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(54) **STEEL SHEET, MEMBER, AND PRODUCTION METHODS THEREFOR**

(57) A steel sheet is provided that has high strength, is excellent in ductility and stretch-flangeability, and excels in the stability of mechanical properties in the width direction. A related member, and methods for manufacturing them are also provided.

The steel sheet has a chemical composition including, in mass%, C: 0.08 to 0.35%, Si: 0.4 to 3.0%, Mn: 1.5 to 3.5%, P: 0.02% or less, S: 0.01% or less, sol. Al: 1.0% or less, and N: 0.015% or less, the balance being Fe and

incidental impurities. The steel sheet includes a steel microstructure in which the area fraction of ferrite is 5% or less (including 0%), the total area fraction of tempered martensite and lower bainite is 70% or more, the volume fraction of retained austenite is 5 to 15%, and the area fraction of fresh martensite is 10% or less (including 0%). The steel sheet has a standard deviation of total elongation (EL) in the width direction of 0.9% or less.

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**Description**

## Technical Field

- 5 **[0001]** The present invention relates to a steel sheet and a member used in various applications, such as automobiles and home appliances, and to methods for manufacturing them.

## Background Art

- 10 **[0002]** In recent years, automobile members are more and more strengthened in order to reduce the weight of automobile bodies, and high-strength steel sheets with a tensile strength (TS) of 1180 MPa or more are used in automobile frame parts and seat parts. In general, the ductility and the stretch-flangeability of steel sheets are lowered with increasing strength. Steel sheets with a TS of 1180 MPa or more are easily cracked during press forming.

- 15 **[0003]** In order to ensure that a high-strength steel sheet with a TS of 1180 MPa or more will exhibit excellent press formability, it is important to design the steel sheet microstructure to include uniform tempered martensite, thereby enhancing stretch-flangeability, and also to finely disperse retained austenite, thereby enhancing ductility. Obtaining such a steel sheet microstructure entails complicated heat treatments. It is therefore industrially difficult to control temperature variations in the width direction of the steel sheet. There is thus a concern that press forming stability will be lowered by variations in ductility in the width direction.

- 20 **[0004]** Patent Literature 1 discloses a high-strength cold rolled steel sheet with excellent workability and impact resistance. The steel sheet contains, in mass%, C: 0.05 to 0.3%, Si: 0.3 to 2.5%, Mn: 0.5 to 3.5%, P: 0.003 to 0.100%, S: 0.02% or less, and Al: 0.010 to 0.5% and has a steel microstructure in which the steel microstructure includes ferrite: 20% or more, tempered martensite: 10 to 60%, martensite: 0 to 10%, and retained austenite: 3 to 15%, and the average crystal grain size of low-temperature transformation phases consisting of martensite, tempered martensite, and retained austenite is 3  $\mu\text{m}$  or less. The technique described in Patent Literature 1 utilizes a process so-called Q&P (quenching & partitioning; quenching and partitioning of carbon from martensite to austenite) in which the steel in a cooling process is cooled to a temperature range between the martensite start temperature ( $M_s$ ) and the martensite finish temperature ( $M_f$ ) and is subsequently reheated and held to stabilize retained  $\gamma$ . This process is recently used for the development of high-strength steels with excellent ductility and stretch-flangeability and methods for manufacturing such steels.

- 30 **[0005]** Patent Literature 2 discloses a high-strength steel sheet that has a tensile strength of 1200 MPa or more and exhibits excellent workability with a hole expansion ratio of 50% or more. The steel sheet contains, in mass%, C: 0.05 to 0.5%, Si: 0.01 to 2.5%, Mn: 0.5 to 3.5%, P: 0.003 to 0.100%, S: 0.02% or less, and Al: 0.010 to 0.5% and has a steel microstructure including 0 to 10% ferrite, 0 to 10% martensite, and 60 to 95% tempered martensite in area fractions, and 5 to 20% retained austenite according to X-ray diffractometry.

- 35 **[0006]** Patent Literature 3 discloses a method for manufacturing a high-strength steel sheet having excellent workability and tensile strength (TS) and also having excellent stability in mechanical properties. A steel sheet containing, in mass%, C: 0.10% to 0.73%, Si: 3.0% or less, Mn: 0.5% to 3.0%, P: 0.1% or less, S: 0.07% or less, Al: 3.0% or less, and N: 0.010% or less is heated to an austenite single-phase region or an (austenite + ferrite) two-phase region. The cooling stop temperature is set while using the martensite start temperature  $M_s$  as an indicator, and the steel sheet is cooled to the target cooling stop temperature within a temperature range from below  $M_s$  to ( $M_s - 150^\circ\text{C}$ ) to transform part of non-transformed austenite into martensite. The steel sheet is then heated to temper martensite. In this production of a high-strength steel sheet, the portion of the steel sheet that is coldest across the sheet width is held in a temperature range from the target cooling stop temperature to (cooling stop temperature +  $15^\circ\text{C}$ ) for 15 seconds or more and 100 seconds or less.

## Citation List

## Patent Literature

- 50 **[0007]**

PTL 1: Japanese Patent No. 5463685

PTL 2: Japanese Patent No. 5402007

PTL 3: Japanese Patent No. 5333298

## Summary of Invention

## Technical Problem

**[0008]** The conventional techniques described above each have the following problems.

**[0009]** The steel sheet reported in Patent Literature 1 is excellent in strength, ductility, and stretch-flangeability and has a product of tensile strength multiplied by total elongation ( $TS \times El$ ) of 22000 MPa·% or more and  $\lambda$  of 70% or more. However, the technique does not take into consideration the stability of mechanical properties in the width direction, and temperature variations that occur in the width direction of the steel sheet during a continuous annealing step may give rise to variations in mechanical properties.

**[0010]** While Patent Literature 2 suggests a steel sheet with excellent workability that has 1200 MPa or more TS, 50% or more  $\lambda$ , and 13% or more El, the technique does not take into consideration variations in ductility in the width direction. In view of the fact that the cooling rate during annealing is as high as 20°C/s or more, the steel sheet is likely to have variations in mechanical properties stemming from temperature variations in the width direction.

**[0011]** In the method for manufacturing a high-strength steel sheet proposed in Patent Literature 3, a steel sheet is heated to an austenite single-phase region or an (austenite + ferrite) two-phase region and is cooled to a target cooling stop temperature that is set within a temperature range from below  $M_s$  to ( $M_s - 150^\circ\text{C}$ ). In this production of a high-strength steel sheet, the portion of the steel sheet that is coldest across the sheet width is held in a temperature range from the target cooling stop temperature to (cooling stop temperature + 15°C) for 15 seconds or more and 100 seconds or less. In this manner, a high-strength steel sheet can be manufactured that is excellent in the stability of mechanical properties in the width direction and has a standard deviation of tensile strength in the width direction of 10 MPa or less and a standard deviation of El in the width direction of 2.0%. However, the standard deviation of El in the width direction is not necessarily sufficient and is still to be improved in order to achieve excellent press formability. Furthermore, the portion of the steel sheet that is coldest across the sheet width is held in a temperature range from the cooling stop temperature to (cooling stop temperature + 15°C). This holding requires a special control, for example, cooling of the steel sheet while checking the temperature distribution, and thus inhibits implementation.

**[0012]** The present invention has been made to solve the problems discussed above. It is therefore an object of the present invention to provide a steel sheet that has high strength, is excellent in ductility and stretch-flangeability, and excels in the stability of mechanical properties in the width direction. Another object of the present invention is to provide a related member and manufacturing methods.

**[0013]** In the present invention, high strength means that the tensile strength TS evaluated in accordance with JIS Z2241 (2011) is 1180 MPa or more.

**[0014]** Excellent ductility means that the total elongation (EL) evaluated in accordance with JIS Z2241 (2011) is 11.0% or more.

**[0015]** Excellent stretch-flangeability means that the limit hole expansion ratio  $\lambda$  (%) =  $\{(D_f - D_0)/D_0\} \times 100$  is 40% or more where  $D_f$ : hole diameter (mm) at the occurrence of cracking, and  $D_0$ : initial hole diameter (mm). Specifically, a 100 mm  $\times$  100 mm steel sheet is punched to create a 10 mm diameter hole with a clearance of 12% of the sheet thickness. While holding the steel sheet on a die having an inner diameter of 75 mm with a blank holder force of 88.2 kN, a 60° conical punch is pushed into the hole to measure the critical hole diameter at the occurrence of cracking.

**[0016]** Excellent stability of mechanical properties in the width direction means that the standard deviation of total elongation (EL) evaluated in accordance with JIS Z2241

(2011) is 0.9% or less. Specifically, a total of twenty JIS No. 5 test pieces for tensile test, including test pieces from both ends in the width direction, that extend parallel to the rolling direction are sampled at regular intervals in the width direction of the sheet and are tested.

## Solution to Problem

**[0018]** The present inventors carried out extensive studies directed to solving the problems described above. As a result, the present inventors have found that variations in mechanical properties in the width direction can be significantly reduced and the stability of press forming can be enhanced by controlling the temperature during coiling so as to homogenize the microstructure of a hot rolled sheet in the width direction and by gradually cooling the steel sheet from near the  $M_s$  temperature to the cooling stop temperature in an annealing step.

**[0019]** More specifically, the present invention provides the following:

[1] A steel sheet having a chemical composition including, in mass%,

C: 0.08 to 0.35%,  
Si: 0.4 to 3.0%,  
Mn: 1.5 to 3.5%,  
P: 0.02% or less,

S: 0.01% or less,  
 sol. Al: 1.0% or less, and  
 N: 0.015% or less,  
 the balance being Fe and incidental impurities,  
 the steel sheet including a steel microstructure in which: the area fraction of ferrite is 5% or less (including 0%), the  
 total area fraction of tempered martensite and lower bainite is 70% or more,  
 the volume fraction of retained austenite is 5 to 15%, and the area fraction of fresh martensite is 10% or less  
 (including 0%),  
 the steel sheet having a standard deviation of total elongation in the width direction of 0.9% or less.

[2] The steel sheet according to [1], wherein the chemical composition includes, in mass%, one, or two or more  
 selected from:

B: 0.01% or less,  
 Ti: 0.1% or less,  
 Cu: 1% or less,  
 Ni: 1% or less,  
 Cr: 1.5% or less,  
 Mo: 1.0% or less,  
 V: 0.5% or less,  
 Nb: 0.1% or less,  
 Zr: 0.2% or less, and  
 W: 0.2% or less.

[3] The steel sheet according to [1] or [2], wherein the chemical composition includes, in mass%, one, or two or more  
 selected from:

Ca: 0.0040% or less,  
 Ce: 0.0040% or less,  
 La: 0.0040% or less,  
 Mg: 0.0040% or less,  
 Sb: 0.1% or less, and  
 Sn: 0.1% or less.

[4] The steel sheet according to any one of [1] to [3], which has a coated layer on a surface of the steel sheet.

[5] A member obtained using the steel sheet described in any one of [1] to [4].

[6] A method for manufacturing a steel sheet, including:  
 a hot rolling step in which:

a steel slab having the chemical composition described in any one of [1] to [3] is  
 held at a slab heating temperature of 1100°C or above for 1800 seconds or more, and is subsequently finish hot  
 rolled at a finish rolling temperature of 850°C or above, and  
 the resultant steel sheet is cooled at an average cooling rate of 40°C/s or more in a temperature range from the  
 finish rolling temperature to 650°C, and is  
 coiled at a coiling temperature of 600°C or below under conditions where coiling takes place in the presence of a  
 maximum temperature difference in the width direction of 50°C or less from the temperature at the center of the  
 sheet width, thereby producing a hot rolled steel sheet;  
 a cold rolling step in which the hot rolled steel sheet is cold rolled with a rolling reduction ratio of 30% or more to give  
 a cold rolled steel sheet; and  
 an annealing step in which:

the cold rolled steel sheet is heated at an average heating rate HR1 of 0.5°C/s or more in a temperature range  
 from 700°C to ( $A_{c3} - 10^\circ\text{C}$ ),

held at an annealing temperature of ( $A_{c3} - 10^\circ\text{C}$ ) or above for 30 seconds or more,  
 cooled at an average cooling rate CR1 of 10°C/s or more in a temperature range from the annealing  
 temperature to a gradual cooling start temperature T1 equal to or higher than ( $M_s - 30^\circ\text{C}$ ) and equal to or  
 lower than ( $M_s + 30^\circ\text{C}$ ),

cooled at an average cooling rate CR2 of 1 to 10°C/s in a temperature range from the gradual cooling start temperature T1 to a gradual cooling stop temperature T2 equal to or higher than (Ms - 220°C) and equal to or lower than (Ms - 100°C),

heated at an average heating rate HR2 of 2°C/s or more in a temperature range from the gradual cooling stop temperature T2 to a reheating holding temperature T3 of 300°C or above and 450°C or below, held at the reheating holding temperature T3 for 20 seconds or more and 3000 seconds or less, and cooled at an average cooling rate CR3 of 0.1°C/s or more in a temperature range from the reheating holding temperature T3 to 50°C.

[7] The method for manufacturing a steel sheet according to [6], wherein the annealing step includes performing a hot-dip coating treatment or a hot-dip coating alloying treatment when the steel sheet is being cooled from the annealing temperature to the gradual cooling start temperature T1, or when the steel sheet is being reheated and held at the reheating holding temperature T3.

[8] The method for manufacturing a steel sheet according to [6], further including performing an electrocoating treatment after the annealing step.

[9] A method for manufacturing a member, including a step of subjecting the steel sheet described in any one of [1] to [4] to at least one working of forming or joining to produce a member.

#### Advantageous Effects of Invention

**[0020]** The present invention can provide a steel sheet that has high strength, is excellent in ductility and stretch-flangeability, and excels in the stability of mechanical properties in the width direction; a related member; and methods for manufacturing them.

#### Description of Embodiments

**[0021]** Embodiments of the present invention will be described below. The present invention is not limited to the following embodiments.

**[0022]** A steel sheet of the present invention has a chemical composition including, in mass%, C: 0.08 to 0.35%, Si: 0.4 to 3.0%, Mn: 1.5 to 3.5%, P: 0.02% or less, S: 0.01% or less, sol. Al: 1.0% or less, and N: 0.015% or less, the balance being Fe and incidental impurities. The steel sheet includes a steel microstructure in which the area fraction of ferrite is 5% or less (including 0%), the total area fraction of tempered martensite and lower bainite is 70% or more, the volume fraction of retained austenite is 5 to 15%, and the area fraction of fresh martensite is 10% or less (including 0%). The steel sheet has a standard deviation of total elongation (EL) in the width direction of 0.9% or less.

**[0023]** First, the chemical composition of the steel sheet of the present invention will be described. In the following description of the chemical composition, the unit "%" for the contents of components means "mass%". Furthermore, the term "high strength" in the present invention means that the tensile strength TS is 1180 MPa or more.

(C: 0.08 to 0.35%)

**[0024]** Carbon is added to increase the strength of tempered martensite or lower bainite and ensure a TS of 1180 MPa or more. When the C content is less than 0.08%, the desired TS cannot be obtained stably. Thus, the C content is limited to 0.08% or more. The C content is preferably 0.10% or more, and more preferably 0.14% or more.

On the other hand, excessive addition of carbon leads to a decrease in stretch-flangeability due to the increase in the number density of carbides, and a decrease in ductility, and further deteriorates the shape fixability of parts as a result of an excessive increase in YS. Thus, the C content is limited to 0.35% or less. The C content is preferably 0.30% or less, and more preferably 0.25% or less.

(Si: 0.4 to 3.0%)

**[0025]** Silicon enhances the strength of steel sheets by solid solution strengthening, and further suppresses the coarsening of carbides to eliminate or reduce the decrease in strength caused by tempering. When the Si content is less than 0.4%, the desired TS may not be obtained stably and the desired ductility cannot be obtained. Thus, the Si content is limited to 0.4% or more. The Si content is preferably 1.0% or more, and more preferably 1.4% or more. On the other hand, excessive addition of silicon significantly deteriorates chemical convertibility and coatability. Thus, the Si content is limited to 3.0% or less. The Si content is preferably 2.5% or less, and more preferably 2.0% or less.

(Mn: 1.5 to 3.5%)

**[0026]** Manganese is an element effective for enhancing hardenability. When the Mn content is less than 1.5%, ferrite or pearlite is formed excessively. As a result, tempered martensite and lower bainite are not obtained sufficiently to cause a failure to achieve the desired TS. Thus, the Mn content is limited to 1.5% or more. The Mn content is preferably 2.0% or more, and more preferably 2.4% or more.

On the other hand, excessive addition of manganese results in coarse MnS and significantly lowers stretch-flangeability and bendability. Thus, the Mn content is limited to 3.5% or less. The Mn content is preferably 3.0% or less.

(P: 0.02% or less)

**[0027]** Phosphorus is an element effective for strengthening steel, but excessive addition thereof significantly lowers spot weldability. Thus, the P content is limited to 0.02% or less. The P content is preferably 0.01% or less.

The lower limit of the P content is not particularly specified. However, dephosphorization to less than 0.002% entails a significant cost and thus the P content is preferably 0.002% or more.

(S: 0.01% or less)

**[0028]** Sulfur forms a coarse sulfide with manganese to lower stretch-flangeability and bendability. Thus, the S content is limited to 0.01% or less. The S content is preferably 0.002% or less, and more preferably 0.001% or less.

The lower limit of the S content is not particularly specified. However, desulfurization to less than 0.0002% entails a significant cost and thus the S content is preferably 0.0002% or more.

(sol. Al: 1.0% or less)

**[0029]** Aluminum is an element added as a deoxidizing agent in the steelmaking process. When the sol. Al content is more than 1.0%, the number of inclusions, such as  $Al_2O_3$  and AlN, is increased to cause decreases in stretch-flangeability and bendability. Thus, the sol. Al content is limited to 1.0% or less. The sol. Al content is preferably 0.2% or less, and more preferably 0.05% or less.

While the lower limit of the sol. Al content is not particularly specified, the sol. Al content is preferably 0.001% or more in order to obtain a sufficient deoxidizing effect. The sol. Al content is more preferably 0.010% or more, and even more preferably 0.020% or more.

(N: 0.015% or less)

**[0030]** Nitrogen, when added excessively, forms a large number of inclusions, such as AlN, to deteriorate stretch-flangeability and bendability. Thus, the N content is limited to 0.015% or less. The N content is preferably 0.008% or less, and more preferably 0.005% or less.

The lower limit of the N content is not particularly specified. However, denitrification to less than 0.001% significantly increases the manufacturing cost and thus the N content is preferably 0.001% or more.

**[0031]** The chemical composition of the steel sheet in the present invention includes the above components as the basic components, and the balance after the deduction of the above components includes iron (Fe) and incidental impurities. In the chemical composition of the steel sheet in the present invention, it is preferable that the balance consist of Fe and incidental impurities.

Examples of the incidental impurities include Zn and Co.

The advantageous effects of the present invention are not impaired even when these elements are contained within the usual range of steel composition.

**[0032]** In addition to the above basic components, one, or two or more selected from B, Ti, Cu, Ni, Cr, Mo, V, Nb, Zr, and W may be added as required in place of part of iron (Fe) and the incidental impurities. Furthermore, one, or two or more selected from Ca, Ce, La, Mg, Sb, and Sn may be added as required.

**[0033]** Specifically, the chemical composition of the steel sheet of the present invention may appropriately include the following (A) and/or (B) as optional elements.

(A) One, or two or more selected from, in mass%, B: 0.01% or less, Ti: 0.1% or less, Cu: 1% or less, Ni: 1% or less, Cr: 1.5% or less, Mo: 1.0% or less, V: 0.5% or less, Nb: 0.1% or less, Zr: 0.2% or less, and W: 0.2% or less.

(B) One, or two or more selected from, in mass%, Ca: 0.0040% or less, Ce: 0.0040% or less, La: 0.0040% or less, Mg: 0.0040% or less, Sb: 0.1% or less, and Sn: 0.1% or less.

**[0034]** ([Group A] B: 0.01% or less, Ti: 0.1% or less, Cu: 1% or less, Ni: 1% or less, Cr: 1.5% or less, Mo: 1.0% or less, V: 0.5% or less, Nb: 0.1% or less, Zr: 0.2% or less, and W: 0.2% or less)

These elements may be added for the purposes of enhancing hardenability, reducing the size of crystal grains, and stably obtaining the desired TS through precipitation strengthening. When, on the other hand, these elements are added in excessively large amounts, coarse precipitates are formed to deteriorate stretch-flangeability and bendability. When boron is added, the B content is limited to 0.01% or less. When titanium is added, the Ti content is limited to 0.1% or less. When copper is added, the Cu content is limited to 1% or less. When nickel is added, the Ni content is limited to 1% or less. When chromium is added, the Cr content is limited to 1.5% or less. When molybdenum is added, the Mo content is limited to 1.0% or less. When vanadium is added, the V content is limited to 0.5% or less. When niobium is added, the Nb content is limited to 0.1% or less. When zirconium is added, the Zr content is limited to 0.2% or less. When tungsten is added, the W content is limited to 0.2% or less.

**[0035]** The B content is preferably 0.0050% or less, and more preferably 0.0030% or less. The B content is preferably 0.0003% or more.

The Ti content is preferably 0.080% or less, and more preferably 0.050% or less. The Ti content is preferably 0.001% or more. The Ti content is more preferably 0.010% or more.

The Cu content is preferably 0.50% or less, and more preferably 0.20% or less. The Cu content is preferably 0.001% or more. The Cu content is more preferably 0.030% or more.

The Ni content is preferably 0.50% or less, and more preferably 0.20% or less. The Ni content is preferably 0.001% or more. The Ni content is more preferably 0.030% or more.

The Cr content is preferably 1.2% or less, and more preferably 1.0% or less. The Cr content is preferably 0.001% or more. The Cr content is more preferably 0.200% or more.

The Mo content is preferably 0.50% or less, and more preferably 0.20% or less. The Mo content is preferably 0.001% or more. The Mo content is more preferably 0.010% or more.

The V content is preferably 0.50% or less, and more preferably 0.20% or less. The V content is preferably 0.001% or more. The V content is more preferably 0.010% or more.

The Nb content is preferably 0.08% or less, and more preferably 0.05% or less. The Nb content is preferably 0.001% or more. The Nb content is more preferably 0.010% or more.

The Zr content is preferably 0.1% or less, and more preferably 0.05% or less. The Zr content is preferably 0.001% or more. The Zr content is more preferably 0.010% or more.

The W content is preferably 0.1% or less, and more preferably 0.05% or less. The W content is even more preferably 0.03% or less.

The W content is preferably 0.001% or more. The W content is more preferably 0.005% or more.

**[0036]** ([Group B] Ca: 0.0040% or less, Ce: 0.0040% or less, La: 0.0040% or less, Mg: 0.0040% or less, Sb: 0.1% or less, and Sn: 0.1% or less)

**[0037]** These elements may be added for the purpose of enhancing stretch-flangeability and bendability by controlling of inclusions. Their effects are saturated when the amounts added are larger than certain levels. When calcium is added, the Ca content is limited to 0.0040% or less. When cerium is added, the Ce content is limited to 0.0040% or less. When lanthanum is added, the La content is limited to 0.0040% or less. When magnesium is added, the Mg content is limited to 0.0040% or less. When antimony is added, the Sb content is limited to 0.1% or less. When tin is added, the Sn content is limited to 0.1% or less.

**[0038]** The Ca content is preferably 0.0030% or less. The Ca content is preferably 0.0003% or more.

The Ce content is preferably 0.0030% or less. The Ce content is preferably 0.0003% or more.

The La content is preferably 0.0030% or less. The La content is preferably 0.0003% or more. The La content is more preferably 0.0010% or more.

The Mg content is preferably 0.0030% or less. The Mg content is preferably 0.0003% or more.

The Sb content is preferably 0.05% or less, and more preferably 0.02% or less. The Sb content is preferably 0.0003% or more. The Sb content is more preferably 0.0020% or more.

The Sn content is preferably 0.05% or less, and more preferably 0.02% or less. The Sn content is preferably 0.0003% or more. The Sn content is more preferably 0.0020% or more.

**[0039]** When the content of any of the above optional components is below the lower limit, the optional element present below the lower limit does not impair the advantageous effects of the present invention. Thus, such an optional element below the lower limit content is regarded as an incidental impurity.

**[0040]** Next, the structure (the microstructure) of the steel sheet of the present invention will be described.

(Area fraction of ferrite: 5% or less (including 0%))

**[0041]** Ferrite contributes to ductility enhancement but also serves as origins of voids during blanking or press forming due to the difference in hardness between ferrite and hard phases, such as tempered martensite, thereby deteriorating

press formability. When the area fraction of ferrite is more than 5%, press formability is significantly deteriorated. Furthermore, more than 5% ferrite does not offer the desired TS or the desired stability of mechanical properties in the width direction.

Thus, the area fraction of ferrite is limited to 5% or less. The area fraction of ferrite is preferably 3% or less, and more preferably 0%.

(Total area fraction of tempered martensite and lower bainite: 70% or more)

**[0042]** In order to obtain stably a TS of 1180 MPa or more, the total area fraction of tempered martensite and lower bainite is limited to 70% or more, and is preferably 80% or more, and more preferably 85% or more. While tempered martensite and lower bainite have different timings of transformation, they are low-temperature transformation products having similar effects on mechanical properties and thus are evaluated based on the total area fraction.

Although the upper limit is not particularly specified, the total area fraction of tempered martensite and lower bainite is preferably 95% or less, and more preferably 93% or less.

(Volume fraction of retained austenite: 5 to 15%)

**[0043]** Retained austenite contributes to enhancing uniform elongation through the TRIP effect. In order to obtain the desired ductility, the volume fraction of retained austenite is limited to 5% or more. Limiting the volume fraction of retained austenite to 5% or more also offers the desired stability of mechanical properties in the width direction. The volume fraction of retained austenite is preferably 7% or more, and more preferably 9% or more.

**[0044]** On the other hand, excessive formation of retained austenite leads to low stretch-flangeability. Thus, the volume fraction of retained austenite is limited to 15% or less.

(Area fraction of fresh martensite: 10% or less (including 0%))

**[0045]** Fresh martensite is very hard and serves as origins of cracking at the time of press forming. When the area fraction of fresh martensite is more than 10%, the desired ductility cannot be obtained and furthermore the desired stability of mechanical properties in the width direction cannot be obtained.

Thus, the area fraction of fresh martensite is limited to 10% or less from the points of view of eliminating or reducing the occurrence of cracks, enhancing ductility, and furthermore the stability of mechanical properties in the width direction. The area fraction is preferably 5% or less, and more preferably 3% or less. Fresh martensite may represent 0%.

**[0046]** In the present invention, one, or two or more types of other microstructures, such as upper bainite and pearlite, are sometimes formed as remaining microstructures other than the above-described ferrite, tempered martensite, lower bainite, retained austenite, and fresh martensite. However, the objects of the present invention can be achieved as long as the above fractions of ferrite, tempered martensite, lower bainite, retained austenite, and fresh martensite are satisfied. The remaining microstructures, such as pearlite and upper bainite, preferably represent 5% or less in total.

**[0047]** The steel sheet of the present invention may have a coated layer on a surface of the steel sheet. The type of the coated layer is not particularly limited and may be a galvanized layer, with examples including electrogalvanized layer, hot-dip galvanized layer, and hot-dip galvanized layer.

**[0048]** Next, methods for measuring the microstructure of the steel sheet will be described.

**[0049]** To measure the area fractions of ferrite, tempered martensite, lower bainite, and fresh martensite, the steel sheet is cut to expose a width cross section that is parallel to the rolling direction. The cross section is mirror-polished and is etched with 1 vol% Nital. Portions at 1/4 thickness are observed with SEM in 10 fields of view at a magnification of 5000 times, and the microstructure is measured by a point count method (in accordance with ASTM E562-83 (1988)). In the above observation, ferrite is equiaxed regions that look blackest in SEM and contain almost no internal carbides. Tempered martensite and lower bainite are regions that look gray and contain lath-like submicrostructures and carbide precipitates according to SEM. Fresh martensite is massive regions that look white and contain no submicrostructures according to SEM.

**[0050]** To determine the volume fraction of retained austenite, the steel sheet is mechanically ground and is polished with oxalic acid by 100  $\mu\text{m}$  or more to expose a measurement surface located at 1/4 of the sheet thickness, and the exposed surface is analyzed by X-ray diffractometry. Co-K $\alpha$  radiation source is used as the incident X-ray, and the volume fraction of retained austenite is calculated from the intensity ratio of (200), (211), and (220) planes of ferrite and (200), (220), and (311) planes of austenite. Because retained austenite is randomly distributed, the volume fraction of retained austenite obtained by X-ray diffractometry is equal to the area fraction.

**[0051]** The steel sheet of the present invention has a tensile strength TS of 1180 MPa or more as evaluated in accordance with JIS Z2241 (2011) and thus is of high strength.

**[0052]** Furthermore, the steel sheet of the present invention has a total elongation (EL) of 11.0% or more as evaluated in



accordance with JIS Z2241 (2011) and thus excels in ductility.

**[0053]** Furthermore, the steel sheet of the present invention has a limit hole expansion ratio  $\lambda$  (%) =  $\{(D_f - D_0)/D_0\} \times 100$  of 40% or more and thus excels in stretch-flangeability. Here,  $D_f$  is the hole diameter (mm) at the occurrence of cracking, and  $D_0$  is the initial hole diameter (mm). Specifically, a 100 mm  $\times$  100 mm steel sheet is punched to create a 10 mm diameter hole with a clearance of 12% of the sheet thickness. While holding the steel sheet on a die having an inner diameter of 75 mm with a blank holder force of 88.2 kN, a 60° conical punch is pushed into the hole to measure the critical hole diameter at the occurrence of cracking.

**[0054]** Furthermore, the steel sheet of the present invention has a standard deviation of total elongation (EL) evaluated in accordance with JIS Z2241 (2011) of 0.9% or less and thus excels in the stability of mechanical properties in the width direction. Specifically, a total of twenty JIS No. 5 test pieces for tensile test, including test pieces from both ends in the width direction, that extend parallel to the rolling direction are sampled at regular intervals in the width direction of the sheet and are tested.

**[0055]** In the steel sheet of the present invention, the standard deviation of tensile strength TS in the width direction may be 15.0 MPa or less.

**[0056]** Next, a method for manufacturing a steel sheet of the present invention will be described. In the following, references to temperatures when a material, such as a steel slab (a steel material) or a steel sheet, is heated or cooled mean the surface temperature of the material, such as the steel slab (the steel material) or the steel sheet, unless otherwise specified.

**[0057]** A method for manufacturing a steel sheet of the present invention includes a hot rolling step in which a steel slab having the chemical composition described hereinabove is held at a slab heating temperature of 1100°C or above for 1800 seconds or more, and is subsequently finish hot rolled at a finish rolling temperature of 850°C or above, and the resultant steel sheet is cooled at an average cooling rate of 40°C/s or more in a temperature range from the finish rolling temperature to 650°C, and is coiled at a coiling temperature of 600°C or below under conditions where coiling takes place in the presence of a maximum temperature difference in the width direction of 50°C or less from the temperature at the center of the sheet width, thereby producing a hot rolled steel sheet; a cold rolling step in which the hot rolled steel sheet is cold rolled with a rolling reduction ratio of 30% or more to give a cold rolled steel sheet; and an annealing step in which the cold rolled steel sheet is heated at an average heating rate HR1 of 0.5°C/s or more in a temperature range from 700°C to ( $A_{c3} - 10^\circ\text{C}$ ), held at an annealing temperature of ( $A_{c3} - 10^\circ\text{C}$ ) or above for 30 seconds or more, cooled at an average cooling rate CR1 of 10°C/s or more in a temperature range from the annealing temperature to a gradual cooling start temperature T1 equal to or higher than ( $M_s - 30^\circ\text{C}$ ) and equal to or lower than ( $M_s + 30^\circ\text{C}$ ), cooled at an average cooling rate CR2 of 1 to 10°C/s in a temperature range from the gradual cooling start temperature T1 to a gradual cooling stop temperature T2 equal to or higher than ( $M_s - 220^\circ\text{C}$ ) and equal to or lower than ( $M_s - 100^\circ\text{C}$ ), heated at an average heating rate HR2 of 2°C/s or more in a temperature range from the gradual cooling stop temperature T2 to a reheating holding temperature T3 of 300°C or above and 450°C or below, held at the reheating holding temperature T3 for 20 seconds or more and 3000 seconds or less, and cooled at an average cooling rate CR3 of 0.1°C/s or more in a temperature range from the reheating holding temperature T3 to 50°C.

**[0058]** In the present invention, the steelmaking process may be carried out in a conventional manner. The hot rolling step, a pickling step, the cold rolling step, and the annealing step will be described below.

[Hot rolling step]

**[0059]** The steel slab may be hot rolled in such a manner that the steel slab that has been cooled to room temperature is reheated and then rolled, that the steel slab from continuous casting is subjected to hot direct rolling without heating, or that the steel slab from continuous casting is quickly heat-treated and then rolled. By any of these methods, the steel slab in the present invention is held at a slab heating temperature of 1100°C or above for 1800 seconds or more and is subsequently finish hot rolled at a finish rolling temperature of 850°C or above. Subsequently, the resultant steel sheet is cooled at an average cooling rate of 40°C/s or more in a temperature range from the finish rolling temperature to 650°C, and is coiled at a coiling temperature of 600°C or below under conditions where coiling takes place in the presence of a maximum temperature difference in the width direction of 50°C or less, thereby producing a hot rolled steel sheet.

(Slab heating temperature: 1100°C or above)

(Slab heating holding time: 1800 seconds or more)

**[0060]** When the slab heating temperature is below 1100°C, inclusions, such as MnS, remain and cause a decrease in stretch-flangeability. Thus, the slab heating temperature is limited to 1100°C or above. The slab heating temperature is preferably 1180°C, and more preferably 1200°C or above.

**[0061]** When the slab heating holding time is less than 1800 seconds, inclusions, such as MnS, remain in large numbers

and stretch-flangeability is similarly lowered. Thus, the slab heating holding time is limited to 1800 seconds or more.

**[0062]** The upper limits of the slab heating temperature and the slab heating holding time are not limited. However, from the point of view of manufacturing costs, the slab heating temperature is preferably 1300°C or below and the slab heating holding time is preferably 3 hours or less.

(Finish rolling temperature: 850°C or above)

**[0063]** When the finish rolling temperature is below 850°C, ferrite is formed during hot rolling to destroy the uniformity of the microstructure after the rolling, and consequently there is a concern that mechanical properties after annealing may have variations in the width direction. Thus, the finish rolling temperature is limited to 850°C or above. While the upper limit is not particularly specified, the finish rolling temperature is preferably 950°C or below.

(Average cooling rate from the finish rolling temperature to 650°C: 40°C/s or more)

**[0064]** When the average cooling rate from the finish rolling temperature to 650°C is less than 40°C/s, ferrite and pearlite tend to be formed during cooling to destroy the uniformity of the hot rolled microstructure. In this case, the grain size after annealing varies in the width direction to cause variations in strength and ductility. Thus, the average cooling rate from the finish rolling temperature to 650°C is limited to 40°C/s or more. This average cooling rate is preferably 60°C/s or more.

**[0065]** Here, the average cooling rate is determined by "(finish rolling temperature (°C) - 650°C)/cooling time (seconds) from the finish rolling temperature to 650°C".

(Coiling temperature: 600°C or below)

(Maximum temperature difference in the width direction from the temperature at the center of the sheet width during coiling: 50°C or less)

**[0066]** When the coiling temperature is above 600°C, ferrite and pearlite are likely to be formed. Consequently, the hot rolled microstructure may become nonuniform even when the maximum temperature difference in the width direction during coiling is small. In this case, the grain size after annealing varies in the width direction to cause variations in strength and ductility. Thus, the coiling temperature is limited to 600°C or below. The coiling temperature is preferably 550°C or below. The lower limit of the coiling temperature is not particularly specified. When, however, the coiling temperature is below 400°C, the hot rolled microstructure is rigidized due to the formation of martensite and the cold rolling load may be excessively increased. Thus, the coiling temperature is preferably 400°C or above.

**[0067]** Here, the maximum temperature difference is the maximum value of temperature difference between the temperature at the center of the sheet width and any position in the width direction. Specifically, the maximum temperature difference indicates the difference between the temperature at the center of the sheet width and the lowest temperature in the width direction.

**[0068]** Even when the coiling temperature is 600°C or below, the presence of a maximum temperature difference of more than 50°C in the width direction during coiling leads to a large difference in microstructure morphology in the width direction, causing variations in strength and ductility in the width direction after annealing. Thus, the maximum difference in coiling temperature in the width direction is limited to 50°C or less. The maximum difference in coiling temperature in the width direction is preferably 30°C or less, and more preferably 20°C or less.

**[0069]** After the hot rolling step, the hot rolled steel sheet may be heat treated as required in order to reduce the cold rolling load.

[Pickling step]

**[0070]** The hot rolling step may be followed by pickling to remove scales from the surface of the hot rolled sheet. The pickling method is not particularly specified and may be performed in a conventional manner.

[Cold rolling step]

(Rolling reduction ratio (cold rolling reduction ratio): 30% or more)

**[0071]** To control the recrystallization behavior in the subsequent annealing and to stabilize the quality, the cold rolling reduction ratio (the cumulative cold rolling reduction ratio) is limited to 30% or more. The upper limit of the cold rolling reduction ratio is not particularly specified. However, the cold rolling load may be excessively increased when achieving more than 95% cold rolling reduction ratio. Thus, the cold rolling reduction ratio is preferably 95% or less.

[Annealing step]

(Average heating rate HR1 from 700°C to ( $A_{c3} - 10^\circ\text{C}$ ): 0.5°C/s or more)

- 5 **[0072]** When the average heating rate HR1 from 700°C to ( $A_{c3} - 10^\circ\text{C}$ ) is less than 0.5°C/s, carbon is partitioned from ferrite to austenite during heating and the C concentration distribution in the steel sheet is biased, resulting in nonuniform quality. In the presence of a biased C concentration distribution in the steel sheet, inequalities in cooling stop temperature or reheating temperature in the width direction produce more significant variations in mechanical properties. Thus, the average heating rate HR1 from 700°C to ( $A_{c3} - 10^\circ\text{C}$ ) is limited to 0.5°C/s or more. The average heating rate HR1 from 700°C to ( $A_{c3} - 10^\circ\text{C}$ ) is preferably 1.0°C/s or more, and more preferably 1.5°C/s or more.

The average heating rate HR1 is preferably 50°C/s or less, and more preferably 20°C/s or less.

**[0073]** The average heating rate HR1 is determined by " $(A_{c3} - 10^\circ\text{C}) - 700^\circ\text{C}$ "/heating time (seconds) from 700°C to ( $A_{c3} - 10^\circ\text{C}$ )".

- 15 (Annealing temperature: ( $A_{c3} - 10^\circ\text{C}$ ) or above)

(Holding time (annealing time): 30 seconds or more)

- 20 **[0074]** In order to control the area fraction of ferrite to the desired range, the annealing temperature is limited to ( $A_{c3} - 10^\circ\text{C}$ ) or above. The upper limit of the annealing temperature is not specified. When, however, the annealing temperature is above ( $A_{c3} + 50^\circ\text{C}$ ), austenite grains are significantly coarsened and the balance between strength and ductility may be deteriorated. Thus, the annealing temperature is preferably ( $A_{c3} + 50^\circ\text{C}$ ) or below.

- 25 **[0075]** When the holding time (the annealing time) is less than 30 seconds, carbides remain undissolved, and stretch-flangeability and bendability may be deteriorated. Furthermore, a holding time (annealing time) of less than 30 seconds does not offer the desired stability of mechanical properties in the width direction. Thus, the holding time is limited to 30 seconds or more. The holding time is preferably 60 seconds or more.

**[0076]**  $A_{c3}$  is calculated by the following formula. In the formula below, [element symbol] means the content (mass%) of the element. (The Physical Metallurgy of Steels, Leslie, Maruzen Publishing Co., Ltd., published May 31, 1985, p. 273.)

- 30  $A_{c3} (^\circ\text{C}) = 910 - 203 \times [\text{C}]^{1/2} - 15.2 \times [\text{Ni}] + 44.7 \times [\text{Si}] + 104 \times [\text{V}] + 31.5 \times [\text{Mo}] + 13.1 \times [\text{W}] - (30 \times [\text{Mn}] + 11 \times [\text{Cr}] + 20 \times [\text{Cu}] - 700 \times [\text{P}] - 400 \times [\text{sol. Al}] - 120 \times [\text{As}] - 400 \times [\text{Ti}])$

(Average cooling rate CR1 from the annealing temperature to a gradual cooling start temperature T1: 10°C/s or more)

- 35 **[0077]** (Gradual cooling start temperature T1: martensite start temperature  $M_s \pm 30^\circ\text{C}$  (( $M_s - 30^\circ\text{C}$ ) or above and ( $M_s + 30^\circ\text{C}$ ) or below))

When CR1 is less than 10°C/s, ferrite and pearlite are formed excessively. As a result, it may be impossible to obtain the desired tempered martensite and lower bainite, and the desired strength may not be obtained. Furthermore, the desired stretch-flangeability cannot be obtained, and the desired stability of mechanical properties in the width direction cannot be obtained. Thus, CR1 is limited to 10°C/s or more. CR1 is preferably 15°C/s or more.

- 40 The upper limit of CR1 is not specified. However, an excessively high average cooling rate contributes to uneven cooling in the width direction and may lead to a decrease in quality uniformity in the width direction. Thus, CR1 is preferably 1000°C/s or less, and more preferably 100°C/s or less.

- 45 **[0078]** The average cooling rate CR1 is determined by " $(\text{annealing temperature } (^\circ\text{C}) - \text{gradual cooling start temperature } T1 (^\circ\text{C}))/\text{cooling time (seconds) from the annealing temperature to the gradual cooling start temperature } T1$ ".

- [0079]** When T1 is above ( $M_s + 30^\circ\text{C}$ ), ferrite and pearlite are formed excessively. As a result, the desired tempered martensite and lower bainite are not obtained, and the desired strength may not be obtained. When T1 is above ( $M_s + 30^\circ\text{C}$ ), the area fraction of fresh martensite exceeds 10% to cause a failure to obtain the desired ductility and a failure to achieve the desired stability of mechanical properties in the width direction. Thus, T1 is limited to ( $M_s + 30^\circ\text{C}$ ) or below. T1 is preferably ( $M_s + 20^\circ\text{C}$ ) or below, and more preferably ( $M_s + 10^\circ\text{C}$ ) or below.

- [0080]** When, on the other hand, T1 is below ( $M_s - 30^\circ\text{C}$ ), the desired amount of retained austenite may not be obtained and it may be impossible to achieve the desired ductility. When T1 is below ( $M_s - 30^\circ\text{C}$ ), furthermore, the desired stability of mechanical properties in the width direction cannot be obtained.

Thus, T1 is limited to ( $M_s - 30^\circ\text{C}$ ) or above. T1 is preferably ( $M_s - 20^\circ\text{C}$ ) or above, and more preferably ( $M_s - 10^\circ\text{C}$ ) or above.

- 55 **[0081]** The martensite start temperature  $M_s (^\circ\text{C})$  may be determined using a Formaster tester by holding a cylindrical test specimen (3 mm in diameter  $\times$  10 mm in height) at an annealing temperature of ( $A_{c3} - 10^\circ\text{C}$ ) or above and quenching the test specimen with helium gas at a cooling rate of 30°C/s or more while measuring the volume change.

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(Average cooling rate CR2 from the gradual cooling start temperature T1 to a gradual cooling stop temperature T2: 1 to 10°C/s)

(Gradual cooling stop temperature T2: (Ms - 220°C) or above and (Ms - 100°C) or below)

**[0082]** Cooling from T1 to T2 at an average cooling rate CR2 of 10°C/s or less reduces temperature variations in the width direction stemming from heat generation by transformation to martensite and lower bainite and ensures that the amount of martensite and lower bainite transformation is uniform in the width direction, with the result that variations in mechanical properties in the width direction can be reduced. Furthermore, controlling CR2 to 10°C/s or less allows carbon to be partitioned from martensite and lower bainite to austenite during the cooling, and thereby stabilizes austenite. As a result, retained austenite resists decomposition even when the edges of the steel sheet are overheated during reheating, and the steel sheet attains no or small variations in mechanical properties in the width direction up to the edges. Thus, CR2 is limited to 10°C/s or less. When CR2 is less than 1°C/s, the line length is extended and the production efficiency is lowered. Thus, CR2 is limited to 1°C/s or more.

**[0083]** The average cooling rate CR2 is determined by "(gradual cooling start temperature T1 (°C) - gradual cooling stop temperature T2 (°C))/cooling time (seconds) from the gradual cooling start temperature T1 to the gradual cooling stop temperature T2".

**[0084]** When T2 is below (Ms - 220°C), martensite transformation proceeds excessively and the desired amount of retained austenite cannot be obtained, with the result that ductility is lowered. Thus, T2 is limited to (Ms - 220°C) or above. T2 is preferably (Ms - 200°C) or above, and more preferably (Ms - 180°C) or above.

When, on the other hand, T2 is above (Ms - 100°C), carbon is not sufficiently partitioned from martensite and lower bainite to austenite during the gradual cooling, and austenite may be decomposed during the reheating and holding process to cause variations in mechanical properties in the width direction.

When T2 is above (Ms - 100°C), furthermore, the area fraction of fresh martensite exceeds 10% to cause a failure to obtain the desired ductility and a failure to achieve the desired stability of mechanical properties in the width direction. Thus, T2 is limited to (Ms - 100°C) or below.

(Average heating rate HR2 from the gradual cooling stop temperature T2 to a reheating holding temperature T3: 2°C/s or more)

**[0085]** Carbide precipitation can be suppressed and high ductility can be ensured by increasing the temperature quickly from the gradual cooling stop temperature T2 to a reheating holding temperature T3. Thus, the average heating rate HR2 is limited to 2°C/s or more. HR2 is preferably 5°C/s or more, and more preferably 10°C/s or more. The upper limit of the average heating rate HR2 is not particularly specified. However, keeping the steel sheet thermally uniform is sometimes more difficult as the average heating rate HR2 increases. Thus, HR2 is preferably 50°C/s or less, and more preferably 20°C/s or less.

**[0086]** The average heating rate HR2 is determined by "reheating holding temperature T3 (°C) - gradual cooling stop temperature T2 (°C))/heating time (seconds) from the gradual cooling stop temperature T2 to a reheating holding temperature T3".

(Reheating holding temperature T3: 300°C or above and 450°C or below)

(Reheating holding time: 20 seconds or more and 3000 seconds or less)

**[0087]** The steel sheet is reheated and held to stabilize austenite by carbon partitioning. When the reheating holding temperature T3 is below 300°C, carbon is not partitioned sufficiently and the desired amount of retained austenite cannot be obtained, with the result that ductility may be lowered. When the reheating holding temperature T3 is below 300°C, the desired stability of mechanical properties in the width direction cannot be obtained. Thus, the reheating holding temperature T3 is limited to 300°C or above. T3 is preferably 330°C or above, and more preferably 350°C or above.

When, on the other hand, the reheating holding temperature T3 is above 450°C, austenite is transformed into pearlite and the desired amount of retained austenite cannot be obtained, with the result that ductility may be lowered. When the reheating holding temperature T3 is above 450°C, the desired stability of mechanical properties in the width direction cannot be obtained. Thus, the reheating holding temperature T3 is limited to 450°C or below. T3 is preferably 420°C or below.

**[0088]** When the reheating holding time (the holding time (the residence time) at the reheating holding temperature T3) is less than 20 seconds, carbon is not partitioned sufficiently and the desired amount of retained austenite cannot be obtained. Thus, the reheating holding time is limited to 20 seconds or more. The reheating holding time is preferably 50 seconds or more, and more preferably 100 seconds or more. The effects of carbon partitioning by reheating and holding

are saturated after 3000 seconds. Thus, the reheating holding time is limited to 3000 seconds or less. The reheating holding time is preferably 1500 seconds or less, and more preferably 600 seconds or less.

(Average cooling rate CR3 from the reheating holding temperature T3 to 50°C: 0.1°C/s or more)

**[0089]** When the average cooling rate CR3 from the reheating holding temperature T3 to 50°C is less than 0.1°C/s, there is a concern that ductility may be lowered by softening or carbide precipitation due to excessive tempering. Thus, the average cooling rate CR3 from the reheating holding temperature T3 to 50°C is limited to 0.1°C/s or more. CR3 is preferably 5°C/s or more, and more preferably 8°C/s or more.

CR3 is preferably 100°C/s or less, and more preferably 50°C/s or less.

**[0090]** The average cooling rate CR3 is determined by "(reheating holding temperature T3 (°C) - 50°C)/cooling time (seconds) from the reheating holding temperature T3 to 50°C".

[Hot-dip coating treatment]

**[0091]** In the present invention, the annealing step may include performing a hot-dip coating treatment when the steel sheet is being cooled from the annealing temperature to the gradual cooling start temperature T1, or when the steel sheet is being reheated and held at the reheating holding temperature T3. The hot-dip coating treatment may be a hot-dip galvanizing treatment. In a preferred hot-dip galvanizing treatment, the steel sheet is hot-dip galvanized by being immersed into a galvanizing bath at 440°C or above and 500°C or below, and the coating weight is adjusted by, for example, gas wiping. The galvanizing bath used in the hot-dip galvanization preferably has an Al content of 0.10% or more and 0.22% or less.

The hot-dip galvanizing treatment may be followed by an alloying treatment for the zinc coating. The alloying treatment for the zinc coating is preferably performed at temperatures of 480°C or above and 600°C or below after the immersion into the galvanizing bath.

[Temper rolling]

**[0092]** In the present invention, the annealed steel sheet may be subjected to temper rolling for the purposes of stabilizing press formability and increasing YS. The elongation is preferably 0.1% or more. The elongation is preferably 0.5% or less.

[Leveler straightening]

**[0093]** In the present invention, the annealed steel sheet may be subjected to leveler straightening to flatten the sheet shape. The leveler straightening method is not particularly specified and may be performed in a conventional manner.

[Electrocoating treatment]

**[0094]** In the present invention, an electrocoating treatment, such as electroganization, may be performed as a surface treatment after the annealing step.

**[0095]** The steel sheet of the present invention obtained as described above preferably has a thickness of 0.5 mm or more. The thickness of the steel sheet of the present invention is preferably 2.0 mm or less.

The width of the sheet is preferably 600 mm or more. The width is preferably 1700 mm or less.

**[0096]** Next, a member and a method for manufacture thereof according to the present invention will be described.

**[0097]** The member of the present invention is obtained by subjecting the steel sheet of the present invention to at least one working of forming or joining. The method for manufacturing a member of the present invention includes a step of subjecting the steel sheet of the present invention to at least one working of forming or joining to produce a member.

**[0098]** The steel sheet of the present invention has a tensile strength of 1180 MPa or more, is excellent in ductility and stretch-flangeability, and excels in the stability of mechanical properties in the width direction. Thus, the member obtained using the steel sheet of the present invention also has high strength, is excellent in ductility and stretch-flangeability, and excels in the stability of mechanical properties in the width direction. Furthermore, weight can be reduced by using the member of the present invention. Thus, for example, the member of the present invention may be suitably used in automobile body frame parts. The member of the present invention also includes a welded joint.

**[0099]** The forming may be performed using any common working process, such as press working, without limitation. Furthermore, the joining may be performed using common welding, such as spot welding or arc welding, or, for example, riveting or caulking without limitation.

## EXAMPLES

**[0100]** The present invention will be described in detail with reference to EXAMPLES. However, the scope of the present invention is not limited to EXAMPLES.

**[0101]** Slabs having a chemical composition described in Table 1 were each held at a slab heating temperature of 1230°C for 3000 seconds, hot rolled at a finish rolling temperature of 870°C, cooled at an average cooling rate of 65°C/s in a temperature range from the finish rolling temperature to 650°C, and coiled at a coiling temperature described in Table 2 in the presence, during coiling, of a maximum temperature difference in the width direction described in Table 2. Hot rolled steel sheets with a thickness of 2.8 mm and a width of 1100 mm were thus produced. The hot rolled steel sheets were each cold rolled with a reduction ratio of 50% to give cold rolled steel sheets with a thickness of 1.4 mm and a width of 1100 mm.

**[0102]** Subsequently, the cold rolled steel sheets were each annealed under conditions described in Table 2. Among the annealing conditions, the average heating rate HR1 during heating from 700°C to (Ac<sub>3</sub> - 10°C) was controlled to 2.0°C/s. Furthermore, the surface of the steel sheet No. 11 was electrogalvanized (EG), and the surface of the steel sheet No. 12 was hot-dip galvanized. Furthermore, the steel sheet No. 12 was subjected to an alloying treatment (GA) in which the steel sheet was held at 510°C for 10 seconds in order to convert the coated layer into a hot-dip galvanized layer.

[Table 1]

| Steel    | Chemical composition (mass%) |             |      |       |        |        |        |                                                     | Remarks     |
|----------|------------------------------|-------------|------|-------|--------|--------|--------|-----------------------------------------------------|-------------|
|          | C                            | Si          | Mn   | P     | S      | sol.Al | N      | Others                                              |             |
| A        | 0.243                        | 0.53        | 1.99 | 0.012 | 0.0005 | 0.060  | 0.0064 | -                                                   | Inv. steel  |
| B        | 0.147                        | 2.40        | 3.41 | 0.003 | 0.0004 | 0.068  | 0.0059 | -                                                   | Inv. steel  |
| C        | 0.179                        | 0.48        | 3.12 | 0.003 | 0.0007 | 0.052  | 0.0044 | Ti:0.020, B:0.0025                                  | Inv. steel  |
| D        | 0.179                        | 0.41        | 2.05 | 0.003 | 0.0003 | 0.048  | 0.0063 | Ti:0.043, B:0.0013                                  | Inv. steel  |
| E        | 0.161                        | 1.26        | 2.94 | 0.009 | 0.0008 | 0.079  | 0.0082 | Ti:0.012, B:0.0045, Nb:0.021                        | Inv. steel  |
| F        | 0.269                        | 0.68        | 2.31 | 0.002 | 0.0006 | 0.088  | 0.0082 | Ti:0.028, B:0.0060, Cu:0.130                        | Inv. steel  |
| G        | 0.176                        | 1.06        | 3.01 | 0.008 | 0.0016 | 0.074  | 0.0071 | Ti:0.019, B:0.0015, Ni:0.100, Cr:0.800, Mo:0.050    | Inv. steel  |
| H        | 0.128                        | 0.53        | 1.90 | 0.005 | 0.0012 | 0.051  | 0.0071 | V:0.019, Zr:0.010, W:0.005                          | Inv. steel  |
| I        | 0.178                        | 2.33        | 1.82 | 0.015 | 0.0015 | 0.031  | 0.0061 | B:0.0038, Nb:0.030, V:0.045                         | Inv. steel  |
| J        | 0.256                        | 1.78        | 3.40 | 0.013 | 0.0018 | 0.056  | 0.0087 | Ti:0.028, B:0.0032, Ca:0.0007, Ce:0.0008, La:0.0019 | Inv. steel  |
| K        | 0.237                        | 1.49        | 3.45 | 0.012 | 0.0019 | 0.066  | 0.0068 | B:0.0040, Mg:0.0021, Sb:0.0100, Sn:0.0100           | Inv. steel  |
| L        | 0.226                        | 2.41        | 2.12 | 0.003 | 0.0010 | 0.057  | 0.0031 | Mg:0.0011                                           | Inv. steel  |
| <u>M</u> | <u>0.040</u>                 | 0.83        | 3.05 | 0.014 | 0.0010 | 0.057  | 0.0068 | -                                                   | Comp. steel |
| <u>N</u> | <u>0.360</u>                 | 1.97        | 1.81 | 0.014 | 0.0016 | 0.080  | 0.0059 | -                                                   | Comp. steel |
| <u>O</u> | 0.242                        | <u>0.20</u> | 1.82 | 0.003 | 0.0008 | 0.067  | 0.0036 | -                                                   | Comp. steel |

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(continued)

| Steel                                                                                                                                                 | Chemical composition (mass%) |      |             |       |        |        |        |        | Remarks     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|------|-------------|-------|--------|--------|--------|--------|-------------|
|                                                                                                                                                       | C                            | Si   | Mn          | P     | S      | sol.Al | N      | Others |             |
| <u>P</u>                                                                                                                                              | 0.152                        | 0.78 | <u>1.24</u> | 0.004 | 0.0018 | 0.056  | 0.0063 | -      | Comp. steel |
| ·The balance after the above components is Fe and incidental impurities.<br>*Underlines indicate being outside of the range of the present invention. |                              |      |             |       |        |        |        |        |             |

[Table 2]

| No. | Steel | Hot rolling conditions |                                                  | Annealing conditions |                      |                    |                 |         |              |                 |              |                 |              |                           |                 |              | Remarks     |
|-----|-------|------------------------|--------------------------------------------------|----------------------|----------------------|--------------------|-----------------|---------|--------------|-----------------|--------------|-----------------|--------------|---------------------------|-----------------|--------------|-------------|
|     |       | Coiling temp. (°C)     | Maximum temp. difference in width direction (°C) | Ac <sub>3</sub> (°C) | Annealing temp. (°C) | Annealing time (s) | CR1 (*1) (°C/s) | Ms (°C) | T1 (*2) (°C) | CR2 (*3) (°C/s) | T2 (*4) (°C) | HR2 (*5) (°C/s) | T3 (*6) (°C) | Residence time (*7) (sec) | CR3 (*8) (°C/s) | Coating (*9) |             |
| 1   | A     | 540                    | 35                                               | 806                  | 870                  | 120                | 40              | 406     | 421          | 1.1             | 213          | 10              | 412          | 300                       | 10              | CR           | Inv. steel  |
| 2   | B     | 540                    | 45                                               | 867                  | 880                  | 120                | 37              | 386     | 383          | 6.7             | 246          | 10              | 382          | 300                       | 10              | CR           | Inv. steel  |
| 3   | C     | 540                    | 43                                               | 783                  | 870                  | 120                | 35              | 385     | 400          | 3.1             | 254          | 10              | 407          | 300                       | 10              | CR           | Inv. steel  |
| 4   | D     | 540                    | 40                                               | 820                  | 900                  | 120                | 32              | 427     | 443          | 7.4             | 324          | 10              | 363          | 300                       | 10              | CR           | Inv. steel  |
| 5   | E     | 540                    | 45                                               | 839                  | 860                  | 120                | 25              | 399     | 415          | 5.0             | 239          | 10              | 394          | 300                       | 10              | CR           | Inv. steel  |
| 6   | F     | 540                    | 38                                               | 811                  | 870                  | 120                | 20              | 384     | 355          | 6.2             | 224          | 10              | 413          | 300                       | 10              | CR           | Inv. steel  |
| 7   | G     | 540                    | 35                                               | 816                  | 890                  | 120                | 33              | 374     | 389          | 7.8             | 224          | 10              | 407          | 300                       | 10              | CR           | Inv. steel  |
| 8   | H     | 500                    | 36                                               | 830                  | 860                  | 120                | 40              | 451     | 466          | 7.2             | 288          | 10              | 397          | 300                       | 10              | CR           | Inv. steel  |
| 9   | I     | 500                    | 45                                               | 902                  | 900                  | 120                | 25              | 436     | 417          | 5.9             | 278          | 10              | 362          | 300                       | 10              | CR           | Inv. steel  |
| 10  | J     | 500                    | 46                                               | 828                  | 890                  | 120                | 32              | 347     | 368          | 4.8             | 177          | 10              | 411          | 300                       | 10              | CR           | Inv. steel  |
| 11  | K     | 500                    | 34                                               | 809                  | 860                  | 120                | 23              | 352     | 349          | 3.8             | 239          | 10              | 391          | 300                       | 10              | EG           | Inv. steel  |
| 12  | L     | 500                    | 44                                               | 883                  | 900                  | 120                | 46              | 407     | 396          | 4.6             | 287          | 10              | 388          | 300                       | 10              | GA           | Inv. steel  |
| 13  | M     | 500                    | 43                                               | 848                  | 920                  | 120                | 24              | 438     | 422          | 6.2             | 295          | 10              | 382          | 300                       | 10              | CR           | Comp. steel |
| 14  | N     | 500                    | 46                                               | 864                  | 870                  | 120                | 19              | 372     | 371          | 5.5             | 166          | 10              | 377          | 300                       | 10              | CR           | Comp. steel |
| 15  | O     | 530                    | 47                                               | 793                  | 870                  | 120                | 26              | 414     | 389          | 3.6             | 277          | 10              | 356          | 300                       | 10              | CR           | Comp. steel |
| 16  | P     | 530                    | 39                                               | 854                  | 910                  | 120                | 20              | 468     | 463          | 1.0             | 363          | 10              | 385          | 300                       | 10              | CR           | Comp. steel |
| 17  | C     | 530                    | 33                                               | 783                  | 760                  | 120                | 18              | 394     | 405          | 7.9             | 209          | 10              | 384          | 300                       | 10              | CR           | Comp. steel |



(continued)

| No. | Steel | Hot rolling conditions |                                                  | Annealing conditions |                      |                    |                 |         |              |                 |              |                 |              |                           |                 | Remarks |              |
|-----|-------|------------------------|--------------------------------------------------|----------------------|----------------------|--------------------|-----------------|---------|--------------|-----------------|--------------|-----------------|--------------|---------------------------|-----------------|---------|--------------|
|     |       | Coiling temp. (°C)     | Maximum temp. difference in width direction (°C) | Ac <sub>3</sub> (°C) | Annealing temp. (°C) | Annealing time (s) | CR1 (*1) (°C/s) | Ms (°C) | T1 (*2) (°C) | CR2 (*3) (°C/s) | T2 (*4) (°C) | HR2 (*5) (°C/s) | T3 (*6) (°C) | Residence time (*7) (sec) | CR3 (*8) (°C/s) |         | Coating (*9) |
| 18  | C     | 530                    | 41                                               | 783                  | 870                  | <u>10</u>          | 16              | 385     | 401          | 1.0             | 276          | 10              | 415          | 300                       | 10              | CR      | Comp. steel  |
| 19  | C     | 530                    | 38                                               | 783                  | 880                  | 120                | <u>5</u>        | 385     | 376          | 1.2             | 204          | 10              | 380          | 300                       | 10              | CR      | Comp. steel  |
| 20  | C     | 530                    | 47                                               | 783                  | 880                  | 120                | 28              | 385     | <u>510</u>   | 3.1             | 197          | 10              | 359          | 300                       | 10              | CR      | Comp. steel  |
| 21  | C     | 530                    | 33                                               | 783                  | 890                  | 120                | 40              | 385     | <u>330</u>   | 4.1             | 270          | 10              | 407          | 300                       | 10              | CR      | Comp. steel  |
| 22  | C     | 530                    | 44                                               | 783                  | 870                  | 120                | 46              | 385     | 365          | <u>15.0</u>     | 199          | 10              | 389          | 300                       | 10              | CR      | Comp. steel  |
| 23  | C     | 560                    | 40                                               | 783                  | 890                  | 120                | 36              | 385     | 370          | 3.2             | <u>340</u>   | 10              | 409          | 300                       | 10              | CR      | Comp. steel  |
| 24  | C     | 560                    | 38                                               | 783                  | 870                  | 120                | 17              | 385     | 388          | 2.0             | <u>160</u>   | 10              | 414          | 300                       | 10              | CR      | Comp. steel  |
| 25  | C     | 560                    | 39                                               | 783                  | 870                  | 120                | 21              | 385     | 400          | 1.4             | 205          | 10              | <u>455</u>   | 300                       | 10              | CR      | Comp. steel  |
| 26  | C     | 560                    | 40                                               | 783                  | 890                  | 120                | 35              | 385     | 408          | 1.4             | 261          | 10              | <u>286</u>   | 300                       | 10              | CR      | Comp. steel  |
| 27  | C     | 560                    | 41                                               | 783                  | 880                  | 120                | 26              | 385     | 376          | 3.8             | 212          | 10              | 406          | <u>10</u>                 | 10              | CR      | Comp. steel  |
| 28  | C     | <u>660</u>             | 39                                               | 783                  | 870                  | 120                | 21              | 385     | 390          | 1.8             | 210          | 10              | 400          | 300                       | 10              | CR      | Comp. steel  |

(continued)

| No. | Steel | Hot rolling conditions |                                            | Annealing conditions |                      |                    |                 |         |              |                 |              |                 |              |                           |                 | Remarks |              |
|-----|-------|------------------------|--------------------------------------------|----------------------|----------------------|--------------------|-----------------|---------|--------------|-----------------|--------------|-----------------|--------------|---------------------------|-----------------|---------|--------------|
|     |       | Coiling temp. (°C)     | Maximum difference in width direction (°C) | Ac <sub>3</sub> (°C) | Annealing temp. (°C) | Annealing time (s) | CR1 (*1) (°C/s) | Ms (°C) | T1 (*2) (°C) | CR2 (*3) (°C/s) | T2 (*4) (°C) | HR2 (*5) (°C/s) | T3 (*6) (°C) | Residence time (*7) (sec) | CR3 (*8) (°C/s) |         | Coating (*9) |
| 29  | C     | 560                    | <u>60</u>                                  | 783                  | 890                  | 120                | 35              | 385     | 400          | 1.8             | 260          | 10              | 400          | 300                       | 10              | CR      | Comp. steel  |

\* Underlines indicate being outside of the range of the present invention.

\*1) CR1: Average cooling rate (°C/s) from the annealing temperature to T1

\*2) T1: Gradual cooling start temperature (°C)

\*3) CR2: Average cooling rate (°C/s) from T1 to T2

\*4) T2: Gradual cooling stop temperature (°C)

\*5) HR2: Average heating rate (°C/s) from T2 to T3

\*6) T3: Reheating holding temperature (°C)

\*7) Residence time: Holding time (s) at T3

\*8) CR3: Average cooling rate (°C/s) from T3 to 50°C

\*9) CR: no coating, EG: electrogalvanized, GA hot-dip galvanized

**[0103]** The steel microstructure was measured by the methods described hereinabove. The measurement results are described in Table 3.

**[0104]** The tensile strength (TS) and the total elongation (EL) were evaluated in accordance with JIS Z2241 (2011). A JIS No. 5 test piece for tensile test was prepared from the steel sheet and was tensile tested. The steel sheet was evaluated as excellent in strength when TS was 1180 MPa or more and was evaluated as excellent in ductility when EL was 11.0% or more.

**[0105]** The stretch-flangeability was evaluated in accordance with The Japan Iron and Steel Federation Standard JFST 1001. Each of the steel sheets obtained was cut to 100 mm × 100 mm and was punched to create a 10 mm diameter hole with a clearance of 12% of the sheet thickness. While holding the steel sheet on a die having an inner diameter of 75 mm with a blank holder force of 88.2 kN, a 60° conical punch was pushed into the hole to measure the critical hole diameter at the occurrence of cracking. The limit hole expansion ratio  $\lambda$  (%) was calculated from formula (1). The stretch-flangeability was evaluated as excellent when  $\lambda$  was 40% or more.

$$\text{Limit hole expansion ratio } \lambda \text{ (\%)} = \{(D_f - D_0)/D_0\} \times 100 \dots (1)$$

**[0106]** Here,  $D_f$  is the hole diameter (mm) at the occurrence of cracking, and  $D_0$  is the initial hole diameter (mm).

**[0107]** To evaluate the stability of mechanical properties in the width direction, a total of twenty JIS No. 5 test pieces for tensile test, including test pieces from both ends in the width direction, that extended parallel to the rolling direction were sampled at regular intervals in the width direction of the sheet. The test pieces were tensile tested in the above-described manner, and the standard deviations of TS and EL were determined. The stability of mechanical properties in the width direction was evaluated as excellent when the standard deviation of EL was 0.9% or less. While the standard deviation of TS is not particularly specified, the stability of mechanical properties in the width direction was evaluated as superior when the standard deviation of TS was 15.0 MPa or less.

[Table 3]

| No. | Steel | Microstructure               |                                                          |                                       |                                             | Properties |        |               |                                                                 |                                                               | Remarks     |
|-----|-------|------------------------------|----------------------------------------------------------|---------------------------------------|---------------------------------------------|------------|--------|---------------|-----------------------------------------------------------------|---------------------------------------------------------------|-------------|
|     |       | Area fraction of ferrite (%) | Area fraction of tempered martensite + lower bainite (%) | Area fraction of fresh martensite (%) | Volume of fraction of retained $\gamma$ (%) | TS (MPa)   | EL (%) | $\lambda$ (%) | Standard deviation of variations in TS in width direction (MPa) | Standard deviation of variations in EL in width direction (%) |             |
| 1   | A     | 0                            | 88                                                       | 3                                     | 9                                           | 1482       | 12.2   | 79            | 9.7                                                             | 0.4                                                           | Inv. steel  |
| 2   | B     | 0                            | 89                                                       | 4                                     | 7                                           | 1288       | 12.9   | 61            | 8.0                                                             | 0.7                                                           | Inv. steel  |
| 3   | C     | 0                            | 89                                                       | 2                                     | 9                                           | 1349       | 12.7   | 75            | 5.7                                                             | 0.7                                                           | Inv. steel  |
| 4   | D     | 0                            | 85                                                       | 5                                     | 10                                          | 1362       | 13.3   | 75            | 5.2                                                             | 0.7                                                           | Inv. steel  |
| 5   | E     | 0                            | 88                                                       | 5                                     | 7                                           | 1315       | 12.3   | 77            | 7.2                                                             | 0.4                                                           | Inv. steel  |
| 6   | F     | 0                            | 83                                                       | 6                                     | 11                                          | 1536       | 11.3   | 57            | 5.6                                                             | 0.4                                                           | Inv. steel  |
| 7   | G     | 0                            | 88                                                       | 4                                     | 8                                           | 1341       | 12.3   | 64            | 6.6                                                             | 0.7                                                           | Inv. steel  |
| 8   | H     | 0                            | 92                                                       | 2                                     | 6                                           | 1244       | 12.7   | 51            | 5.8                                                             | 0.4                                                           | Inv. steel  |
| 9   | I     | 0                            | 90                                                       | 2                                     | 8                                           | 1360       | 12.3   | 61            | 8.8                                                             | 0.8                                                           | Inv. steel  |
| 10  | J     | 0                            | 85                                                       | 4                                     | 11                                          | 1510       | 11.5   | 79            | 7.4                                                             | 0.3                                                           | Inv. steel  |
| 11  | K     | 0                            | 83                                                       | 5                                     | 12                                          | 1474       | 12.3   | 74            | 8.7                                                             | 0.6                                                           | Inv. steel  |
| 12  | L     | 0                            | 86                                                       | 3                                     | 11                                          | 1454       | 12.3   | 78            | 8.2                                                             | 0.4                                                           | Inv. steel  |
| 13  | M     | 0                            | 93                                                       | 4                                     | 3                                           | 1063       | 10.8   | 71            | 4.0                                                             | 0.4                                                           | Comp. steel |
| 14  | N     | 0                            | 85                                                       | 4                                     | 11                                          | 1739       | 8.9    | 32            | 9.6                                                             | 0.7                                                           | Comp. steel |
| 15  | O     | 0                            | 82                                                       | 7                                     | 11                                          | 1496       | 9.1    | 75            | 6.4                                                             | 0.6                                                           | Comp. steel |
| 16  | P     | 17                           | 69                                                       | 5                                     | 9                                           | 1020       | 13.7   | 57            | 12.1                                                            | 1.7                                                           | Comp. steel |
| 17  | C     | 9                            | 82                                                       | 3                                     | 6                                           | 1102       | 11.9   | 38            | 10.8                                                            | 1.3                                                           | Comp. steel |
| 18  | C     | 9                            | 77                                                       | 4                                     | 10                                          | 1150       | 13.1   | 43            | 15.3                                                            | 2.5                                                           | Comp. steel |
| 19  | C     | 7                            | 83                                                       | 3                                     | 7                                           | 1148       | 11.9   | 36            | 13.0                                                            | 1.3                                                           | Comp. steel |
| 20  | C     | 0                            | 78                                                       | 12                                    | 10                                          | 1393       | 9.5    | 45            | 17.0                                                            | 1.0                                                           | Comp. steel |
| 21  | C     | 0                            | 91                                                       | 3                                     | 6                                           | 1349       | 10.1   | 51            | 8.4                                                             | 1.6                                                           | Comp. steel |
| 22  | C     | 0                            | 93                                                       | 3                                     | 4                                           | 1354       | 9.1    | 60            | 7.5                                                             | 1.8                                                           | Comp. steel |
| 23  | C     | 0                            | 77                                                       | 13                                    | 10                                          | 1349       | 9.4    | 64            | 16.0                                                            | 1.3                                                           | Comp. steel |

(continued)

| No.                                                                       | Steel | Microstructure               |                                                          |                                       |                                          | Properties |            |               |                                                                 |                                                               | Remarks     |
|---------------------------------------------------------------------------|-------|------------------------------|----------------------------------------------------------|---------------------------------------|------------------------------------------|------------|------------|---------------|-----------------------------------------------------------------|---------------------------------------------------------------|-------------|
|                                                                           |       | Area fraction of ferrite (%) | Area fraction of tempered martensite + lower bainite (%) | Area fraction of fresh martensite (%) | Volume fraction of retained $\gamma$ (%) | TS (MPa)   | EL (%)     | $\lambda$ (%) | Standard deviation of variations in TS in width direction (MPa) | Standard deviation of variations in EL in width direction (%) |             |
| 24                                                                        | C     | 0                            | 93                                                       | 3                                     | 4                                        | 1347       | <u>8.6</u> | 65            | 8.9                                                             | 0.7                                                           | Comp. steel |
| 25                                                                        | C     | 0                            | 92                                                       | 4                                     | <u>4</u>                                 | 1320       | <u>9.6</u> | 48            | 13.5                                                            | <u>1.5</u>                                                    | Comp. steel |
| 26                                                                        | C     | 0                            | 93                                                       | 3                                     | <u>4</u>                                 | 1404       | <u>8.8</u> | 65            | 14.1                                                            | <u>1.3</u>                                                    | Comp. steel |
| 27                                                                        | C     | 0                            | 94                                                       | 2                                     | <u>4</u>                                 | 1349       | <u>9.5</u> | 53            | 13.3                                                            | <u>1.3</u>                                                    | Comp. steel |
| 28                                                                        | C     | 0                            | 90                                                       | 4                                     | 6                                        | 1305       | <u>9.6</u> | 50            | 13.5                                                            | <u>2.2</u>                                                    | Comp. steel |
| 29                                                                        | C     | 0                            | 91                                                       | 3                                     | 6                                        | 1312       | <u>8.8</u> | 52            | 13.8                                                            | <u>2.0</u>                                                    | Comp. steel |
| *Underlines indicate being outside of the range of the present invention. |       |                              |                                                          |                                       |                                          |            |            |               |                                                                 |                                                               |             |

**[0108]** Inventive Examples described in Tables 2 and 3 achieved excellent strength, ductility, stretch-flangeability, and stability of mechanical properties. In contrast, Comparative Examples were unsatisfactory in one or more of these properties. Furthermore, Inventive Examples achieved a standard deviation of tensile strength TS of 15.0 MPa or less.

**[0109]** The steel sheets of Inventive Examples have high strength and excellent ductility, stretch-flangeability, and stability of mechanical properties in the width direction. This has shown that members obtained by forming of the steel sheets of Inventive Examples, members obtained by joining of the steel sheets of Inventive Examples, and members obtained by forming and joining of the steel sheets of Inventive Examples will have high strength and excellent ductility, stretch-flangeability, and stability of mechanical properties in the width direction similarly to the steel sheets of Inventive Examples.

## Claims

1. A steel sheet having a chemical composition comprising, in mass%,

C: 0.08 to 0.35%,  
Si: 0.4 to 3.0%,  
Mn: 1.5 to 3.5%,  
P: 0.02% or less,  
S: 0.01% or less,  
sol. Al: 1.0% or less, and  
N: 0.015% or less,  
the balance being Fe and incidental impurities,  
the steel sheet comprising a steel microstructure in which:

the area fraction of ferrite is 5% or less (including 0%),  
the total area fraction of tempered martensite and lower bainite is 70% or more,  
the volume fraction of retained austenite is 5 to 15%, and  
the area fraction of fresh martensite is 10% or less (including 0%),  
the steel sheet having a standard deviation of total elongation in the width direction of 0.9% or less.

2. The steel sheet according to claim 1, wherein the chemical composition comprises, in mass%, one, or two or more selected from:

B: 0.01% or less,  
Ti: 0.1% or less,  
Cu: 1% or less,  
Ni: 1% or less,  
Cr: 1.5% or less,  
Mo: 1.0% or less,  
V: 0.5% or less,  
Nb: 0.1% or less,  
Zr: 0.2% or less, and  
W: 0.2% or less.

3. The steel sheet according to claim 1 or 2, wherein the chemical composition comprises, in mass%, one, or two or more selected from:

Ca: 0.0040% or less,  
Ce: 0.0040% or less,  
La: 0.0040% or less,  
Mg: 0.0040% or less,  
Sb: 0.1% or less, and  
Sn: 0.1% or less.

4. The steel sheet according to any one of claims 1 to 3, which has a coated layer on a surface of the steel sheet.

5. A member obtained using the steel sheet described in any one of claims 1 to 4.

6. A method for manufacturing a steel sheet, comprising:

a hot rolling step in which:

a steel slab having the chemical composition described in any one of claims 1 to 3 is

held at a slab heating temperature of 1100°C or above for 1800 seconds or more, and is

subsequently finish hot rolled at a finish rolling temperature of 850°C or above, and

the resultant steel sheet is cooled at an average cooling rate of 40°C/s or more in a temperature range from the finish rolling temperature to 650°C, and is

coiled at a coiling temperature of 600°C or below under conditions where coiling takes place in the presence of a maximum temperature difference in the width direction of 50°C or less from the temperature at the center of the sheet width, thereby producing a hot rolled steel sheet;

a cold rolling step in which the hot rolled steel sheet is cold rolled with a rolling reduction ratio of 30% or more to give a cold rolled steel sheet; and

an annealing step in which:

the cold rolled steel sheet is

heated at an average heating rate HR1 of 0.5°C/s or more in a temperature range from 700°C to ( $A_{c3} - 10^\circ\text{C}$ ), held at an annealing temperature of ( $A_{c3} - 10^\circ\text{C}$ ) or above for 30 seconds or more,

cooled at an average cooling rate CR1 of 10°C/s or more in a temperature range from the annealing temperature to a gradual cooling start temperature T1 equal to or higher than ( $M_s - 30^\circ\text{C}$ ) and equal to or lower than ( $M_s + 30^\circ\text{C}$ ),

cooled at an average cooling rate CR2 of 1 to 10°C/s in a temperature range from the gradual cooling start temperature T1 to a gradual cooling stop temperature T2 equal to or higher than ( $M_s - 220^\circ\text{C}$ ) and equal to or lower than ( $M_s - 100^\circ\text{C}$ ),

heated at an average heating rate HR2 of 2°C/s or more in a temperature range from the gradual cooling stop temperature T2 to a reheating holding temperature T3 of 300°C or above and 450°C or below,

held at the reheating holding temperature T3 for 20 seconds or more and 3000 seconds or less, and

cooled at an average cooling rate CR3 of 0.1°C/s or more in a temperature range from the reheating holding temperature T3 to 50°C.

7. The method for manufacturing a steel sheet according to claim 6, wherein the annealing step comprises performing a hot-dip coating treatment or a hot-dip coating alloying treatment when the steel sheet is being cooled from the annealing temperature to the gradual cooling start temperature T1, or when the steel sheet is being reheated and held at the reheating holding temperature T3.

8. The method for manufacturing a steel sheet according to claim 6, further comprising performing an electrocoating treatment after the annealing step.

9. A method for manufacturing a member, comprising a step of subjecting the steel sheet described in any one of claims 1 to 4 to at least one working of forming or joining to produce a member.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/034299

## A. CLASSIFICATION OF SUBJECT MATTER

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

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21D9/46; C22C38/00-38/60

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

Published examined utility model applications of Japan 1922-1996  
Published unexamined utility model applications of Japan 1971-2023  
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. |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y<br>A    | JP 2002-302734 A (KOBE STEEL, LTD.) 18 October 2002 (2002-10-18)<br>claims, paragraph [0083], no. 2, 7-11, 14 in tables 1, 2, no. 1, 2 in tables 4, 5, CT in tables 7, 8                                                     | 1-5, 9<br>6-8         |
| Y<br>A    | WO 2017/138504 A1 (JFE STEEL CORP.) 17 August 2017 (2017-08-17)<br>claims, paragraph [0080], A, E in table 1, sample no. 2-4 11, 25, 26 in table 3                                                                           | 1-5, 9<br>6-8         |
| Y<br>A    | WO 2017/138503 A1 (JFE STEEL CORP.) 17 August 2017 (2017-08-17)<br>claims, paragraph [0059], A, E in table 1, sample no. 1-3, 11 in table 3                                                                                  | 1-5, 9<br>6-8         |
| Y<br>A    | WO 2021/070951 A1 (NIPPON STEEL CORP.) 15 April 2021 (2021-04-15)<br>claims, steel H1, J1, H2, J2, K2, L2, N2, P2 in table 1, test no. 17, 21, 24, 27, 29, 31, 32, 51, 52, 58, 59, 62-64, 66, 67, 70-73 in tables 2-1 to 3-2 | 1-5, 9<br>6-8         |

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Date of the actual completion of the international search

13 November 2023

Date of mailing of the international search report

21 November 2023

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/034299

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                             | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
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| Y<br>A    | WO 2018/055695 A1 (NIPPON STEEL & SUMITOMO METAL CORP.) 29 March 2018 (2018-03-29)<br>tables 1, samples A-6, A-8, B-1, C-1, E-1, F-1, G-1, G-3 to G-5, I-1, K-1, Q-1, R-1, i-1, j-1, k-1 in tables 2-7                                                                         | 1-5, 9<br>6-8         |
| Y<br>A    | WO 2020/262652 A1 (NIPPON STEEL CORP.) 30 December 2020 (2020-12-30)<br>no. 1, 10, 14, 16, 18-22, 24, 27, 28, 30, 32, 33, 35, 36, 38-43, 45, 46, 48-52, 54, 63, 74 in tables 1-4, tables 5-8, test no. 01, 10, 14, 16, 18-22, 24, 27, 28, 30-32, 39, 40, 54, 78 in tables 9-12 | 1-5, 9<br>6-8         |
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**REFERENCES CITED IN THE DESCRIPTION**

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