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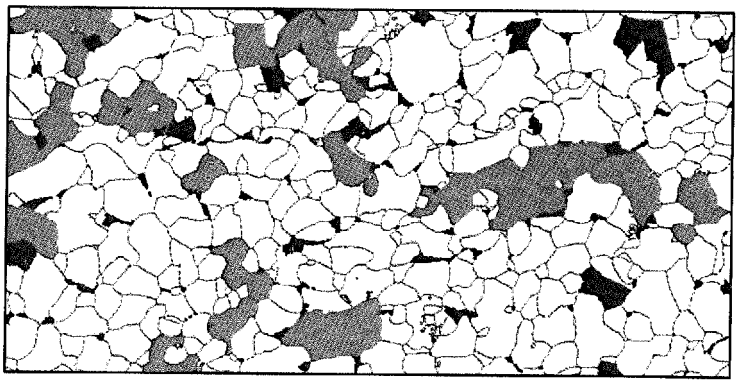
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(54) **HOT-ROLLED STEEL SHEET**

(57) A hot-rolled steel sheet includes a predetermined chemical composition, and a structure which includes, by area ratio, ferrite and bainite in a range of 75% to 95% in total, and martensite in a range of 5% to 20%, in which in the structure, in a case where a boundary having an orientation difference of equal to or greater than 15° is set as a grain boundary, and an area which is surrounded by the grain boundary, and has an equivalent circle diameter of equal to or greater than 0.3 μm is defined as a grain, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is, by area ratio, in a range of 10% to 60%.

FIG. 1



EP 3 260 566 A1

## Description

[Technical Field of the Invention]

**[0001]** The present invention relates to a hot-rolled steel sheet excellent in workability and particularly relates to a hot-rolled steel sheet having a composite structure and excellent in stretch flangeability.

[Related Art]

**[0002]** In recent years, in response to the demand for reduction in weight of various members for the purpose of improving fuel economy of vehicles, a reduction in thickness was accomplished by increasing the strength of a steel sheet such as an iron alloy used for the members, and application of light metals such as an Al alloy to the various members have been proceeded. However, as compared with heavy metals such as steel, the light metals such as an Al alloy have an advantage of high specific strength, but are extremely expensive. For this reason, the application of the light metal such as an Al alloy is limited to special applications. Accordingly, in order to apply the reduction in the weight of the various members to a cheaper and wider range, it is required to reduce the thickness by increasing the strength of the steel sheet.

**[0003]** When the steel sheet is strengthened, the material properties such as formability (workability) are generally deteriorated. Thus, in the developing of the high-strength steel sheet, it is an important problem to achieve the high strength of the steel sheet without deteriorating the material properties. Particularly, stretch-flange formability, burring workability, ductility, fatigue durability, impact resistance, corrosion resistance, and the like are required for the steel sheet used as vehicle members such as an inner plate member, a structural member, and a suspension member, depending on the application, and it is important to realize both of material properties and strength.

**[0004]** For example, among the vehicle members, the steel sheets used for the structural member, the suspension member, and the like, which account for about 20% of the vehicle body weight are press-formed mainly based on stretch flange processing and burring processing after performing blanking and drilling by shearing or punching. For this reason, excellent stretch flangeability is required for such steel sheets.

**[0005]** With respect to the above-described problem, for example, Patent Document 1 discloses a hot-rolled steel sheet in which the fraction and the size of the martensite, the number density, and the average gap between martensite is specified, and is excellent in elongation and hole expansibility. Patent Document 2 discloses a hot-rolled steel sheet in which average particle diameters of ferrite and a second phase and a carbon concentration of the second phase are limited, and is excellent in burring workability. Patent Document 3 discloses a hot-rolled steel sheet which is obtained by coiling the steel sheet at a low temperature after being kept at a temperature in a range of 750°C to 600°C for 2 to 15 seconds, and is excellent in workability, surface texture, and plate flatness.

**[0006]** However, in Patent Document 1, since a primary cooling rate should be set to be equal to or higher than 50°C/s after completing the hot rolling, the load applied on an apparatus becomes higher. In addition, in a case of setting the primary cooling rate to be equal to or higher than 50°C/s, there is a problem in that unevenness in material properties is caused by unevenness in the cooling rate.

**[0007]** In addition, as described above, in recent years, the demand for the high-strength steel sheet to the automobile members have been required. In a case where the high-strength steel sheet is press-formed by cold working, cracks likely to occur at an edge of a portion which is subjected to the stretch flange forming during the forming process. The reason for this is that work hardening occurs only on an edge portion due to the strain which is introduced to a punched end surface at the time of blanking. In the related art, as a method of evaluation a test of the stretch flangeability, a hole expansion test has been used. However, in the hole expansion test, breaking occurs without the strains in the circumferential direction are hardly distributed; however, in the actual process of components, strain distribution is present, and thus a gradient of the strain and the stress in the vicinity of the broken portion affects a breaking limit. Accordingly, regarding the high-strength steel sheet, even if the stretch flangeability is sufficient in the hole expansion test, in a case of performing cold pressing, the breaking may occur due to the strain distribution.

**[0008]** The techniques disclosed in Patent Documents 1 to 3 disclose that in all of the inventions, the hole expansibility is improved by specifying only the structures observed using an optical microscope. However, it is not clear whether or not sufficient stretch flangeability can be secured even in consideration of the strain distribution.

[Prior Art Document]

[Patent Document]

**[0009]**

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2013-19048
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2001-303186
[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2005-213566

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

**[0010]** The present invention has been made in consideration of the above-described circumstance.

**[0011]** An object of the present invention is to provide a high-strength hot-rolled steel sheet which is excellent in the stretch flangeability and can be applied to a member which requires high strength and the strict stretch flangeability. In the present invention, the stretch flangeability means a value evaluated by a product of limit forming height H (mm) and tensile strength TS (MPa) of the flange obtained as a result of the test by the saddle type stretch flange test method, which is an index of the stretch flangeability in consideration of the strain distribution. In addition, the excellent stretch flangeability means that the product of the limit forming height H (mm) and the tensile strength TS (MPa) is equal to or greater than 19500 (mm·MPa). In addition, the high strength means that the tensile strength is equal to or greater than 590 MPa. There is no need to particularly set the upper limit of the strength; however, in the range of the structure defined in the present invention, it is difficult to secure a strength of greater than 1470 MPa.

[Means for Solving the Problem]

**[0012]** According to the related art, the improvement of the stretch flangeability (hole expansibility) has been performed by inclusion control, homogenization of structure, unification of structure, and/or reduction in hardness difference between structure, as disclosed in Patent Documents 1 to 3. In other words, in the related art, hole expansibility, workability, or the like have been improved by controlling the structure which can be observed using an optical microscope.

**[0013]** In this regard, the present inventors made an intensive study by focusing an intragranular orientation difference in grains in consideration that the stretch flangeability under the presence of the strain distribution cannot be improved even by controlling only the structure observed using an optical microscope. As a result, it was found that it is possible to greatly improve the stretch flangeability by controlling the ratio of the grains in which the intragranular orientation difference is in a range of 5° to 14° with respect to the entire grains to be within a certain range.

**[0014]** The present invention is configured on the basis of the above findings, and the gists thereof are as follows.

**[0015]**

(1) A hot-rolled steel sheet according to one aspect of the present invention includes, as a chemical composition, by mass%, C: 0.04% to 0.18%, Si: 0.10% to 1.70%, Mn: 0.50% to 3.00%, Al: 0.010% to 1.00%, B: 0% to 0.005%, Cr: 0% to 1.0%, Mo: 0% to 1.0%, Cu: 0% to 2.0%, Ni: 0% to 2.0%, Mg: 0% to 0.05%, REM: 0% to 0.05%, Ca: 0% to 0.05%, Zr: 0% to 0.05%, P: limited to equal to or less than 0.050%, S: limited to equal to or less than 0.010%, and N: limited to equal to or less than 0.0060%, with the remainder including of Fe and impurities; and a structure which includes, by area ratio, a ferrite and a bainite in a range of 75% to 95% in total, and a martensite in a range of 5% to 20%, in which in the structure, in a case where a boundary having an orientation difference of equal to or greater than 15° is defined as a grain boundary, and an area which is surrounded by the grain boundary and has an equivalent circle diameter of equal to or greater than 0.3 μm is defined as a grain, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is, by area ratio, in a range of 10% to 60%.

(2) In the hot-rolled steel sheet described in the above (1), a tensile strength may be equal to or greater than 590 MPa, and a product of the tensile strength and a limit forming height in a saddle type stretch flange test may be equal to or greater than 19500 mm·MPa.

(3) In the hot-rolled steel sheet described in the above (1) or (2), the chemical composition may contain, by mass%, one or more selected from the group consisting of: B: 0.0001% to 0.005%, Cr: 0.01% to 1.0%, Mo: 0.01% to 1.0%, Cu: 0.01% to 2.0%, and Ni: 0.01% to 2.0%.

(4) In the hot-rolled steel sheet described in any one of the above (1) to (3), the chemical composition may contain, by mass%, one or more selected from the group consisting of: Mg: 0.0001% to 0.05%, REM: 0.0001% to 0.05%, Ca: 0.0001% to 0.05%, and Zr: 0.0001% to 0.05%.

[Effects of the Invention]

**[0016]** According to the above-described aspects of the present invention, it is possible to provide a high-strength hot-rolled steel sheet which has high strength, can be applied to a member that requires strict stretch flangeability, and is excellent in stretch flangeability.

[Brief Description of the Drawings]

**[0017]**

FIG. 1 is an analysis result obtained by EBSD at 1/4t portion (a 1/4 thickness position from the surface in the sheet thickness direction) of a hot-rolled steel sheet according to the present embodiment.
FIG. 2 is a diagram showing a shape of a saddle-shaped formed product which is used in a saddle type stretch flange test method.

[Embodiments of the Invention]

**[0018]** Hereinafter, a hot-rolled steel sheet (hereinafter, referred to as a hot-rolled steel sheet according to the present embodiment in some case) of the embodiment of the present invention will be described in detail.

**[0019]** The hot-rolled steel sheet according to the present embodiment includes, as a chemical composition, by mass%, C: 0.04% to 0.18%, Si: 0.10% to 1.70%, Mn: 0.50% to 3.00%, Al: 0.010% to 1.00%, and optionally B: 0.005% or less, Cr: 1.0% or less, Mo: 1.0% or less, Cu: 2.0% or less, Ni: 2.0% or less, Mg: 0.05% or less, REM: 0.05% or less, Ca: 0.05% or less, Zr: 0.05% or less, P: limited to equal to or less than 0.050%, S: limited to equal to or less than 0.010%, and N: limited to equal to or less than 0.0060%, with the remainder including Fe and impurities.

**[0020]** In addition, in the hot-rolled steel sheet according to the present embodiment, a structure includes, by area ratio, ferrite and bainite in a range of 75% to 95% in total, and martensite in a range of 5% to 20%. In addition, in the structure, when a boundary having an orientation difference of equal to or greater than 15° is defined as a grain boundary, and an area which is surrounded by the grain boundary and has an equivalent circle diameter of equal to or greater than 0.3 μm is defined as a grain, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is, by area ratio, in a range of 10% to 60%.

**[0021]** First, the reason for limiting the chemical composition of the hot-rolled steel sheet according to the present embodiment will be described. The amount (%) of the respective elements is based on mass%.

C: 0.04% to 0.18%

**[0022]** C is an element which contributes to improvement of the strength of steel. In order to obtain the aforementioned effect, the lower limit of the C content is set to 0.04%. In addition, when the C content is less than 0.04%, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is decreased. From this point, the lower limit of the C content is set to 0.04%. The lower limit of the C content is preferably 0.045%, and the lower limit of the C content is further preferably 0.05%. On the other hand, when the C content is greater than 0.18%, the stretch flangeability and the weldability are deteriorated. Further, the hardenability is excessively enhanced, and the grains having an intragranular orientation difference of greater than 14° are increased, thereby the ratio of grains having an intragranular orientation difference in a range of 5° to 14° is decreased. Thus, the upper limit of the C content is set to 0.18%. The upper limit of the C content is preferably 0.17%, and the upper limit of the C content is further preferably 0.16%.

Si: 0.10% to 1.70%

**[0023]** Si is an element which contributes to improvement of the strength of steel. In addition, Si is an element having a role as a deoxidizing agent of molten steel. In order to obtain the aforementioned effect, the lower limit of the Si content is set to 0.10%. The lower limit of the Si content is preferably 0.12%, the lower limit of the Si content is further preferably 0.15%. On the other hand, when the Si content is greater than 1.70%, since Ar3 transformation temperature becomes excessively high, it is difficult to perform hot rolling in a γ region, processed ferrite is generated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is decreased, thereby deteriorating the stretch flangeability. For this reason, the upper limit of the Si content is set to 1.70%. The upper limit of the Si content is preferably 1.60%, and the upper limit of the Si content is further preferably 1.50%.

Mn: 0.50% to 3.00%

**[0024]** Mn is an element which contributes to the improvement of the strength of steel by the solid solution strengthening and/or improving the hardenability of the steel. In order to obtain the aforementioned effect, the lower limit of the Mn content is set to 0.50%. The lower limit of the Mn content is preferably 0.65%, and the lower limit of the Mn content is further preferably 0.70%. On the other hand, when the Mn content is greater than 3.00%, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is decreased, and thereby the stretch flangeability is deteriorated. For this reason, the upper limit of the Mn content is set 3.00%. The upper limit of the Mn content is preferably

2.60%, and is further preferably the upper limit of the Mn content is 2.30%.

Al: 0.010% to 1.00%

**[0025]** Al is an effective element as a deoxidizing agent of molten steel. In order to obtain such effects, the lower limit of the Al content is set to 0.010%. The lower limit of the Al content is preferably 0.015%, and the lower limit of the Al content is further preferably 0.020%. On the other hand, the Al content is greater than 1.00%, the weldability and the toughness are deteriorated. For this reason, the upper limit of the Al content is set to 1.00%. The upper limit of the Al content is preferably 0.90%, and the upper limit of the Al content is further preferably 0.80%.

P: equal to or less than 0.050%

**[0026]** P is an impurity. P causes the toughness, the workability, and the weldability to be deteriorated, and thus the less the content, the better. However, in a case where the P content is greater than 0.050%, the stretch flangeability is remarkably deteriorated, and thus the P content is limited to be equal to or less than 0.050%. The P content is further preferably equal to or less than 0.040%. Although, there is no need to particularly specify the lower limit of the P content, excessive reduction of the P content is undesirable from the viewpoint of manufacturing cost, and thus the P content may be equal to or greater than 0.005%.

S: equal to or less than 0.010%

**[0027]** S is an element for forming an A type inclusion which not only causes cracks at the time of hot rolling, but also makes the stretch flangeability deteriorated. For this reason, the less the S content, the better. However, when the S content is greater than 0.010%, the stretch flangeability is remarkably deteriorated, and thus the upper limit of the S content is limited to 0.010%. The S content is further preferably equal to or less than 0.005%. Although, there is no need to particularly specify the lower limit of the S content, excessive reduction of the S content is undesirable from the viewpoint of manufacturing cost, and thus the S content may be equal to or greater than 0.001%.

N: equal to or less than 0.0060%

**[0028]** N is an element which forms AlN during the cooling after hot rolling, and deteriorates the formability of the steel sheet. Particularly, in a case where the N content is greater than 0.0060%, the stretch flangeability is remarkably deteriorated. For this reason, the upper limit of the N content is limited to be equal to or less than 0.0060%. The upper limit of the N content is preferably 0.0040%. Although, there is no need to particularly specify the N content, excessive reduction of the N content is undesirable from the viewpoint of manufacturing cost, and thus the lower limit of the N content may be equal to or greater than 0.0010%.

**[0029]** The above-described chemical elements are base elements contained in the hot-rolled steel sheet according to the present embodiment, and a chemical composition which contains such basic elements, with the remainder including Fe and impurities is a base composition of the hot-rolled steel sheet according to the present embodiment. The impurities are elements contaminated in the steel, which are caused from raw materials such as ore and scrap at the time of industrially manufacturing an alloy such as As and Sn, or caused by various factors in the manufacturing process, and are in an allowable range which does not adversely affect the properties of the hot-rolled steel sheet according to the present embodiment.

**[0030]** However, for the purpose of further improving the strength and the toughness, the hot-rolled steel sheet further contains, if necessary, one or more of B, Cr, Mo, Cu, Ni, Mg, REM, Ca, and Zr within a range described below. It is not necessary to contain these elements, and thus the lower limit of the content is 0%. Among the aforementioned elements, Nb and Ti limit the recrystallization and thus the workability is deteriorated. For this reason, Nb is preferably less than 0.005%, and Ti is preferably less than 0.015.

B: 0.0001% to 0.0050%

**[0031]** B is an element which improves the hardenability, and contributes to strengthening of steel. In order to obtain the aforementioned effect, the B content is preferably set to be equal to or greater than 0.0001%. On the other hand, when the B content is greater than 0.0050%, the workability is deteriorated. In addition, bainite having a large orientation dispersion is likely to be generated at the time of quenching, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is decreased. For this reason, even in a case of containing B, the upper limit of the B content is preferably 0.0050%.

Cr: 0.01 to 1.0%

**[0032]** Cr is an element which contributes to improvement of the strength of steel. In addition, Cr is an element having an effect of limiting cementite. In a case of obtaining such effects, the Cr content is preferably equal to or greater than 0.01%. On the other hand, when the Cr content is greater than 1.0%, the ductility is deteriorated. Accordingly, even in a case of containing Cr, the upper limit of the Cr content is preferably 1.0%.

Mo: 0.01% to 1.0%

**[0033]** Mo is an element which improves the hardenability and has an effect of enhancing the strength by forming a carbide. In order to obtain such effects, the Mo content is preferably equal to or greater than 0.01%. On the other hand, when the Mo content is greater than 1.0%, the ductility and the weldability are deteriorated. For this reason, the upper limit of the Mo content is set to 1.0% even in a case of containing Mo.

Cu: 0.01% to 2.0%

**[0034]** Cu is an element which enhances the strength of steel sheet and improves corrosion resistance and the exfoliation properties of the scale. In order to obtain such effects, the Cu content is preferably equal to or greater than 0.01%, and is further preferably equal to or greater than 0.04%. On the other hand, when the Cu content is greater than 2.0%, it is concerned that surface flaws occur. For this reason, even in the case of containing Cu, the upper limit of the Cu content is preferably set to 2.0%, and is further preferably set to 1.0%.

Ni: 0.01% to 2.0%

**[0035]** Ni is an element which enhances the strength and improves the toughness of the steel sheet. In order to obtain such effects, the Ni content is preferably equal to or greater than 0.01%. On the other hand, when the Ni content is greater than 2.0%, the ductility is deteriorated. For this reason, even in the case of containing Ni, the upper limit of the Ni content is preferably set to 2.0%.

Ca: 0.0001% to 0.05%

Mg: 0.0001% to 0.05%

Zr: 0.0001% to 0.05%

REM: 0.0001% to 0.05%

**[0036]** All of Ca, Mg, Zr, and REM are elements which improve the toughness by controlling the shape of sulfides and oxides. Accordingly, in order to obtain such effects, each of one or more of these elements is preferably equal to or greater than 0.0001%, and is further preferably equal to or greater than 0.0005%. However, when the amount of these elements is excessively high, the stretch flangeability is deteriorated. For this reason, even in the case of containing these elements, the upper limit of each content is preferably set to 0.05%.

**[0037]** Next, the structure (metallographic structure) of the hot-rolled steel sheet according to the present embodiment will be described.

**[0038]** It is necessary that the hot-rolled steel sheet according to the present embodiment contain, by area ratio, ferrite and bainite in a range of 75% to 95% in total, and martensite in a range of 5% to 20%, in the structure observed using an optical microscope. With such a composite structure, it is possible to improve the strength and the stretch flangeability in good balance. When the total amount of the ferrite and the bainite is less than 75% by area ratio, the stretch flangeability is deteriorated. In addition, when the total area ratio of the ferrite and the bainite is greater than 95%, the strength is deteriorated, the ductility is deteriorated, and thereby it is difficult to secure the properties which are generally required for the vehicle members. Although each of the fraction (the area ratio) of the ferrite and the bainite is not necessarily limited, when the fraction of the ferrite is greater than 90%, sufficient strength cannot be obtained in some cases, and thus the fraction of the ferrite is preferably equal to less than 90%, and is further preferably less than 70%. On the other hand, when the fraction of the bainite is greater than 60%, the ductility may be deteriorated, and thus the fraction of the bainite is preferably less than 60%, and is further preferably less than 50%.

**[0039]** In the hot-rolled steel sheet according to the present embodiment, the structures of the remainders other than the ferrite, bainite, and martensite are not particularly limited, and for example, it may be residual austenite, pearlite, or the like. However, when the structures of the remainder other than the ferrite, bainite, and martensite are greater than

5% in total, the stretch flangeability and the ductility are deteriorated. For this reason, the ratio of the structures of the remainders is preferably equal to or less than 5%, further preferably equal to or less than 3%, and still further preferably 0%, by area ratio.

**[0040]** The structure fraction (the area ratio) can be obtained using the following method. First, a sample collected from the hot-rolled steel sheet is etched using nital. After etching, a structure photograph obtained at a 1/4 thickness position in a visual field of 300 μm × 300 μm using an optical microscope is subjected to image analysis, and thereby the area ratio of ferrite and pearlite, and the total area ratio bainite and martensite are obtained. Then, a sample etched by LePera solution, the structure photograph obtained at a 1/4 thickness position in the visual field of 300 μm × 300 μm using the optical microscope is subjected to the image analysis, and thereby the total area ratio of residual austenite and martensite is calculated.

**[0041]** Further, with a sample obtained by grinding the surface to a depth of 1/4 thickness from the normal direction to the rolled surface, the volume fraction of the residual austenite is obtained through X-ray diffraction measurement. The volume fraction of the residual austenite is equivalent to the area ratio, and thus is set as the area ratio of the residual austenite.

**[0042]** With such a method, it is possible to obtain the area ratio of each of ferrite, bainite, martensite, residual austenite, and pearlite.

**[0043]** In the hot-rolled steel sheet according to the present embodiment, it is necessary to control the structure observed using the optical microscope to be within the above-described range, and to control the ratio of the grains having an intragranular orientation difference in a range of 5° to 14°, obtained using an EBSD method (electron beam back scattering diffraction pattern analysis method) frequently used for the crystal orientation analysis. Specifically, in a case where a boundary having the orientation difference of equal to or higher than 15° is defined as a grain boundary, and an area which is surrounded by the grain boundary and has an equivalent circle diameter of equal to or greater than 0.3 μm is defined as a grain, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is set to be in a range of 10% to 60% by area ratio, with respect to the entire grains.

**[0044]** The grains having such intragranular orientation difference are effective to obtain the steel sheet which has the strength and the workability in the excellent balance, and thus when the ratio is controlled, it is possible to greatly improve the stretch flangeability while maintaining a desired steel sheet strength. When the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is less than 10% by area ratio, the stretch flangeability is deteriorated. In addition, when the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is greater than 60% by area ratio, the ductility is deteriorated.

**[0045]** Here, it is considered that an intragranular orientation difference is related to a dislocation density contained in the grains. Typically, the increase in the intragranular dislocation density causes the workability to be deteriorated while bringing about the improvement of the strength. However, in the grain in which the intragranular orientation difference is controlled to be in a range of 5° to 14°, it is possible to improve the strength without deteriorating the workability. For this reason, in the hot-rolled steel sheet according to the present embodiment, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is controlled to be in a range of 10% to 60%. The grains having an intragranular orientation difference of less lower 5° are excellent in the workability, but are hard to be highly strengthened, and the grains having an intragranular orientation difference of greater than 14° have different deformations therein, and thus do not contribute to the improvement of the stretch flangeability.

**[0046]** The ratio of the grains having an intragranular orientation difference in a range of 5° to 14° can be measured by the following method.

**[0047]** First, at a position of depth of 1/4 (1/4t portion) thickness t from surface of the steel sheet in a cross section vertical to a rolling direction, an area of 200 μm in the rolling direction, and 100 μm in the normal direction to the rolled surface is subjected to EBSD analysis at a measurement pitch of 0.2 μm so as to obtain crystal orientation information. Here, the EBSD analysis is performed using an apparatus which is configured to include a thermal field emission scanning electron microscope (JSM-7001F, manufactured by JEOL) and an EBSD detector (HIKARI detector manufactured by TSL), at an analysis speed in a range of 200 to 300 points per second. Then, with respect to the obtained crystal orientation information, an area having the orientation difference of equal to or greater than 15° and an equivalent circle diameter of equal to or greater than 0.3 μm is defined as a grain, the average intragranular orientation difference of the grains is calculated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is obtained. The grain defined as described above and the average intragranular orientation difference can be calculated using software "OIM Analysis (trademark)" attached to an EBSD analyzer.

**[0048]** The "intragranular orientation difference" of the present invention means "Grain Orientation Spread (GOS)" which is an orientation dispersion in the grains, and the value thereof is obtained as an average value of reference crystal orientations and misorientations of all of the measurement points within the same grain as disclosed in "Misorientation Analysis of Plastic Deformation of Stainless Steel by EBSD and X-Ray Diffraction Methods", KIMURA Hidehiko, journal of the Japan Society of Mechanical Engineers (Series A) Vol.71, No.712, 2005, p. 1722 to 1728. In the present embodiment, the reference crystal orientation is an orientation obtained by averaging all of the measurement points in the same

grain, a value of GOS can be calculated using "OIM Analysis (trademark) Version 7.0.1" which is software attached to the EBSD analyzer.

**[0049]** FIG. 1 is an example of an EBSD analysis result of an area of 100 μm × 100 μm at 1/4t portion in the cross section vertical to the rolling direction of the hot-rolled steel sheet according to the present embodiment. In FIG. 1, an area in which a boundary having the orientation difference of equal to or greater than 15° is indicated as a grain boundary in a range of 5° to 14° is shown in gray. In the drawing, an area shown in black indicates martensite.

**[0050]** In the present embodiment, the stretch flangeability is evaluated using the saddle type stretch flange test method in which the saddle-shaped formed product is used. Specifically, the saddle-shaped formed product simulating the stretch flange shape formed of a linear portion and an arc portion as illustrated in FIG. 2 is pressed, and the stretch flangeability is evaluated using a limit forming height at this time. In the saddle type stretch flange test of the present embodiment, the limit forming height H (mm) when a clearance at the time of punching a corner portion is set to 11% is measured using the saddle-type formed product in which a radius of curvature R of a corner is set to be in a range of 50 to 60 mm, and an opening angle θ is set to 120°. Here, the clearance indicates the ratio of a gap between a punching die and a punch, and the thickness of the test piece. Actually, the clearance is determined by combination of a punching tool and the sheet thickness, and thus the value of 11% means a range of 10.5% to 11.5%. The existence of the cracks having a length of 1/3 of the sheet thickness are visually observed after forming, and then a forming height of the limit in which the cracks are not present is determined as the limit forming height.

**[0051]** In a hole expansion test which is used as a test method to evaluate the stretch flange formability in the related art, breaking occurs without strains are mostly distributed in the circumferential direction, and thus the strain and the gradient of stress in the vicinity of the broken portion during hole expansion test are different from that in the case of actually forming the stretch flange. In addition, in the hole expansion test, the evaluation reflecting the original stretch flange forming is not performed since, the evaluation is performed when the rupture of the thickness penetration occurred. On the other hand, in the saddle type stretch flange test used in the present embodiment, it is possible to evaluate the stretch flangeability in consideration of the strain distribution, and thus the evaluation reflecting the original stretch flange forming can be performed.

**[0052]** In the hot-rolled steel sheet according to the present embodiment, the area ratio of each of the structures of the ferrite and bainite which are observed using the optical microscope is not directly related to the ratio of the grains having an intragranular orientation difference in a range of 5° to 14°. In other words, for example, even if there are hot-rolled steel sheets in which the area ratio of ferrite and bainite are the same each other, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° are not necessarily the same. Accordingly, it is not possible to obtain the properties corresponding to the hot-rolled steel sheet according to the present embodiment only by controlling the ferrite area ratio, the bainite area ratio, and the martensite area ratio. Details for this will be described in Examples below.

**[0053]** The hot-rolled steel sheet according to the present embodiment can be obtained using a manufacturing method including a hot rolling process and a cooling process as follows.

<Hot rolling process>

**[0054]** In the hot rolling process, the hot-rolled steel sheet is obtained by heating and hot rolling a slab having the above-described chemical composition. The slab heating temperature is preferably in a range of 1050°C to 1260°C. When the slab heating temperature is lower than 1050°C, it is difficult to secure the hot rolling finishing temperature, which is not preferable. On the other hand, when the slab heating temperature is equal to or higher than 1260°C, the yield is decreased due to the scale off, and thus the heating temperature is preferably equal to or lower than 1260°C.

**[0055]** In a case where the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is set to be in a range of 10% to 60% by area ratio, in the hot rolling performed on the heated slab, it is important to set cumulative strains in a latter three stages (last three passes) of finish rolling to be greater than 0.6 to 0.7, and then perform cooling described below. The reason for this is that since the grain having an intragranular orientation difference in a range of 5° to 14° is generated by being transformed at a relatively low temperature in a para-equilibrium state, it is possible to control the generation of grain having an intragranular orientation difference in a range of 5° to 14° by limiting the dislocation density of austenite before the transformation to be in a certain range and limiting the cooling rate after transformation to be in a certain range. In other words, when the cumulative strain at the latter three stages in the finish rolling, and the subsequent cooling are controlled, the grain nucleation frequency of the grain having an intragranular orientation difference in a range of 5° to 14°, and the subsequent growth rate can be controlled, and thus it is possible to control the area ratio which is obtained as a result. More specifically, the dislocation density of the austenite introduced through the finish rolling is mainly related to the grain nucleation frequency, and the cooling rate after rolling is mainly related to the growth rate.

**[0056]** When the cumulative strain at the latter three stages in the finish rolling is equal to or less than 0.6, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is less than 10%, which is not preferable.

Further, when the cumulative strain at the latter three stages in the finish rolling is greater than 0.7, the recrystallization of the austenite occurs during the hot rolling, the accumulated dislocation density at the time of the transformation is decreased, and thus the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is less than 10%, which is not preferable.

**[0057]** The cumulative strain (εeff.) at the latter three stages in the finish rolling in the present embodiment can be obtained from the following Equation (1).

$$\varepsilon eff. = \Sigma \varepsilon i(t,T) \ldots (1)$$

Here,

$$\varepsilon i(t,T) = \varepsilon i0/\exp\{(t/\iota R)^{2/3}\},$$

$$\iota R = \iota 0 \times \exp(Q/RT),$$

$$\iota 0 = 8.46 \times 10^{-6},$$

$$Q = 183200\ J,$$

and

$$R = 8.314\ J/K \cdot mol,$$

εi0 represents a logarithmic strain at the time of rolling reduction, t represents a cumulative time immediately before the cooling in the pass, and T represents a rolling temperature in the pass.

**[0058]** The rolling finishing temperature of the hot rolling is preferably in a range of Ar3°C to Ar3 + 60°C. When the rolling finishing temperature is higher than Ar3 + 60°C, the grain size of the hot-rolled sheet becomes larger, thus the workability is deteriorated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is decreased, which is not preferable. In addition, when the rolling finishing temperature is lower than Ar3, the hot rolling is performed in the two phase region, thus the ferrite phase is deformed, the ductility and the hole expansibility of the hot-rolled steel sheet are deteriorated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is decreased, which is not preferable.

**[0059]** Further, the hot rolling includes rough rolling and finish rolling, and the finish rolling is preferably performed using a tandem mill with which a plurality of mills are linearly arranged and continuously rolling in one direction so as to obtain a desired thickness. In addition, in a case where the finish rolling is performed using a tandem mill, it is preferable that cooling (cooling between stands) is performed between the mills such that the maximum temperature of the steel sheet during the finish rolling is controlled to be in a range of Ar3 + 60°C to Ar3 + 150°C. When the maximum temperature of the steel sheet during the finish rolling is higher than Ar3 + 150°C, the grain size becomes excessively large and thus the toughness may be deteriorated and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° may be decreased. On the other hand, when the maximum temperature of the steel sheet during the finish rolling is lower than Ar3 + 60°C, there is a concern in that the rolling finishing temperature of the finish rolling cannot be secured.

**[0060]** When the hot rolling is performed under the above-described conditions, the range of the dislocation density of austenite before the transformation can be limited, and as a result, it is possible to obtain a desired ratio of the grains having an intragranular orientation difference in a range of 5° to 14°.

**[0061]** Ar3 can be calculated by the following Expression (2) in consideration of the influence on the transformation point by rolling reduction.

$$Ar3 = 970 - 325 \times [C] + 33 \times [Si] + 287 \times [P] + 40 \times [Al] - 92 \times ([Mn] + [Mo] + [Cu]) - 46 \times ([Cr] + [Ni]) \ldots (2)$$

**[0062]** Here, [C], [Si], [P], [Al], [Mn], [Mo], [Cu], [Cr], and [Ni] each represent, by mass%, the amount of each of C, Si, P, Al, Mn, Mo, Cu, Cr, and Ni. The elements which are not contained are calculated as 0%.

<Cooling process>

**[0063]** In the hot-rolled steel sheet which was subjected to the hot rolling controlled as described above is cooled. In the cooling process, the hot-rolled steel sheet after completing the hot rolling is cooled (first cooling) down to a temperature range in a range of 650°C to 750°C at a cooling rate of equal to or greater than 10°C/s, and the temperature is kept for 3 to 10 seconds in the temperature range, and thereafter, the hot-rolled steel sheet is cooled (second cooling) down to the temperature of equal to or lower than 100°C at a cooling rate of equal to or greater than 30°C/s.

**[0064]** When the cooling rate in the first cooling is lower than 10°C/s, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is less than 10%, which is not preferable. In addition, when a cooling stopping temperature in the first cooling is lower than 650°C, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is less than 10%, which is not preferable.

**[0065]** On the other hand, when the cooling stopping temperature in the first cooling is higher than 750°C, the martensite fraction is excessively low, the strength is decreased, and the ratio of the grains having an intragranular orientation difference in a range of 5 ° to 14° is greater than 60%, which is not preferable. When the retention time is shorter than three seconds at a temperature range of 650°C to 750°C, the martensite fraction is excessively high, the ductility is deteriorated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is less than 10%, which is not preferable. When the retention time at a temperature range of 650°C to 750°C is longer than 10 seconds, the martensite fraction is decreased, the strength is deteriorated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is less than 10%, which is not preferable. In addition, when the cooling rate of the second cooling is lower than 30°C/s, the martensite fraction is decreased, the strength is deteriorated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is greater than 60%, which is not preferable. When the cooling stopping temperature of the second cooling is higher than 100°C, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is greater than 60%, which is not preferable.

**[0066]** Although the upper limit of the cooling rate in the first cooling and the second cooling is not necessarily limited, the cooling rate may be set to be equal to or lower than 200°C/s in consideration of the equipment capacity of the cooling facility.

**[0067]** According to the above-described manufacturing method, it is possible to obtain a structure which has, by area ratio, ferrite and bainite in a range of 75% to 95% in total, and martensite in a range of 5% to 20%, in which a boundary having an orientation difference of equal to or greater than 15° is set as a grain boundary, and in a case where an area which is surrounded by the grain boundary, and has an equivalent circle diameter of equal to or greater than 0.3 μm is defined as a grain, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is, by area ratio, in a range of 10% to 60%.

**[0068]** In the aforementioned manufacturing method, it is important that processed dislocations are introduced into the austenite by controlling the hot rolling conditions, and then the processed dislocations introduced by controlling the cooling conditions appropriately remain. That is, the hot rolling conditions and the cooling conditions each have an influence, it is important to control these conditions at the same time. A known method may be used for conditions other than the above-described ones, and there is no particular limitation.

[Examples]

**[0069]** Hereinafter, the present invention will be described more specifically with reference to examples of the hot-rolled steel sheet of the present invention. However, the present invention is not limited to Example described below, and can be implemented by being properly modified the extent that it can satisfy the object before and after description, which are all included in the technical range of the present invention.

**[0070]** First, the steel having the chemical composition indicated in the following Table 1 was melted, and continuous cast so as to produce a slab. Then, the slab was heated at a temperature indicated in Table 2, and was subjected to rough rolling. After the rough rolling, the finish rolling was performed under the conditions indicated in Table 2 so as to obtain a hot-rolled steel sheet having the sheet thickness in a range of 2.2 to 3.4 mm. Ar3 (°C) indicated in Table 2 was obtained from the chemical composition indicated in Table 1 using the following Expression (2).

$$Ar3 = 970 - 325 \times [C] + 33 \times [Si] + 287 \times [P] + 40 \times [Al] - 92 \times ([Mn] + [Mo] + [Cu]) - 46 \times ([Cr] + [Ni]) \ldots (2)$$

**[0071]** Here, [C], [Si], [P], [Al], [Mn], [Mo], [Cu], [Cr], and [Ni] each represent, by mass%, the amount of each of C, Si, P, Al, Mn, Mo, Cu, Cr, and Ni, by mass%, and in a case of not containing the elements, 0 is substituted.

**[0072]** In addition, in Table 2, the cumulative strains at the latter three stages of the finish rolling were the value obtained by the following Expression (1).

$$\varepsilon eff. = \Sigma \varepsilon i(t,T) \ldots (1)$$

Here,

$$\varepsilon i(t,T) = \varepsilon i0/\exp\{(t/\iota R)^{2/3}\},$$

$$\iota R = \iota 0 \cdot \exp(Q/RT),$$

$$\iota 0 = 8.46 \times 10^{-6},$$

$$Q = 183200\ J,$$

and

$$R = 8.314\ J/K \cdot mol,$$

$\varepsilon i0$ represents a logarithmic strain at the time of rolling reduction, t represents a cumulative time immediately before the cooling in the pass, and T represents a rolling temperature in the pass.

**[0073]** The blank column in Table 1 means that the analysis value was less than the detection limit.

[Table 1]

| Steel No. | Chemical compositions (mass%, remainder Fe and impurities) | | | | | | | | | | | | | | | | Ar3 (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Al | N | B | Cr | Mo | Cu | Ni | Mg | REM | Ca | Zr | |
| A | 0.06 | 0.90 | 1.90 | 0.018 | 0.005 | 0.35 | 0.0018 | | | | | | | | | | 825 |
| B | 0.06 | 1.20 | 1.20 | 0.030 | 0.002 | 0.030 | 0.0021 | | 0.10 | | | | | | | | 885 |
| c | 0.07 | 0.50 | 1.80 | 0.010 | 0.003 | 0.25 | 0.0020 | | | | 0.06 | 0.03 | | | | | 804 |
| D | 0.06 | 1.00 | 1.10 | 0.030 | 0.004 | 0.25 | 0.0031 | | | | | | | | | | 901 |
| E | 0.09 | 0.90 | 0.90 | 0.020 | 0.003 | 0.030 | 0.0028 | | | | | | | | 0.0005 | | 895 |
| F | 0.09 | 0.30 | 1.00 | 0.015 | 0.004 | 0.040 | 0.0025 | | 0.15 | | | | | | | | 858 |
| G | 0.08 | 0.80 | 1.60 | 0.009 | 0.004 | 0.30 | 0.0032 | | | | | | | | | | 838 |
| H | 0.12 | 1.00 | 1.50 | 0.030 | 0.003 | 0.040 | 0.0038 | 0.0005 | | | | | | | | | 836 |
| I | 0.10 | 0.40 | 0.80 | 0.012 | 0.003 | 0.030 | 0.0020 | | | | | | | | | | 882 |
| J | 0.14 | 0.50 | 1.10 | 0.006 | 0.002 | 0.030 | 0.0026 | | | 0.13 | | | 0.0003 | | | | 831 |
| K | 0.10 | 0.70 | 0.80 | 0.013 | 0.003 | 0.020 | 0.0031 | | 0.20 | | | | | | | | 882 |
| L | 0.09 | 0.90 | 0.90 | 0.015 | 0.003 | 0.040 | 0.0028 | | | | | | | | | | 894 |
| M | 0.08 | 1.20 | 1.30 | 0.013 | 0.004 | 0.030 | 0.0018 | | | | | | | | | 0.0005 | 869 |
| N | 0.09 | 0.80 | 1.50 | 0.012 | 0.003 | 0.050 | 0.0020 | | | | | | | 0.0005 | | | 835 |
| 0 | 0.06 | 1.20 | 1.30 | 0.010 | 0.005 | 0.030 | 0.0042 | | | | | | | | | | 875 |
| P | 0.07 | 0.90 | 1.10 | 0.011 | 0.004 | 0.100 | 0.0035 | | 0.30 | | | | | | | | 869 |
| Q | 0.08 | 1.00 | 0.90 | 0.015 | 0.005 | 0.030 | 0.0040 | | | | 0.10 | 0.0)5 | | | | | 888 |
| a | 0.23 | 0.50 | 1.30 | 0.010 | 0.003 | 0.030 | 0.0018 | | | | | | | | | | 796 |
| b | 0.05 | 2.30 | 0.70 | 0.015 | 0.003 | 0.030 | 0.0022 | | | | | | | | | | 971 |
| c | 0.16 | 0.80 | 3.50 | 0.013 | 0.004 | 0.040 | 0.0025 | | 0.15 | | | | | | | | 621 |
| d | 0.01 | 0.50 | 0.90 | 0.016 | 0.003 | 0.030 | 0.0043 | | | | | | 0.0020 | | | | 906 |
| e | 0.10 | 1.00 | 1.20 | 0.015 | 0.005 | 0.020 | 0.0038 | 0.0200 | | | | | | | | | 865 |
| f | 0.09 | 0.90 | 0.20 | 0.018 | 0.003 | 0.030 | 0.0023 | | | | | | | | 0.0006 | | 958 |
| Underlines represent being outside of the range defined in the present invention | | | | | | | | | | | | | | | | | |

[Table 2]

| Test No. | Steel No. | Ar3 (°C) | Heating temperature (°C) | Rolling finishing temperature (°C) | Difference between rolling finishing temperature and Ar3 (°C) | Cumulative strains at latter three stages after finish rolling | Maximum temperature of steel sheet during finish rolling (°C) | Colling rate in first colling (°C/s) | Cooling stopping temperature in first cooling (°C) | Retention time at a temperature range of 650°C to 750°C (seconds) | Coolling rate in second cooling (°C/s) | Cooling stopping temperature in second cooling (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 825 | 1150 | 882 | 57 | 0.678 | 957 | 15 | 670 | 4 | 35 | 90 |
| 2 | B | 885 | 1150 | 923 | 38 | 0.623 | 1012 | 20 | 680 | 5 | 40 | 80 |
| 3 | C | 804 | 1150 | 845 | 41 | 0.665 | 947 | 38 | 700 | 6 | 46 | 70 |
| 4 | D | 901 | 1200 | 912 | 11 | 0.618 | 1030 | 42 | 720 | 5 | 50 | 80 |
| 5 | E | 895 | 1150 | 926 | 31 | 0.623 | 1030 | 18 | 730 | 6 | 35 | 50 |
| 6 | F | 858 | 1100 | 900 | 42 | 0.666 | 1000 | 25 | 700 | 7 | 62 | 30 |
| 7 | G | 838 | 1170 | 878 | 40 | 0.682 | 975 | 42 | 660 | 5 | 40 | 30 |
| 8 | H | 836 | 1150 | 890 | 54 | 0.643 | 982 | 40 | 680 | 41 | 45 | 30 |
| 9 | I | 882 | 1120 | 910 | 28 | 0.635 | 1020 | 35 | 690 | 3 | 60 | 40 |
| 10 | J | 831 | 1140 | 889 | 58 | 0.614 | 970 | 40 | 700 | 8 | 33 | 30 |
| 11 | K | 882 | 1150 | 923 | 41 | 0.623 | 1010 | 50 | 710 | 7 | 38 | 60 |
| 12 | L | 894 | 1150 | 943 | 49 | 0.65 | 1020 | 30 | 720 | 5 | 40 | 40 |
| 13 | M | 869 | 1160 | 919 | 50 | 0.679 | 1.000 | 28 | 730 | 9 | 36 | 80 |
| 14 | N | 835 | 1150 | 894 | 59 | 0.647 | 981 | 36 | 740 | 7 | 41 | 50 |
| 15 | O | 8.75 | 1090 | 930 | 55 | 0.653 | 1018 | 19 | 690 | 5 | 43 | 70 |
| 16 | P | 869 | 1150 | 918 | 49 | 0.629 | 1002 | 26 | 680 | 4 | 56 | 60 |
| 17 | Q | 888 | 1180 | 923 | 35 | 0.691 | 1030 | 30 | 670 | 6 | 37 | 80 |
| 18 | a | 796 | 1200 | 827 | 31 | 0.624 | 927 | 25 | 690 | 9 | 37 | 80 |
| 19 | b | 971 | 1150 | 955 | -16 | 0.610 | 1050 | 15 | 720 | 5 | 43 | 50 |
| 20 | c | 621 | 1150 | 820 | 199 | 0.654 | 950 | 25 | 720 | 6 | 38 | 50 |
| 21 | d | 906 | 1100 | 936 | 30 | 0.672 | 1002 | 30 | 680 | 7 | 36 | 80 |
| 22 | e | 865 | 1180 | 895 | 30 | 0.601 | 1000 | 25 | 700 | 7 | 40 | 70 |

(continued)

| Test No. | Steel No. | Ar3 (°C) | Heating temperature (°C) | Rolling finishing temperature (°C) | Difference between rolling finishing temperature and Ar3 (°C) | Cumulative strains at latter three stages after finish rolling | Maximum temperature of steel sheet during finish rolling (°C) | Colling rate in first colling (°C/s) | Cooling stopping temperature in first cooling (°C) | Retention time at a temperature range of 650°C to 750°C (seconds) | Coolling rate in second cooling (°C/s) | Cooling stopping temperature in second cooling (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | f | 958 | 1150 | 988 | 30 | 0.615 | 1085 | 40 | 680 | 5 | 39 | 40 |
| 24 | B | 885 | 1000 | 875 | -10 | 0.623 | 1002 | 18 | 670 | 4 | 50 | 60 |
| 25 | B | 885 | 1150 | 840 | -45 | 0.658 | 987 | 32 | 670 | 6 | 35 | 70 |
| 26 | B | 885 | 1160 | 950 | 65 | 0.653 | 1001 | 19 | 700 | 6 | 43 | 80 |
| 27 | B | 885 | 12 | 917 | 32 | 0.473 | 1013 | 22 | 690 | 7 | 47 | 70 |
| 28 | B | 885 | 1100 | 920 | 35 | 0.821 | 1005 | 21 | 710 | 4 | 33 | 70 |
| 29 | B | 885 | 1240 | 925 | 40 | 0.627 | 1120 | 18 | 740 | 9 | 41 | 80 |
| 30 | B | 885 | 1150 | 900 | 15 | 0.674 | 1034 | 3 | 710 | 7 | 49 | 80 |
| 31 | D | 901 | 1150 | 920 | 19 | 0.662 | 1017 | 32 | 820 | 5 | 46 | 70 |
| 32 | D | 901 | 1160 | 913 | 12 | 0.632 | 1010 | 25 | 600 | 9 | 38 | 40 |
| 33 | H | 836 | 1120 | 889 | 53 | 0.654 | 982 | 19 | 690 | 1 | 34 | 50 |
| 34 | H | 836 | 1130 | 890 | 54 | 0.682 | 980 | 32 | 670 | 15 | 37 | 60 |
| 35 | O | 875 | 1150 | 895 | 20 | 0.612 | 1010 | 35 | 700 | 7 | 2 | 80 |
| 36 | O | 875 | 1100 | 907 | 32 | 0.692 | 1000 | 27 | 680 | 6 | 38 | 500 |

**[0074]** With respect to the obtained hot-rolled steel sheet, each structure fraction (the area ratio), and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° were obtained. The structure fraction (the area ratio) was obtained using the following method. First, a sample collected from the hot-rolled steel sheet was etched using nital. After etching, a structure photograph obtained at a 1/4 thickness position in a visual field of 300 μm × 300 μm using an optical microscope was subjected to image analysis, and thereby the area ratio of ferrite and pearlite, and the total area ratio bainite and martensite were obtained. Then, With a sample etched by LePera solution, the structure photograph obtained at a 1/4 thickness position in the visual field of 300 μm × 300 μm using the optical microscope was subjected to the image analysis, and thereby the total area ratio of residual austenite and martensite was calculated.

**[0075]** Further, with a sample obtained by grinding the surface to a depth of 1/4 thickness in the normal direction to the rolled surface, the volume fraction of the residual austenite was obtained through X-ray diffraction measurement. The volume fraction of the residual austenite was equivalent to the area ratio, and thus was set as the area ratio of the residual austenite.

**[0076]** With such a method, the area ratio of each of ferrite, bainite, martensite, residual austenite, and pearlite was obtained.

**[0077]** Further, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° was measured using the following method. First, at a position of depth of 1/4 (1/4t portion) thickness t from surface of the steel sheet in a cross section vertical to a rolling direction , an area of 200 μm in the rolling direction, and 100 μm in the normal direction to the rolled surface was subjected to EBSD analysis at a measurement pitch of 0.2 μm so as to obtain crystal orientation information. Here, the EBSD analysis was performed using an apparatus which is configured to include a thermal field emission scanning electron microscope (JSM-7001F, manufactured by JEOL) and an EBSD detector (HIKARI detector manufactured by TSL), at an analysis speed in a range of 200 to 300 points per second. Then, with respect to the obtained crystal orientation information, an area having the orientation difference of equal to or greater than 15° and an equivalent circle diameter of equal to or greater than 0.3 μm was defined as a grain, the average intragranular orientation difference of the grains was calculated, and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° was obtained. The grain defined as described above and the average intragranular orientation difference can be calculated using software "OIM Analysis (trademark)" attached to an EBSD analyzer.

**[0078]** Next, the yield strength and the tensile strength were obtained in the tensile test, and the limit forming height was obtained by the saddle type stretch flange test. In addition, a product of tensile strength (MPa) and limit forming height (mm) was evaluated as an index of the stretch flangeability, and in a case where the product thereof is equal to or greater than 19500 mm·MPa, it was determined that the steel sheet was excellent in the stretch flangeability.

**[0079]** The tensile test was performed based on JIS Z 2241 using tensile test pieces No.5 of JIS which were collected in the longitudinal direction which is orthogonal to the rolling direction.

**[0080]** Further, the saddle type stretch flange test was conducted by setting a clearance at the time of punching a corner portion to 11% using a saddle-type formed product in which a radius of curvature R of a corner was set to 60 mm, and an opening angle θ was set to 120°. In addition, the existence of the cracks having a length of 1/3 of the sheet thickness were visually observed after forming, and then a forming height of the limit in which the cracks were not present was determined as the limit forming height.

**[0081]** The results are indicated in Table 3.

[Table 3]

| Test No. | Ferrite area ratio (%) | Baininte area ratio (%) | Ferrite + bainite area ratio (%) | Mattensite area ratio (%) | Ratio of the grains having intragranular orientation difference in a range of 5° to 14° (%) | Yield strength (MPa) | Tensite strength (MPa) | Index of stretch (mm ·MPa) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 45 | 42 | 87 | 13 | 56 | 525 | 821 | 21346 | Example of Present invention |
| 2 | 87 | 6 | 93 | 7 | 31 | 372 | 602 | 21672 | Example of Present invention |
| 3 | 55 | 33 | 88 | 12 | 42 | 541 | 873 | 20079 | Example of Present invention |
| 4 | 90 | 3 | 93 | 7 | 33 | 412 | 610 | 21350 | Example of Present |
| 5 | 79 | 16 | 95 | 5 | 41 | 450 | 652 | 20864 | Example of Present invention |
| 6 | 56 | 34 | 90 | 10 | 46 | 512 | 800 | 21600 | Example of Present invention |
| 7 | 42 | 45 | 87 | 13 | 58 | 543 | 817 | 21242 | Example of Present invention |
| 8 | 48 | 42 | 90 | 10 | 58 | 551 | 810 | 22680 | Example of Present invention |
| 9 | 67 | 24 | 91 | 9 | 47 | 500 | 787 | 21249 | Example of Present invention |
| 10 | 38 | 51 | 89 | 11 | 21 | 531 | 850 | | Example of Present invention |

(continued)

| Test No. | Ferrite area ratio (%) | Baininte area ratio (%) | Ferrite + bainite area ratio (%) | Mattensite area ratio (%) | Ratio of the grains having intragranular orientation difference in a range of 5° to 14° (%) | Yield strength (MPa) | Tensite strength (MPa) | Index of stretch (mm ·MPa) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 11 | 42 | 51 | 93 | 7 | 28 | 569 | 830 | 20750 | Example of Present invention |
| 12 | 86 | 8 | 94 | 6 | 59 | 426 | 640 | 22400 | Example of Present invention |
| 13 | 80 | 13 | 93 | 7 | 57 | 411 | 632 | 20856 | Example of Present invention |
| 14 | 52 | 38 | 90 | 10 | 51 | 510 | 810 | 20250 | Example of Present invention |
| 15 | 88 | 4 | 92 | 8 | 46 | 399 | 609 | 21924 | Example of Present invention |
| 16 | 69 | 18 | 87 | 13 | 32 | 393 | 645 | 20640 | Example of Present invention |
| 17 | 83 | 5 | 88 | 12 | 57 | 372 | 600 | 20400 | Example of Present invention |
| 18 | 0 | 0 | 0 | 100 | 0 | 91.8 | 997 | 3988 | Comparative Example |
| 19 | 9 5 | 5 | 96 | 0 | 7 | 345 | 459 | 16065 | Comparative Example |
| 20 | 3 | 42 | 45 | 65 | 4 | 820 | 1120 | 11200 | Comparative Example |

(continued)

| Test No. | Ferrite area ratio (%) | Baininte area ratio (%) | Ferrite + bainite area ratio (%) | Mattensite area ratio (%) | Ratio of the grains having intragranular orientation difference in a range of 5° to 14° (%) | Yield strength (MPa) | Tensite strength (MPa) | Index of stretch (mm ·MPa) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 88 | 10 | 98 | 2 | 5 | 276 | 460 | 18860 | Comparative Example |
| 22 | 20 | 58 | 78 | 18 | 3 | 689 | 899 | 13485 | Comparative Example |
| 23 | 90 | 6 | 96 | 4 | 15 | 292 | 463 | 17594 | Comparative Example |
| 24 | 88 | 5 | 93 | 7 | 2 | 380 | 585 | 18720 | Comparative Example |
| 25 | 82 | 13 | 95 | 5 | 1 | 418 | 592 | 17760 | Comparative Example |
| 26 | 56 | 22 | 78 | 22 | 2 | 526 | 813 | 16432 | Comparative Example |
| 27 | 84 | 3 | 87 | 8 | 1 | 405 | 610 | 15250 | Comparative Example |
| 28 | 79 | 4 | 83 | 17 | 4 | 378 | 593 | 17790 | Comparative Example |
| 29 | 78 | 14 | 92 | 8 | 2 | 403 | 605 | 17545 | Comparative Example |
| 30 | 67 | 19 | 86 | 14 | 3 | 410 | 613 | 18390 | Comparative Example |
| 31 | 79 | 18 | 97 | 3 | 78 | 408 | 575 | 18975 | Comparative Example |
| 32 | 72 | 9 | 81 | 19 | 6 | 411 | 623 | 18690 | Comparative Example |
| 33 | 46 | 26 | 72 | 28 | 5 | 570 | 812 | 18676 | Comparative Example |

(continued)

| Test No. | Ferrite area ratio (%) | Baininte area ratio (%) | Ferrite + bainite area ratio (%) | Mattensite area ratio (%) | Ratio of the grains having intragranular orientation difference in a range of 5° to 14° (%) | Yield strength (MPa) | Tensite strength (MPa) | Index of stretch (mm ·MPa) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 34 | 90 | 7 | 97 | 3 | 7 | 510 | 750 | 18750 | Comparative Example |
| 35 | 88 | 4 | 92 | 2 | 62 | 432 | 549 | 18666 | Comparative Example |
| 36 | 89 | 11 | 100 | 0 | 73 | 495 | 582 | 11640 | Comparative Example |

**[0082]** As apparent from the results of Table 3, in a case where the slab including the chemical composition specified in the present invention was hot-rolled under the preferable conditions (Test Nos.1 to 17), it was possible to obtain the high-strength hot-rolled steel sheet in which the strength is equal to or greater than 590 MPa, and an index of the stretch flangeability is equal to or greater than 19500 mm·MPa.

**[0083]** On the other hand, regarding Manufacture Nos. 18 to 23, the chemical composition was outside the range of the present invention, and thus any one or both of the structure observed using the optical microscope and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° did not satisfy the range of the present invention. As a result, the stretch flangeability did not satisfy the target value. In addition, in some examples, the tensile strength is also decreased.

**[0084]** In addition, Nos. 24 to 36 are examples in which the manufacturing method was outside the preferable range, and thus any one or both of the structure observed using the optical microscope and the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° did not satisfy the range of the present invention. In these examples, the stretch flangeability did not satisfy the target value. In addition, in some examples, the tensile strength was also decreased.

[Industrial Applicability]

**[0085]** According to the present invention, it is possible to provide an high-strength hot-rolled steel sheet which is excellent in the stretch flangeability and can be applied to a member which requires high strength and the strict stretch flangeability. The steel sheet contributes to improving fuel economy of vehicles, and thus has high industrial applicability.

## Claims

**1.** A hot-rolled steel sheet comprising, as a chemical composition, by mass%,

C: 0.04% to 0.18%,
Si: 0.10% to 1.70%,
Mn: 0.50% to 3.00%,
Al: 0.010% to 1.00%,
B: 0% to0.005%,
Cr: 0% to 1.0%,
Mo: 0% to 1.0%,
Cu: 0% to 2.0%,
Ni: 0% to 2.0%,
Mg: 0% to 0.05%,
REM: 0% to 0.05%,
Ca: 0% to 0.05%,
Zr: 0% to 0.05%,
P: limited to equal to or less than 0.050%,
S: limited to equal to or less than 0.010%, and
N: limited to equal to or less than 0.0060%, with the remainder including Fe and impurities;

wherein a structure includes, by area ratio, a ferrite and a bainite in a range of 75% to 95% in total, and a martensite in a range of 5% to 20%, and
wherein in the structure, in a case where a boundary having an orientation difference of equal to or greater than 15° is defined as a grain boundary, and an area which is surrounded by the grain boundary and has an equivalent circle diameter of equal to or greater than 0.3 μm is defined as a grain, the ratio of the grains having an intragranular orientation difference in a range of 5° to 14° is, by area ratio, in a range of 10% to 60%.

**2.** The hot-rolled steel sheet according to Claim 1,
wherein a tensile strength is equal to or greater than 590 MPa, and a product of the tensile strength and a limit forming height in a saddle type stretch flange test is equal to or greater than 19500 mm·MPa.

**3.** The hot-rolled steel sheet according to Claim 1 or 2,
wherein the chemical composition contains, by mass%,
one or more selected from the group consisting of:

B: 0.0001% to 0.005%,
Cr: 0.01% to 1.0%,
Mo: 0.01% to 1.0%,
Cu: 0.01% to 2.0%, and
Ni: 0.01% to 2.0%.

**4.** The hot-rolled steel sheet according to any one of Claims 1 to 3, wherein the chemical composition contains, by mass%, one or more selected from the group consisting of:

Mg: 0.0001% to 0.05%,
REM: 0.0001% to 0.05%,
Ca: 0.0001% to 0.05%, and
Zr: 0.0001% to 0.05%.

FIG. 1

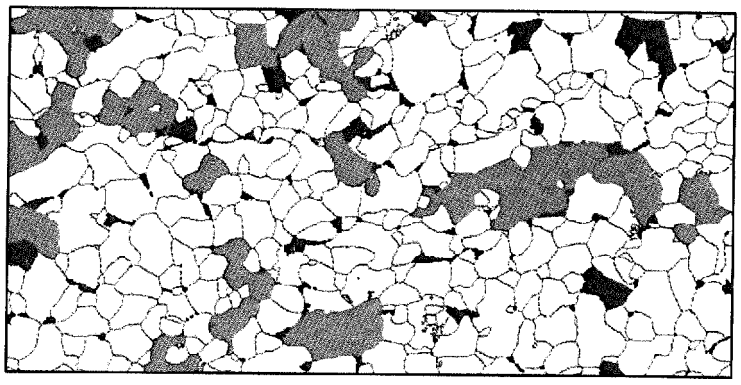
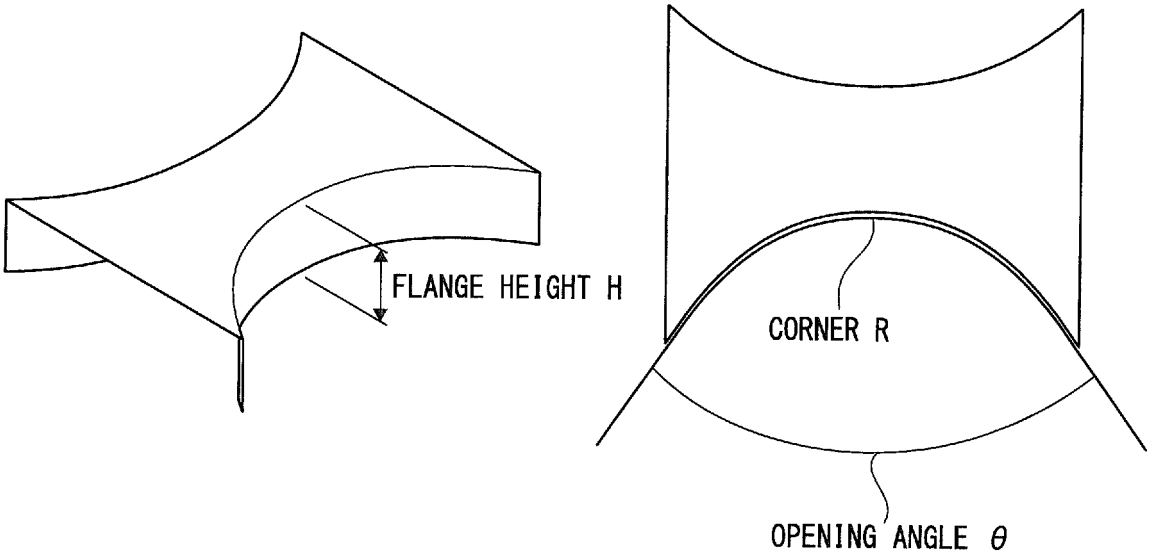


FIG. 2



**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2015/054860

A. CLASSIFICATION OF SUBJECT MATTER
*C22C38/00*(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/58*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, C21D9/46, C22C38/58

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2015
Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | JP 2014-37595 A (Nippon Steel & Sumitomo Metal Corp.), 27 February 2014 (27.02.2014), entire text (Family: none) | 1-4 |
| A | JP 2009-270171 A (Sumitomo Metal Industries, Ltd.), 19 November 2009 (19.11.2009), entire text (Family: none) | 1-4 |
| A | JP 2009-24227 A (Nippon Steel Corp.), 05 February 2009 (05.02.2009), entire text; all drawings (Family: none) | 1-4 |

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 08 May 2015 (08.05.15) | 19 May 2015 (19.05.15) |
| Name and mailing address of the ISA/<br>Japan Patent Office<br>3-4-3,Kasumigaseki,Chiyoda-ku,<br>Tokyo 100-8915,Japan | Authorized officer<br><br>Telephone No. |

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**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2015/054860

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | JP 2002-226943 A (Kawasaki Steel Corp.), 14 August 2002 (14.08.2002), entire text (Family: none) | 1-4 |
| A | JP 9-49026 A (Kobe Steel, Ltd.), 18 February 1997 (18.02.1997), entire text; all drawings (Family: none) | 1-4 |
| A | JP 2009-19265 A (Nippon Steel Corp.), 29 January 2009 (29.01.2009), entire text; all drawings (Family: none) | 1-4 |

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## REFERENCES CITED IN THE DESCRIPTION

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- JP 2013019048 A **[0009]**
- JP 2001303186 A **[0009]**
- JP 2005213566 A **[0009]**


### Non-patent literature cited in the description


- Misorientation Analysis of Plastic Deformation of Stainless Steel by EBSD and X-Ray Diffraction Methods. *KIMURA Hidehiko, journal of the Japan Society of Mechanical Engineers,* 2005, vol. 71 (712), 1722-1728 **[0048]**