 17 μm or less, in the presence of the metal coated layer, the fracture (appearance crack) in the axial compression test was rated as "Excellent".

[0289] 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 yield ratio (YR), the total elongation (El), the limiting hole expansion ratio (λ), R/t in the V-bending test, the critical spacer thickness (ST) in the U-bending + tight bending bending test, and the stroke at the maximum load (SFmax) measured in the V-bending + orthogonal VDA bending test, had no fracture (appearance crack) in the axial compression test, and had good characteristics of the present invention.

Reference Signs List

[0290]

10 hat-shaped member
20 steel sheet
30 test member
40 spot weld
50 base plate
60 impactor
A1 die
A2 support roll
A3 die
A4 support roll
B1 punch
B2 punch
B3 punch
B4 punch

D1 width (C) direction
D2 rolling (L) direction
D3 compression direction
S spacer
T1 test specimen
F ferrite
M martensite
RA retained austenite
M' isolated island-like fresh martensite
RA' isolated island-like retained austenite
B bainite
BT tempered bainite
TM tempered martensite

Industrial Applicability

[0291] The present invention enables the production of a steel sheet and a member with a TS of 780 MPa or more, high YS and YR, high press formability (ductility, flangeability, and bendability), and fracture resistance characteristics (bending fracture characteristics and axial compression characteristics) in case of a collision. A steel sheet and a member produced by a method according to the present invention can improve, for example, fuel efficiency due to the weight reduction of automobile bodies when used in automobile structural members and have significantly high industrial utility value.

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: 0.030% or more and 0.250% or less,
Si: 0.01% or more and 0.75% or less,
Mn: 2.00% or more and less than 3.50%,
P: 0.001% or more and 0.100% or less,
S: 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,
and has a steel microstructure,
as a microstructure at a quarter thickness position of the base steel sheet,

in which

an area fraction of ferrite: 20.0% or more and 80.0% or less,
an area fraction of fresh martensite: 15.0% or less,
an area fraction of retained austenite: 3.0% or less,
a value obtained by dividing a total area fraction of island-like fresh martensite and island-like retained austenite in a ferrite grain by a sum of an area fraction of fresh martensite and an area fraction of retained austenite in the entire steel sheet: 0.65 or more,
an area fraction of bainite and tempered bainite: 10.0% or less,
an area fraction of tempered martensite: 10.0% or more and 70.0% or less, and
the island-like fresh martensite and the island-like retained austenite in the ferrite grain has an average grain size of 2.0 μm or less, and
an amount of diffusible hydrogen in the base steel sheet is 0.50 ppm by mass or less, and the steel sheet has a tensile strength of 780 MPa or more.

2. The steel sheet according to Claim 1, wherein the chemical composition further contains, on a mass percent basis, at least one element 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.

3. The steel sheet according to claim 1 or 2, comprising 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 Claims 1 to 3, wherein

when a region of 200 μm 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 μm × 50 μm 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,
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 σ 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 σ of 2.2 GPa or less.

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.

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 under a condition of a finish rolling temperature of 820°C or more to produce a hot-rolled steel sheet;
a heating step of heating the steel sheet after the hot rolling step in a temperature range of 350°C or more and

600°C or less at an average heating rate of 7°C/s or more;
an annealing step of annealing under conditions of an annealing temperature: 750°C or more and 900°C or less and an annealing time: 20 seconds or more;
after the annealing step, a first cooling step of cooling under conditions of an average cooling rate of 7°C/s or more from (the annealing temperature - 30°C) to 650°C and an average cooling rate of 14°C/s or less from 650°C to 500°C;
after the first cooling step, a second cooling step of applying a tension of 2.0 kgf/mm^2 or more to the steel sheet in a temperature range of 300°C or more and 450°C or less, then subjecting the steel sheet to five 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 then cooling the steel sheet to a cooling stop temperature of 250°C or less;
a reheating step of reheating the steel sheet to a temperature range of the cooling stop temperature or more and 440°C or less and holding the steel sheet for 20 seconds or more after the second cooling step; and
optionally a cold rolling step of cold-rolling the steel sheet after the hot rolling step and before the heating step at a rolling reduction of 20% or more and 80% or less to produce a cold-rolled steel sheet.

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 hot rolling 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

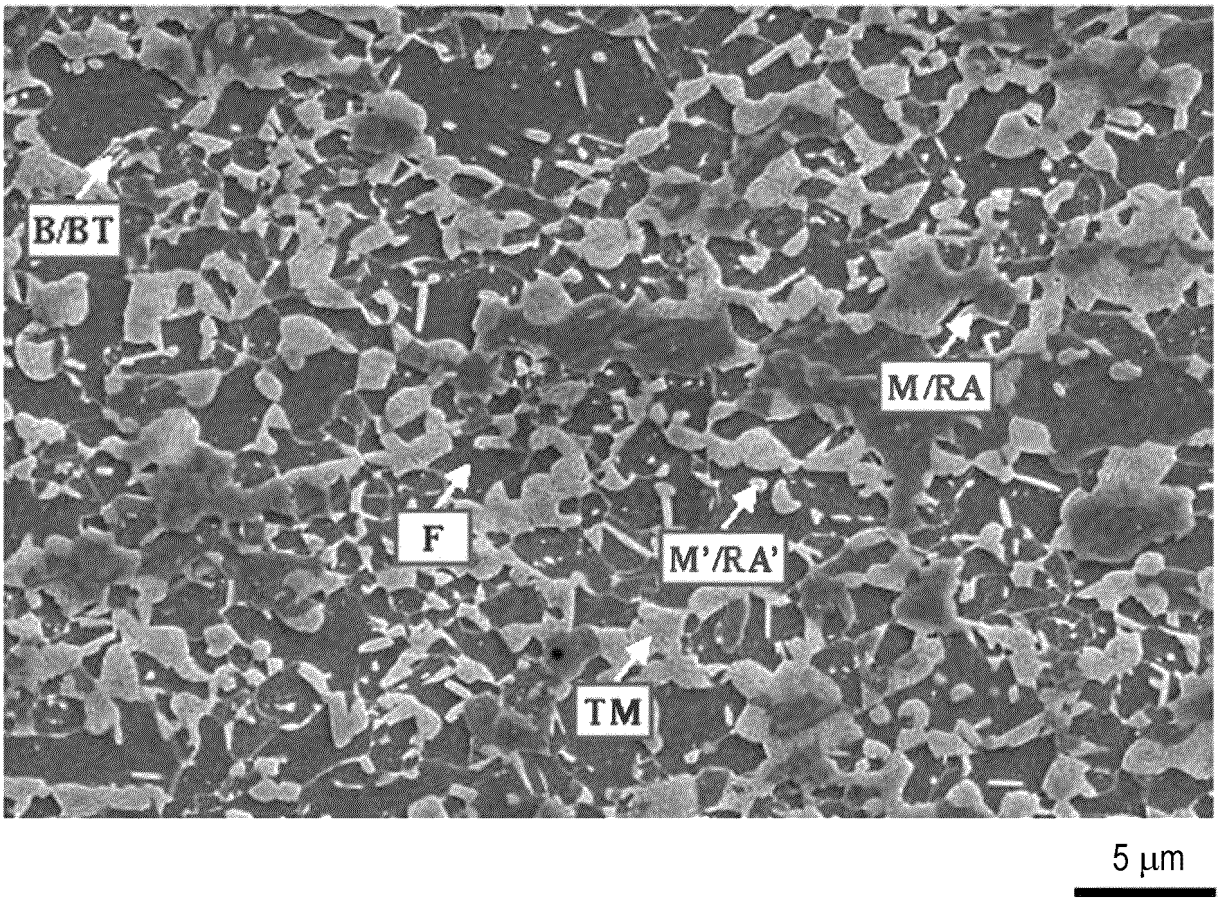


FIG. 2

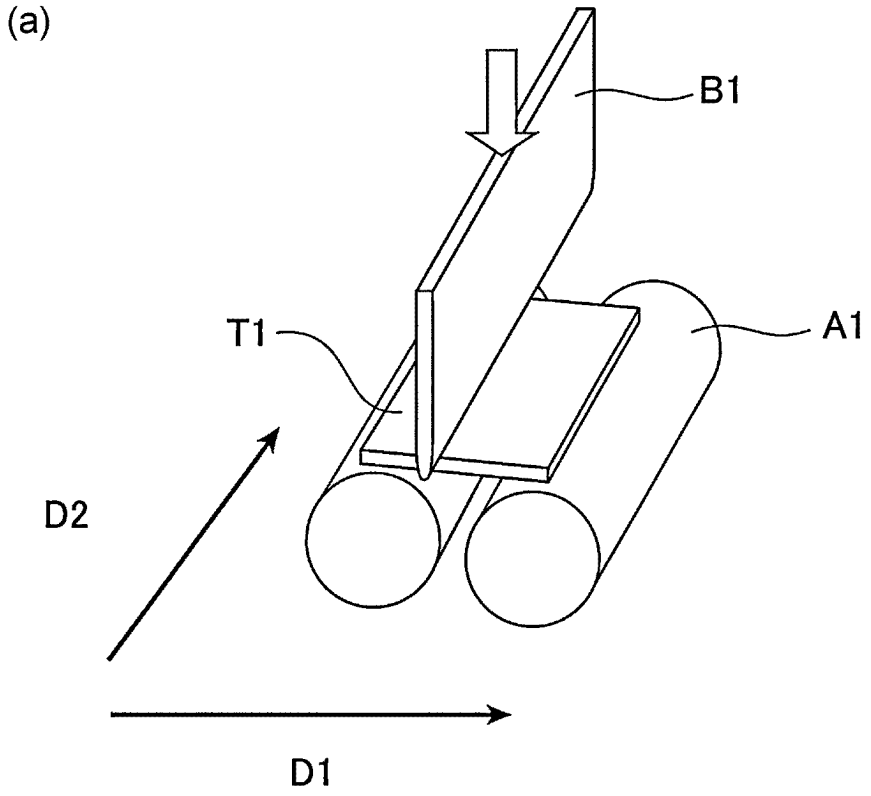


FIG. 3

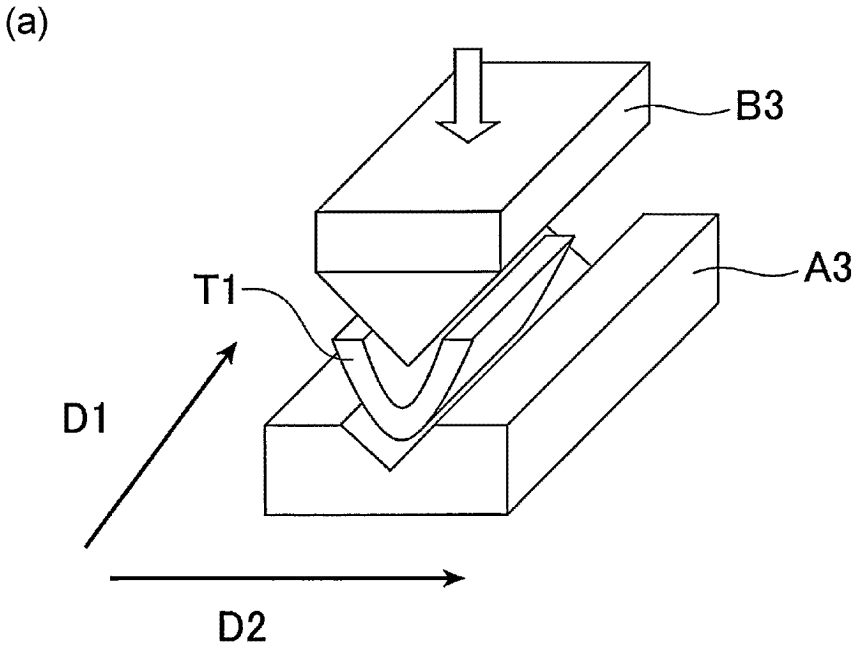
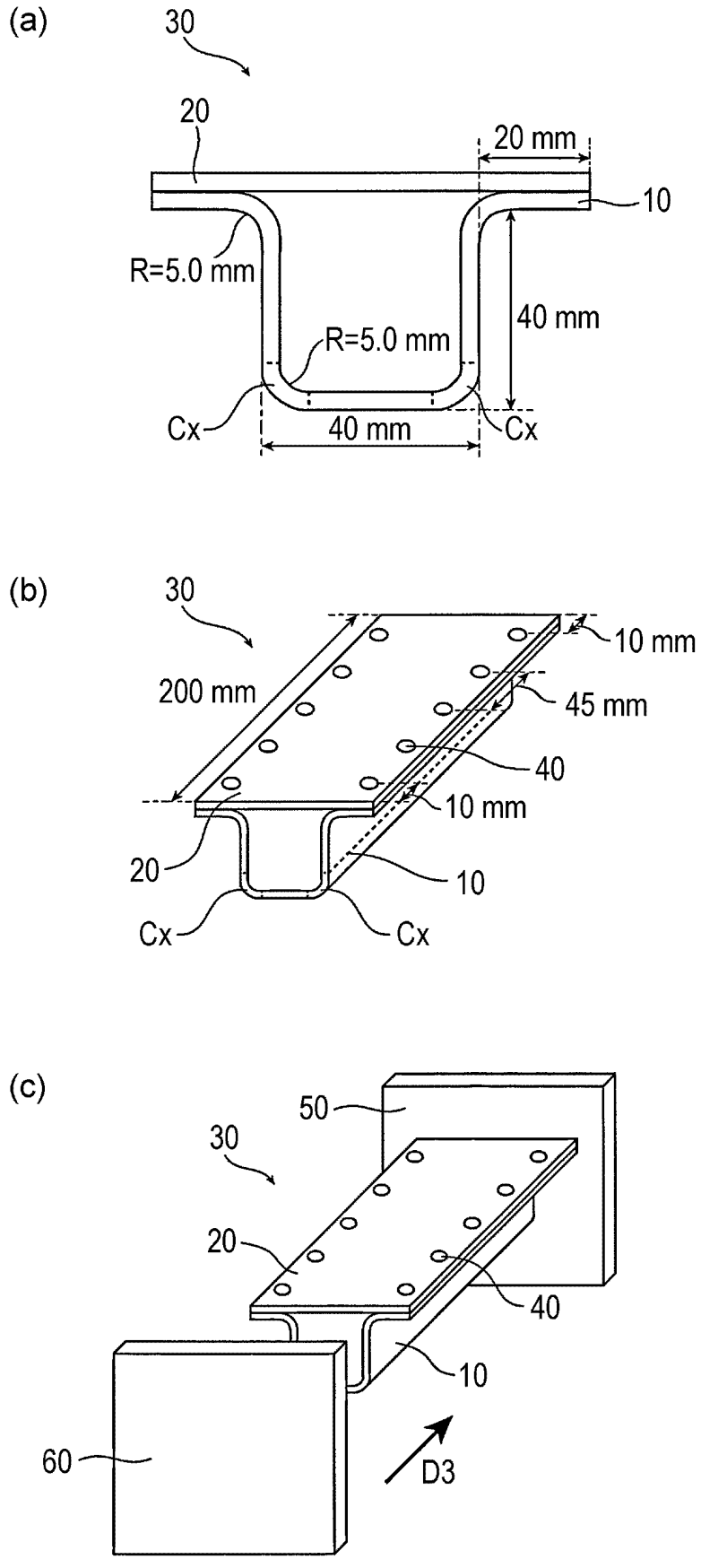


FIG. 4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20 mm
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R=5.0 mm
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R=5.0 mm
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40 mm
Cx
(b)
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200 mm
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10 mm
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Cx
Cx
(c)
50
30
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40
10
60
D3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/006924

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/06***(2006.01)i; ***C22C 38/60***(2006.01)i; *C22C 18/00*(2006.01)n
FI: C22C38/00 301S; C22C38/00 301T; C22C38/00 301W; C22C38/06; C22C38/60; C21D9/46 G; C21D9/46 J; C21D9/46 T; C21D9/46 U; C22C18/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60; C21D9/46; C22C18/00

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2020/170542 A1 (JFE STEEL CORP.) 27 August 2020 (2020-08-27)	1-11
A	WO 2019/189841 A1 (JFE STEEL CORP.) 03 October 2019 (2019-10-03)	1-11
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Date of the actual completion of the international search	Date of mailing of the international search report
24 April 2023	**16 May 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/006924

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