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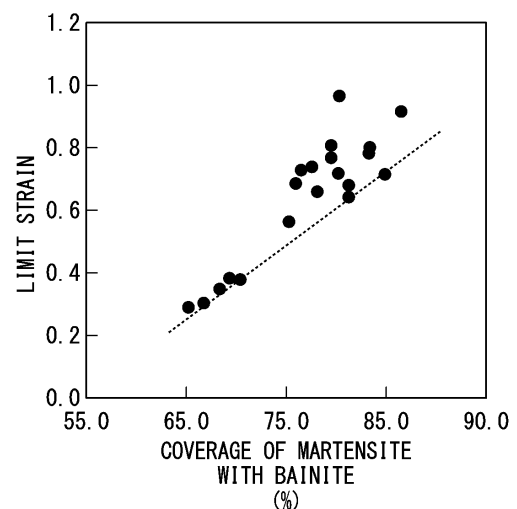
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(54) **HOT-ROLLED STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) This hot-rolled steel sheet has a predetermined chemical composition and has a metallographic structure containing ferrite with an area ratio of 53.0% or more and 76.0% or less, martensite with an area ratio of 3.0% or more and 10.0% or less, bainite with an area ratio of 14.0% or more and 39.0% or less, and pearlite with an area ratio of 2.6% or less, and with an average diameter of martensite of 0.26 μm or more and 0.70 μm or less, wherein, among all interfaces of the martensite, the total length of the interfaces between the martensite and the bainite is 75.0% or more with respect to the total length of all interfaces of the martensite.

FIG. 5



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Description

[Technical Field]

5 **[0001]** The present invention relates to a hot-rolled steel sheet and a method for manufacturing the same.

[Background Art]

10 **[0002]** In recent years, in consideration of global environment protection, the weights of automobile bodies and parts have been reduced in order to improve fuel efficiency of automobiles. In order to further reduce the weight of automobile bodies and parts, it is necessary to increase the strength of steel sheets applied to automobile bodies and parts.

15 **[0003]** Among automobile parts, chassis parts represented by lower arms or the like have complicated shapes in order to perform part functions. Therefore, in order to secure both the strength and processability, a high-strength hot-rolled steel sheet having a sheet thickness of 2.0 to 6.0 mm may be applied to chassis parts. In addition, hot-rolled steel sheets used in automobile parts are processed into complicated shapes as described above and thus, within processability, ductility and hole expandability are particularly required. Particularly, in recent years, as hot-rolled steel sheets to be applied to automobile parts, high-strength hot-rolled steel sheets having a tensile strength of 780 MPa or more and excellent ductility and hole expandability have been required.

20 **[0004]** As a method for improving the strength of hot-rolled steel sheets, there is a method using Ti and Nb. Ti and Nb are elements that precipitate fine alloy carbides in ferrite, and these fine alloy carbides contribute to improving the strength. Si may be added to the hot-rolled steel sheet in order to strengthen the ferrite by precipitation with such Ti and Nb. Particularly, in the hot rolling line, since the line length of the section from final rolling to winding is limited, when ferrite is formed in this section and carbides of Ti and Nb are precipitated, Si may be added in many cases. On the other hand, if the hot-rolled steel sheet contains Si, there is a risk of a scale pattern being formed on the surface of the steel sheet, impairing the appearance and also deteriorating fatigue properties.

25 **[0005]** In order to address such problems, Patent Document 1 discloses a steel sheet having a structure mainly composed of ferrite-bainite to which 0.25 mass% or less of Si and Al are added, and a method for manufacturing the same.

30 **[0006]** In addition, Patent Document 2 discloses a high-strength steel sheet having both elongation (ductility) and hole expandability and improved fatigue strength using a structure mainly composed of ferrite in the metallographic structure and reducing the area ratio of martensite.

[Citation List]

[Patent Document]

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[0007]

[Patent Document 1]

Japanese Unexamined Patent Application, First Publication No. 2004-204326

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[Patent Document 2]

PCT International Publication No. WO 2014/051005

[Summary of the Invention]

45 [Problems to be Solved by the Invention]

50 **[0008]** However, in the hot-rolled steel sheet containing a large amount of Ti and Nb as in Patent Document 1, although ductility and hole expandability can be secured, there are problems that peeling off of the sheared end surface (hereinafter also referred to as fine cracks on the sheared end surface) occurs during shearing, and molding cracks occur at the elongation-flanged part starting from fine cracks on the sheared end surface. That is, conventional hot-rolled steel sheets have a problem of sufficient elongation-flangeability not being obtained due to the occurrence of fine cracks on the sheared end surface during shearing.

55 **[0009]** The present invention has been made in view of the above circumstances and an object of the present invention is to provide a hot-rolled steel sheet having excellent strength, ductility, hole expandability and elongation-flangeability and a method for manufacturing the same.

[Means for Solving the Problem]

[0010] In view of the above problems, the inventors conducted extensive studies regarding the relationship between the chemical composition and the metallographic structure of the hot-rolled steel sheets and the above properties. As a result, the following findings (a) to (e) were obtained, and the present invention was completed.

[0011]

(a) In order to obtain excellent strength, it is effective to include a desired amount of martensite in the metallographic structure.

(b) In order to obtain excellent ductility, it is necessary to include a desired amount of ferrite in the metallographic structure and to control the amount of the bainite in the metallographic structure to be within a desired range.

(c) In order to obtain excellent hole expandability, it is important to control the amount of pearlite in the metallographic structure to be within a desired range.

(d) In order to obtain excellent elongation-flangeability, it is important to prevent fine cracks on the sheared end surface during shearing. In order to prevent fine cracks on the sheared end surface, it is effective to arrange bainite having intermediate deformability between ferrite and martensite so that it is covered with martensite, that is, to arrange bainite to be adjacent to martensite, and control the average diameter of martensite to be within a desired range. In this manner, when respective metallographic structures are appropriately arranged and the shape of martensite is controlled, it is possible to prevent the occurrence of fine cracks on the sheared end surface during shearing, and as a result, excellent elongation-flangeability can be obtained.

(e) In order to appropriately arrange the metallographic structure as described above and set the average particle size of martensite to be within a desired range, it is important to precisely control cooling conditions after hot rolling. Particularly, it is important to form a large number of uniform samples of bainite by setting cooling conditions in a bainite transformation temperature range after hot rolling to be within desired ranges.

[0012] The gist of the present invention based on the above findings is as follows.

[1] A hot-rolled steel sheet according to one aspect of the present invention having a chemical composition containing, in mass%,

C: 0.035% or more and 0.085% or less,

Si: 0.001% or more and 0.15% or less,

Mn: 0.70% or more and 1.80% or less,

P: 0.020% or less,

S: 0.0050% or less,

Ti: 0.075% or more and 0.170% or less,

Nb: 0.003% or more and 0.050% or less,

Al: 0.10% or more and 0.40% or less,

N: 0.0080% or less,

Cr: 0% or more and 0.27% or less,

B: 0% or more and 0.0050% or less,

Ca: 0% or more and 0.0050% or less,

Mo: 0% or more and 0.40% or less,

Ni: 0% or more and 0.50% or less,

Cu: 0% or more and 0.50% or less, and

REM: 0% or more and 0.0300% or less,

with the remainder being made up of Fe and impurities, and

having a metallographic structure containing,

ferrite with an area ratio of 53.0% or more and 76.0% or less,

martensite with an area ratio of 3.0% or more and 10.0% or less,

bainite with an area ratio of more than 14.0% and 39.0% or less, and

pearlite with an area ratio of 2.6% or less,

with an average diameter of martensite of 0.26 μm or more and 0.70 μm or less,

wherein, among all interfaces of the martensite, the total length of the interfaces between the martensite and the bainite is 75.0% or more with respect to the total length of all interfaces of the martensite.

[2] The hot-rolled steel sheet according to [1],

wherein the chemical composition may contain, in mass,
one, or two or more selected from the group consisting of

Cr: 0.06% or more and 0.27% or less,
B: 0.0003% or more and 0.0050% or less,
Ca: 0.0003% or more and 0.0050% or less,
Mo: 0.01% or more and 0.40% or less,
Ni: 0.01% or more and 0.50% or less,
Cu: 0.01 % or more and 0.50% or less, and
REM: 0.0003% or more and 0.0300% or less.

[3] A method for manufacturing a hot-rolled steel sheet according to one aspect of the present invention that is performed on a slab having the chemical composition according to [1] or [2], the method including:

a hot rolling process in which rolling is performed under conditions in which a final finishing temperature is 880°C or higher and 950°C or lower;
a primary cooling process in which cooling is performed to a primary cooling stop temperature of 680°C or higher and 760°C or lower at an average cooling rate of 60 °C/sec or faster, after the hot rolling process;
a secondary cooling process in which cooling is performed at an average cooling rate of 20 °C/sec or slower for 1.6 seconds or longer and 6.3 seconds or shorter, after the primary cooling process;
a tertiary cooling process in which cooling is performed to a tertiary cooling stop temperature of 195°C or higher and 440°C or lower at an average cooling rate of 60 °C/sec or faster and 130 °C/sec or slower, after the secondary cooling process;
a quaternary cooling process in which water cooling is performed at a water density of 2.0 m³/min/mm² or more and 7.2 m³/min/mm² or less for 0.33 seconds or longer and 1.50 seconds or shorter, after the tertiary cooling process;
a quinary cooling process in which air cooling is performed for 3.0 seconds or longer and 5.0 seconds or shorter, after the quaternary cooling process; and
a winding process in which winding is performed at lower than 180°C, after the quinary cooling process.

[Effects of the Invention]

[0013] According to the above aspects of the present invention, it is possible to provide a hot-rolled steel sheet having excellent strength, ductility, hole expandability and elongation-flangeability and a method for manufacturing the same.

[Brief Description of Drawings]

[0014]

FIG. 1 is a graph showing the relationship between molding height of an elongation-flanging molded part and breaking limit strain according to a side bend test in a conventional hot-rolled steel sheet having a tensile strength of 340 to 780 MPa.

FIG. 2 is a schematic view of a test piece used in the side bend test.

FIG. 3 is an image of cracks occurring on a sheared end surface that had been subjected to elongation-flanging molding, captured with a microscope.

FIG. 4A is a cross-sectional image of the sheared end surface that had not been subjected to elongation-flanging molding.

FIG. 4B is an SEM image of the vicinity of cracks formed on the sheared end surface shown in FIG. 4A.

FIG. 5 is a diagram showing the relationship between breaking limit strain and coverage in this example.

FIG. 6 is a diagram showing the relationship between breaking limit strain and an average diameter dM of martensite in this example.

FIG. 7 is a diagram showing the relationship between coverage and water density in a quaternary cooling process in this example.

FIG. 8 is a diagram showing the relationship between an average diameter dM of martensite and a cooling time in the quaternary cooling process in this example.

FIG. 9 is a diagram showing the relationship between coverage and an air cooling time in this example.

FIG. 10A is a structure image (SEM image) of Test No. 21 in this example.

FIG. 10B is a structure image (SEM image) of the vicinity of a sheared end surface after shearing was performed on Test No. 21 in this example.

FIG. 11A is a structure image (SEM image) of Test No. 17 in this example.

FIG. 11B is an enlarged view of an area A shown in FIG. 11A.

[Embodiment(s) for implementing the Invention]

[0015] First, the inventors will describe the results of examination of factors that influence elongation-flangeability in hot-rolled steel sheets, and new findings they obtained regarding the relationship between elongation-flangeability and a metallographic structure.

[0016] In conventional hot-rolled steel sheets, it is known that an appropriate design of a chemical composition, particularly active utilization of Ti and Nb, is effective in improving ductility and hole expandability. However, as a result of further extensive studies performed by the inventors, it was found that, when a hot-rolled steel sheet having favorable ductility and hole expandability was subjected to shearing, the sheared end surface was slightly peeled off, and when elongation-flanging molding was additionally performed on the hot-rolled steel sheet in which fine cracks occurred on the sheared end surface, molding cracks may occur at the elongation-flanged part. That is, the inventors have found that, in conventional hot-rolled steel sheets, even though they had favorable ductility and hole expandability, fine cracks on the sheared end surface during shearing, and molding cracks at the elongation-flanged part caused by these fine cracks occur, and as a result, sufficient elongation-flangeability may not be obtained. Therefore, the inventors examined factors that caused molding cracks at the elongation-flanged part and an index indicating elongation-flangeability.

[0017] First, using a slab having a steel composition B in Table 1 for examples to be described below, hot-rolled steel sheets were manufactured by variously changing cooling conditions after the hot rolling process, and a sample was cut out from the 1/4 position of the manufactured hot-rolled steel sheet in the width direction, and properties were examined. As a result, the strength and ductility (elongation at break) in the direction perpendicular to the rolling direction, and hole expandability were favorable. However, when hot-rolled steel sheets manufactured under certain cooling conditions were subjected to shearing, and elongation-flanging molding (side bend test) was additionally performed, cracks penetrating in the sheet thickness direction and breakage occurred. FIG. 3 shows the observation results of the broken surface of the broken area.

FIG. 3 is an image of cracks occurring on the sheared end surface that had been subjected to elongation-flanging molding, captured with a microscope. As shown in FIG. 3, within the sheared end surface after shearing, on the sheared end surface subjected to elongation-flanging molding in the direction perpendicular to the rolling direction, cracks parallel to the sheet surface occurred. That is, the hot-rolled steel sheets manufactured under certain cooling conditions are speculated to have broken as described above because cracks penetrated in the sheet thickness direction starting from cracks parallel to the sheet surface.

[0018] Cracks parallel to the sheet surface were examined in detail. FIG. 4A is a cross-sectional image of the sheared end surface that had not been subjected to elongation-flanging molding. As shown in FIG. 4A, it was found that cracks parallel to the sheet surface were already formed on the sheared end surface during a shearing stage.

[0019] In addition, FIG. 4B shows the examination results of the relationship between cracks parallel to the sheet surface and the metallographic structure. FIG. 4B is an SEM image of the vicinity of cracks formed on the sheared end surface shown in FIG. 4A. Here, FIG. 4B is an SEM image captured after corrosion with LePera in which white areas indicate martensite, gray areas indicate ferrite, and black areas indicate voids formed by cracking in martensite. As a result of examination, as shown in FIG. 4B, in the vicinity of cracks formed on the sheared end surface, an area (arrow (1)) in which martensite was deformed and peeled off and there were cracks in martensite itself (arrow (2)) was observed. Accordingly, it was found that peeling off and shape cracking in martensite itself as indicated by arrow (1) in FIG. 4B were main factors that caused cracks parallel to the sheet surface during shear cross section processing. Here, in this specification, the area (arrow (1)) in which martensite was deformed and peeled off and cracks in martensite itself (arrow (2)) as shown in FIG. 4B are collectively called "martensite molding cracks."

[0020] Based on the above examination results, next, in order to prevent martensite molding cracks, focusing on bainite of which the deformability magnitude is intermediate between ferrite and martensite, the morphology of an effective metallographic structure was examined. As a result, the inventors have found that, instead of simply specifying the area ratio of bainite, allowing bainite to surround martensite is effective against martensite molding cracks. That is, it was found that, when the proportion of interfaces with bainite among all interfaces of martensite was increased, it was possible to prevent martensite molding cracks and as a result, elongation-flangeability was improved.

[0021] Although the mechanism by which bainite acts effectively against martensite molding cracks is not clear, it is thought that bainite has a role of a cushion.

[0022] In addition, the investors examined whether there was any factor that causes cracks during shear cross section processing in addition to martensite molding cracks, and found that the diameter of martensite also has an influence.

[0023] Some cracks during shear cross section processing occurred due to voids and the inventors examined the method for minimizing formation of the voids. As a result, the following was found. That is, in order to minimize formation of voids and prevent the occurrence of cracks, it is important to set the diameter of martensite to be within a desired range.

[0024] That is, according to the inventors, it is important to prevent cracks parallel to the sheet surface during shear cross section processing. That is, if the diameter of martensite is too large, even if martensite is surrounded by bainite, deformation concentrates at the interfaces between bainite and martensite due to a difference in hardness between the two, and as a result, there is a risk of voids being formed. Therefore, in order to prevent cracks parallel to the sheet surface during shear cross section processing and improve elongation-flangeability, it is important to arrange bainite and martensite as desired, and to set the diameter of martensite to be within a desired range.

[0025] Next, elongation-flangeability in the present invention will be described.

[0026] In the related art, as a method for evaluating elongation-flangeability, a hole expansion test, a notch tensile test and the like have been generally applied. However, in these tests, when there were cases in which tensile deformation was dominant in automobile parts, particularly, in frame parts and chassis parts, elongation-flangeability could not be accurately evaluated in some cases.

[0027] For example, in the hole expansion test method, while the strain distribution sharply changes in the circumferential direction, it changes with a gentle strain gradient in the circumferential and radial directions in elongation flanging deformation. In this manner, in the hole expansion test used in the related art, it was not possible to evaluate elongation-flangeability that reflects influences of the shape of the part when the part was actually molded and properties of the steel sheet that was the material, and it was difficult to accurately evaluate elongation-flangeability according to actual conditions of molding.

[0028] Here, in the present invention, the breaking limit strain evaluated by the side bend test is used as an index of elongation-flangeability. That is, the term "elongation-flangeability" as used in the present invention refers to the breaking limit strain (hereinafter simply referred to as limit strain) when the open cross section of the steel sheet is subjected to in-plane deformation and cracks penetrate in the sheet thickness direction. In the present invention, elongation-flangeability is evaluated based on the breaking limit strain by this side bend test.

[0029] Next, the chemical composition and the metallographic structure of the hot-rolled steel sheet according to the present embodiment (hereinafter simply referred to as a steel sheet) will be described below in more detail. However, the present invention is not limited to the configuration disclosed in the present embodiment, and various modifications can be made without departing from the gist of the present invention.

[0030] Hereinafter, a limited numerical value range indicated by "to" includes the lower limit value and the upper limit value. Numerical values of "less than" or "more than" are not included in the numerical value range. In the following description, % related to the chemical composition of the steel sheet is mass% unless otherwise specified.

(Chemical composition)

[0031] The hot-rolled steel sheet according to the present embodiment has a chemical composition containing, in mass%, C: 0.035% or more and 0.085% or less, Si: 0.001% or more and 0.15% or less, Mn: 0.70% or more and 1.80% or less, P: 0.020% or less, S: 0.005% or less, Ti: 0.075% or more and 0.170% or less, Nb: 0.003% or more and 0.050% or less, Al: 0.10% or more and 0.40% or less, and N: 0.008% or less, with the remainder: Fe and impurities. Hereinafter, respective elements will be described in detail.

C: 0.035% or more and 0.085% or less

[0032] The C (carbon) content is 0.035% or more and 0.085% or less. If the C content is less than 0.035%, it is difficult to secure a sufficient area ratio of martensite. Therefore, the C content is 0.035% or more. In addition, it is not preferable to excessively reduce the C content in consideration of steelmaking cost. Accordingly, the C content is preferably 0.037% or more and more preferably 0.040% or more. On the other hand, if the C content is more than 0.085%, there is a risk of the area ratio of martensite becoming excessively large. Therefore, the C content is 0.085% or less. In addition, it is preferable to minimize the C content in order to reduce the incidence of slab cracking in the casting process. Accordingly, the C content is preferably 0.065% or less.

Si: 0.001% or more and 0.15% or less

[0033] A lower Si (silicon) content is preferable in consideration of the appearance of the steel sheet. In addition, if the Si content is more than 0.15%, there is a risk of the area ratio of ferrite becoming excessively large. Therefore, the Si content is 0.15% or less. In addition, in order to reduce costs in the pickling process for removing scale formed in the hot rolling process, a lower Si content is preferable. Accordingly, the Si content is preferably 0.07% or less. On the other hand, if the Si content is excessively lowered, the manufacturing cost in the steelmaking process significantly increases,

and the above effect is maximized, and thus the Si content is set to 0.001% or more. The Si content is preferably 0.003% or more.

Mn: 0.70% or more and 1.80% or less

[0034] Mn (manganese) has a function of inhibiting ferrite transformation and increasing the strength of the hot-rolled steel sheet. If the Mn content is less than 0.70%, the area ratio of ferrite increases and a desired strength may not be obtained. Therefore, the Mn content is 0.70% or more. The Mn content is preferably 0.80% or more and more preferably 0.90% or more. On the other hand, if the Mn content is more than 1.80%, the area ratio of ferrite excessively decreases, the area ratio of bainite increases, and ductility deteriorates. Therefore, the Mn content is 1.80% or less. The Mn content is preferably 1.75% or less, or 1.70% or less. Here, if the Mn content is less than 1.20%, an ear wrinkle pattern may be formed at the width direction edge of the steel sheet or steel sheet coil. Generally, such an ear-wrinkle pattern part is trimmed, which leads to a decrease in yield. Therefore, the Mn content is preferably 1.20% or more.

P: 0.020% or less

[0035] P (phosphorus) is an element that is generally contained as an impurity, but has a function of increasing the strength of the hot-rolled steel sheet according to solid solution strengthening. Therefore, P may be intentionally included, but P is an element that segregates at grain boundaries, and also has a function of causing a decrease in ductility. In addition, if the P content is more than 0.020%, there is a risk of the toughness of the hot-rolled slab decreasing, and cracks, particularly, cracks at the corner parts (corner cracks) of the casting slab, in the rolling process, occurring. Therefore, the P content is 0.020% or less. The P content is preferably 0.015% or less. It is not necessary to particularly specify the lower limit of the P content, and a lower P content is preferable. The lower limit of the P content can include 0%. However, if the P content is less than 0.001%, the refining cost in the steelmaking process becomes extremely high. Therefore, the P content is preferably 0.001% or more.

S: 0.0050% or less

[0036] S (sulfur) is an element that is contained as an impurity, and is an element that forms non-metallic inclusions to reduce ductility of the hot-rolled steel sheet. In addition, if the S content is more than 0.0050%, the ductility of the hot-rolled steel sheet significantly decreases, and flaws occur and breakage is caused in the hot rolling process. Therefore, the S content is 0.0050% or less. The S content is preferably 0.0040% or less. It is not necessary to particularly specify the lower limit of the S content, and a lower S content is preferable. The lower limit of the S content can include 0%. However, if the S content is less than 0.0001%, the refining cost in the steelmaking process increases. The S content is preferably 0.0001 % or more in consideration of the refining cost.

Ti: 0.075% or more and 0.170% or less

[0037] Ti (titanium) is an element that precipitates fine alloy carbides in ferrite and has a function of increasing the strength. If the Ti content is less than 0.075%, a sufficient strength cannot be obtained. Therefore, the Ti content is 0.075% or more. In addition, Ti is an effective element for improving hole expandability. In order to obtain these effects, the Ti content is preferably 0.090% or more. On the other hand, if the Ti content is more than 0.170%, the cold slab piece may crack. Therefore, the Ti content is 0.170% or less. The Ti content is preferably 0.150% or less.

Nb: 0.003% or more and 0.050% or less

[0038] Nb (niobium) is an element that precipitates fine alloy carbides. In addition, Nb has a function of minimizing austenite crystal grain growth during hot rolling, and minimizing coarsening of the crystal grain size of ferrite that is transformed and formed thereafter. When these functions are exhibited, it is possible to increase the strength of the steel sheet. In order to obtain this effect, the Nb content is 0.003% or more. In addition, Nb has a function of minimizing coarsening of crystal grains in the heat-affected zone during arc welding and minimizing softening of the heat-affected zone. In order to exhibit these effects, the Nb content is preferably 0.010% or more. On the other hand, if the Nb content is more than 0.050%, the toughness of the hot-rolled slab decreases, and as a result, cracks and flaws may occur in the rolling process. Therefore, the Nb content is 0.050% or less. The Nb content is preferably 0.045% or less.

Al: 0.10% or more and 0.40% or less

[0039] Al (aluminum) is an element that is effective in deoxidizing steel and making the steel sheet sound. In addition,

Al is an element that effectively acts to improve the area ratio of ferrite. If the Al content is less than 0.10%, the area ratio of ferrite becomes insufficient. Therefore, the Al content is 0.10% or more. In addition, Al also has a function of lowering the melting point of scale formed on the surface of the steel sheet in the hot rolling process, and thus it is possible to easily remove scale during heating. In order to obtain these effects, the Al content is preferably 0.20% or more. On the other hand, if the Al content is more than 0.40%, the area ratio of ferrite becomes excessively large, and the strength becomes insufficient. Therefore, the Al content is 0.40% or less. The Al content is preferably 0.35% or less.

N: 0.0080% or less

[0040] N (nitrogen) is an element that forms a nitride with Ti, Nb or Al. These nitrides lower the toughness of the hot-rolled slab and cause flaws and cracks, particularly, cracks at the corner parts (corner cracks) of the casting slab, in the rolling process. Therefore, in consideration of manufacturing, a lower N content is preferable, and the N content is 0.0080% or less. The lower limit of the N content can include 0%. On the other hand, if the N content is less than 0.0005%, there is a risk of the steelmaking cost becoming extremely high. Therefore, the N content is preferably 0.0005% or more and more preferably 0.0010% or more.

[0041] The remainder of the chemical composition of the hot-rolled steel sheet according to the present embodiment may include Fe and impurities. In the present embodiment, impurities are elements that are mixed in from ores or scrap as raw materials or a manufacturing environment or the like, or elements that are intentionally added in very small amounts, and have a meaning that they are allowable as long as they do not adversely affect the hot-rolled steel sheet according to the present embodiment.

[0042] The hot-rolled steel sheet according to the present embodiment may contain the following elements as optional elements in addition to the above elements in order to improve the strength, ductility or other properties. That is, in place of some Fe, one, two or more of Cr, B, Ca, Mo, Ni, Cu and REM may be contained as optional elements within the ranges to be described below. The lower limit of the content when these optional elements are not contained is 0%. Hereinafter, respective optional elements will be described in detail.

Cr: 0.06% or more and 0.27% or less

[0043] Cr (chromium) has a function of increasing the tensile strength of the steel sheet. In order to obtain the effect of this function, the Cr content is preferably 0.06% or more. The Cr content is more preferably 0.10%. On the other hand, if the Cr content is more than 0.27%, the area ratio of bainite may become excessively large. Therefore, the Cr content is preferably 0.27% or less. The Cr content is more preferably 0.25% or less.

B: 0.0003% or more and 0.0050% or less

[0044] B (boron) has a function of increasing the tensile strength of the steel sheet. In order to obtain the effect of this function, the B content is preferably 0.0003% or more. The B content is more preferably 0.0005% or more. On the other hand, if the B content is more than 0.0050%, it is difficult to obtain a sufficient area ratio of ferrite and also the area ratio of bainite may become excessively large. Therefore, the B content is preferably 0.0050% or less. The B content is more preferably 0.0040% or less.

Ca: 0.0003% or more and 0.0050% or less

[0045] Ca (calcium) has a function of spheroidizing non-metallic inclusions and increasing ductility. In order to obtain the effect of this function, the Ca content is preferably 0.0003% or more. The Ca content is more preferably 0.0005% or more. On the other hand, if the Ca content is more than 0.0050%, the toughness of the slab decreases, and cracks and flaws may occur in the slab in the rolling process. Therefore, the Ca content is preferably 0.0050% or less. The Ca content is more preferably 0.0040% or less.

Mo: 0.01% or more and 0.40% or less

[0046] Mo has a function of increasing the tensile strength of the steel sheet. In order to obtain the effect of this function, the Mo content is preferably 0.01% or more. The Mo content is more preferably 0.03% or more. On the other hand, if the Mo content is more than 0.40%, the area ratio of bainite may become excessively large. Therefore, the Mo content is preferably 0.40% or less. The Mo content is more preferably 0.35% or less.

Ni: 0.01% or more and 0.50% or less

[0047] Ni has a function of increasing the tensile strength of the steel sheet. In order to obtain the effect of this function, the Ni content is preferably 0.01% or more. The Ni content is more preferably 0.08% or more. On the other hand, if the Ni content is more than 0.50%, the area ratio of bainite may become excessively large. Therefore, the Ni content is preferably 0.50% or less. The Ni content is more preferably 0.40% or less.

Cu: 0.01% or more and 0.50% or less

[0048] Cu has a function of increasing the tensile strength of the steel sheet. In order to obtain the effect of this function, the Cu content is preferably 0.01 % or more. The Cu content is more preferably 0.08% or more. On the other hand, if the Cu content is more than 0.50%, the area ratio of bainite may become excessively large. Therefore, the Cu content is preferably 0.50% or less. The Cu content is more preferably 0.40% or less.

REM: 0.0003% or more and 0.0300% or less

[0049] REM (rare earth metals) are elements that have a function of reducing the size of inclusions and are elements that contribute to improve hole expandability and ductility (elongation at break). If the REM content is less than 0.0003%, it is not possible to obtain a sufficient effect of these functions. Therefore, the REM content is preferably 0.0003% or more. The REM content is more preferably 0.0005% or more. On the other hand, if the REM content is more than 0.0300%, since castability and hot processability may deteriorate, the REM content is preferably 0.0300% or less.

[0050] Here, REM refers to a total of 17 elements composed of Sc, Y and lanthanides, and the REM content refers to a total content of these elements. In the case of lanthanides, they are industrially added in the form of misch metals.

[0051] The chemical composition of the hot-rolled steel sheet described above may be measured by ICP optical emission spectroscopy using chips according to JIS G 1201:2014. For example, inductively coupled plasma-atomic emission spectrometry (ICP-AES) may be used for measurement. C and S may be measured using a combustion-infrared absorption method, and N may be measured using an inert gas fusion-thermal conductivity method.

(Metallographic structure)

[0052] Next, the metallographic structure of the hot-rolled steel sheet according to the present embodiment will be described.

[0053] In the hot-rolled steel sheet according to the present embodiment, the metallographic structure contains, in area%, 53.0% or more and 76.0% or less of ferrite, 3.0% or more and 10.0% or less of martensite, 14.0% or more and 39.0% or less of bainite, and 2.6% or less of pearlite. In addition, in the hot-rolled steel sheet according to the present embodiment, the average diameter of martensite is 0.26 μm or more and 0.70 μm or less, and among all interfaces of martensite, the total length of interfaces between martensite and bainite is 75.0% or more with respect to the total length of all interfaces of martensite.

[0054] Here, in the present embodiment, the metallographic structure at a depth of 1/4 of the sheet thickness from the surface of the sheet thickness cross section parallel to the rolling direction and at the center position in the sheet width direction is specified. The reason for this is that the metallographic structure at this position shows a typical metallographic structure of the hot-rolled steel sheet.

ferrite: 53.0% or more and 76.0% or less

[0055] Since ferrite is a soft structure, it is a metallographic structure that is mainly responsible for deformation. When a dual-phase steel sheet containing martensite such as the hot-rolled steel sheet of the present embodiment is used, it is possible to obtain an effect of increasing elongation as the area ratio of ferrite increases, that is, an effect of improving ductility. However, if the area ratio of ferrite is less than 53.0%, ductility decreases. Therefore, the area ratio of ferrite is 53.0% or more. The area ratio of ferrite is preferably 57.0% or more and more preferably 60.0% or more. On the other hand, if the area ratio of ferrite is more than 76.0%, a desired strength may not be obtained. Therefore, the area ratio of ferrite is 76.0% or less. The area ratio of ferrite is preferably 73.0% or less, and more preferably 70.0% or less.

martensite: 3.0% or more and 10.0% or less

[0056] Since martensite is a rigid structure, it contributes to improving the strength of the hot-rolled steel sheet. If the area ratio of martensite is less than 3.0%, a desired strength may not be obtained. Therefore, the area ratio of martensite is 3.0% or more. The area ratio of martensite is preferably 4.0% or more. On the other hand, if the area ratio of martensite

is more than 10.0%, hole expandability may significantly deteriorate. Therefore, the area ratio of martensite is 10.0% or less. The area ratio of martensite is preferably 9.0% or less, more preferably 8.0 or less, and still more preferably 7.0% or less.

5 bainite: 14.0% or more and 39.0% or less

[0057] Bainite is a structure that improves the strength and ductility of the hot-rolled steel sheet. In addition, when the metallographic structure is arranged so that martensite is surrounded by bainite, it is possible to improve elongation-flangeability. If the area ratio of bainite is less than 14.0%, it is difficult to arrange the above metallographic structure, and a desired elongation-flangeability cannot be obtained. Therefore, the area ratio of bainite is 14.0% or more. The area ratio of bainite is preferably 17.0% or more, more preferably 20.0% or more, and still more preferably 25.0% or more. On the other hand, if the area ratio of bainite is more than 39.0%, the ductility (elongation at break) may significantly deteriorate. Therefore, the area ratio of bainite is 39.0% or less. The area ratio of bainite is preferably 35.0% or less, more preferably 30.0% or less, and still more preferably 28.0% or less.

15 pearlite: 2.6% or less

[0058] If the area ratio of pearlite is more than 2.6%, hole expandability may deteriorate. Therefore, the area ratio of pearlite is 2.6% or less, preferably 1.7% or less, and more preferably 1.2% or less. The area ratio of pearlite may be 0%.

20 **[0059]** In addition, in addition to the above metallographic structure, retained austenite may be included. However, if the area ratio of retained austenite is more than 4.0%, the toughness may decrease. Therefore, if retained austenite is included, the area ratio of retained austenite is preferably 4.0% or less and more preferably 3.0% or less. The area ratio of retained austenite may be 0%.

[0060] Next, regarding the metallographic structure of the steel sheet of the present embodiment, the ratio (area%) of each structure can be measured by the following method.

[0061] As the area ratio of the metallographic structure of the hot-rolled steel sheet, a value measured from metallographic structure information such as a metallographic structure image captured with a scanning electron microscope in the cross section parallel to the rolling direction of the hot-rolled steel sheet may be used. The metallographic structure information such as a metallographic structure image may be obtained by cutting out a width center position in the direction perpendicular to the rolling direction and the sheet thickness direction in parallel to the rolling direction and using an observation field including a depth of 3/8 of the sheet thickness from the surface in the sheet thickness direction at the center. Three or more observation fields are set, and the average value of area ratios of the metallographic structures measured in respective fields of view can be used as the value of the area ratio of the typical metallographic structure of the steel sheet. Here, the area ratios of ferrite, pearlite, bainite, martensite, and retained austenite, the average diameter of martensite, and the coverage are measured in the same field of view.

[0062] In the present embodiment, the area ratio of ferrite (hereinafter referred to as V_{α}) is an area ratio of the ferrite structure determined by an electron backscatter diffraction (EBSD) method. In order to measure the area ratio of ferrite, first, crystal orientation information (crystal orientation mapping data) measured by the EBSD method is obtained. For measurement, a device composed of a thermal field emission scanning electron microscope ("JSM-7001F" commercially available from JEOL) and an EBSD detector ("Hikari detector" commercially available from TSL) is used. The crystal orientation mapping data can be obtained using software "O1M Analysis (registered trademark)" bundled in the EBSD analysis device. During measurement, the degree of vacuum in the device may be 9.6×10^{-5} Pa or less, and the accelerating voltage may be 20 kv.

[0063] The procedure of determining the area ratio of ferrite from this crystal orientation mapping data is divided into the following three steps.

[0064] In the first step, crystal grains are defined from crystal orientation mapping data. Here, the crystal grain refers to an area surrounded by boundaries in which a crystal orientation difference between an arbitrary measurement point in the crystal orientation mapping data and a measurement point adjacent thereto is 15° or more, that is, grain boundaries.

[0065] In the second step, it is determined whether the crystal grains defined in the first step are crystal grains of ferrite. A local misorientation average (GAM value) is used for this method for determining ferrite. This GAM value is a value indicating misorientation of crystal grains. If the GAM value of crystal grains to be determined is within 0.35° , the crystal grains are determined to be ferrite.

[0066] In the third step, determination in the second step is performed for all crystal grains recorded in the crystal orientation mapping data. Then, a ratio of the number of measurement points belonging to the crystal grains determined to be ferrite to the total number of measurement points of the crystal orientation mapping data is calculated. This ratio is defined as an area ratio of ferrite.

[0067] Crystal orientation mapping data may include a total of 1,000 crystal grains so that the error due to the measurement position in the area ratio of ferrite can be sufficiently reduced. The measurement magnification when crystal

orientation mapping data is obtained by EBSD analysis is set so that the field of view includes 1,000 crystal grains. In addition, in analysis at a low magnification of less than 200, the measurement accuracy decreases due to the influence of electron beam distortion. Therefore, the measurement magnification may be 250. In the present embodiment, an area of $500\text{ }\mu\text{m}\times 500\text{ }\mu\text{m}$ is measured at a magnification of 250.

[0068] The measurement range of the area ratio of ferrite is a quadrangle having sides in the sheet thickness direction and the rolling direction. The length of the side in the sheet thickness direction is $500\text{ }\mu\text{m}$, and the length of the side in the rolling direction may be the same as that of the side in the sheet thickness direction. The area ratio of ferrite is measured in a range including a position of $3/8$ of the sheet thickness from the surface in the sheet thickness direction. In addition, the crystal orientation measurement interval within the measurement range is $0.03\text{ }\mu\text{m}$. If the measurement interval is less than $0.03\text{ }\mu\text{m}$, the electron beam interference range may overlap. On the other hand, if the measurement interval is more than $0.03\text{ }\mu\text{m}$, the number of crystal orientation measurement points included in the crystal grain is insufficient, and measurement errors are likely to occur.

[0069] A ferrite measurement sample may be cut out so that the width center position in the direction perpendicular to the rolling direction and the sheet thickness direction is parallel to the rolling direction, and may be observed in the direction perpendicular to the rolling direction and the sheet thickness direction.

[0070] In the present embodiment, the area ratio of martensite (hereinafter referred to as VM) is a value measured from the metallographic structure exposed by corrosion with LePera. Within the metallographic structure exposed due to corrosion with LePera, the metallographic structure observed with white contrast is identified as martensite. The ratio of the white contrast area within the entire area in the observation field, that is, the area of the metallographic structure identified as martensite, is the area ratio VM of martensite.

[0071] Hereinafter, a method for measuring the area ratio VM of martensite will be described.

[0072] First, a scanning electron microscope is used for imaging a field of view used for measuring the area ratio VM of martensite. In order to improve the measurement accuracy, the metallographic structure may be imaged at a magnification of 5,000. In addition, if the magnification is 5,000, at least one martensite grain can be imaged within one field of view. Therefore, the magnification is preferably 5,000. In the present embodiment, an area of $500\text{ }\mu\text{m}\times 500\text{ }\mu\text{m}$ is observed at a magnification of 5,000, and the area ratio of martensite is measured.

[0073] When the area ratio VM of martensite is measured, the accelerating voltage when an electron beam is emitted is in a range of 10.0 kV or more and 15.0 kV or less. If the accelerating voltage is more than 15.0 kV, grain boundaries may become blurred. On the other hand, if the accelerating voltage is less than 10.0 kV, since the resolution decreases, it is unsuitable for observation.

[0074] Backscattered electron images obtained from these observation samples under observation conditions are used to measure the area ratio VM of martensite. Specifically, in order to reduce errors between observation fields, the area ratio VM of martensite is obtained from the measurement range in which the total number of crystal grains is 600 or more. The total number of crystal grains within the measurement range may be 1,000. The measurement range is a range including a position of $3/8$ of the sheet thickness from the surface in the sheet thickness direction. In addition, the measurement range is $500\text{ }\mu\text{m}$ in the sheet thickness direction and is a range of $500\text{ }\mu\text{m}$ in the rolling direction.

[0075] Regarding the area ratio of bainite (hereinafter referred to as VB), the area ratio VB of the bainite structure is defined as the remainder obtained by subtracting a sum of the area ratios of ferrite and martensite obtained by the above method, retained austenite to be described below, and pearlite from 100%.

[0076] The area ratio of pearlite (hereinafter referred to as VP) is a value measured from the metallographic structure exposed due to nital corrosion.

[0077] A pearlite measurement sample may be cut out so that the width center position in the direction perpendicular to the rolling direction and the sheet thickness direction is parallel to the rolling direction, and may be observed in the direction perpendicular to the rolling direction and the sheet thickness direction.

[0078] In the collected pearlite measurement sample, a metallographic structure image is obtained in the measurement range centered at a position of $3/8$ in the sheet thickness direction from the surface of the steel sheet. Here, the pearlite measurement sample is the same as the sample for measuring the area ratios of ferrite and martensite.

[0079] In the present embodiment, a metallographic structure image for measuring the area ratio of pearlite is obtained to use a scanning electron microscope. In imaging with a scanning electron microscope, the accelerating voltage when an electron beam is emitted is in a range of 10.0 kV or more and 15.0 kV. If the accelerating voltage is more than 15.0 kV, grain boundaries may become blurred. On the other hand, if the accelerating voltage is less than 10.0 kV, since the resolution decreases, it is unsuitable for observation. Thus, in order to sufficiently improve the measurement accuracy, the metallographic structure may be imaged at a magnification of 2,000 or more. Here, if the magnification is 10,000 or less, one or more pearlite grains can be imaged within one field of view. Therefore, the magnification may be 10,000 or less. Here, in order to reduce the number of fields of view and obtain measurement accuracy, the magnification is preferably 5,000. In addition, the measurement range is a range of $10\text{ }\mu\text{m}$ or more and $40\text{ }\mu\text{m}$ or less in the sheet thickness direction and $10\text{ }\mu\text{m}$ or more and $55\text{ }\mu\text{m}$ or less in the rolling direction.

[0080] The area ratio of retained austenite (hereinafter referred to as Vy) is a value obtained by dividing the number

of crystal orientation measurement points in which the crystal structure is determined to be fcc among the crystal orientation mapping data used when the above area ratio V_{α} of ferrite is obtained by the total number of measurement points of the crystal orientation mapping data. The crystal orientation mapping data used for measuring the area ratio V_{γ} of retained austenite is the same data used for measuring the area ratio V_{α} of ferrite. That is, the measurement range, the measurement magnification, and the field of view may be the same as in the method for measuring the area ratio of ferrite.

(Morphology of metallographic structure)

[0081] Next, the morphology of the metallographic structure of the hot-rolled steel sheet according to the present embodiment will be described.

[0082] In order to obtain excellent elongation-flangeability in the hot-rolled steel sheet of the present embodiment, it is important to configure the metallographic structure as described above, set the area ratio to be within a desired range and set the ratio of the interface length between martensite and bainite to the total length of interfaces of martensite, and the average diameter d_M of martensite to be within a desired range.

[0083] The ratio of the interface length between martensite and bainite to the total length of interfaces of martensite (hereinafter referred to as coverage) is 75.0% or more. It is thought that, since bainite is a metallographic structure with an intermediate strength between ferrite and martensite, it has a role of reducing the difference in deformation between ferrite and martensite, that is, a role such as a cushion. If the coverage of martensite with bainite is less than 75.0%, the role as the cushion becomes insufficient, and fine cracks occur on the sheared end surface. Then, as a result, it is difficult to obtain excellent elongation-flangeability. In addition, if the coverage is less than 75.0%, the breaking limit strain to be described below decreases. Therefore, the ratio of the interface length between martensite and bainite to the total length of interfaces of martensite is preferably as high as possible, and preferably 78% or more. On the other hand, the upper limit of the ratio of the length of the interface between martensite and the bainite to the total length of interfaces of martensite is not particularly defined, and may be 100%.

[0084] As described above, in order to improve elongation-flangeability, it is effective not only to increase the area ratio of bainite but also to arrange bainite so that it surrounds martensite, that is, to increase the ratio of the interface length between martensite and bainite to the total length of interfaces of martensite.

[0085] The average diameter d_M of martensite is 0.26 μm or more and 0.70 μm or less in order to reduce the occurrence of voids. If the average diameter d_M is set to be within the above range, it is possible to minimize the occurrence of fine cracks on the sheared end surface, and as a result, it is possible to obtain high elongation-flangeability. If the average diameter d_M of martensite is more than 0.70 μm , deformation concentrates at the interfaces between martensite and bainite due to a difference in hardness. As a result, even if the coverage with bainite is satisfactory, there is a risk of voids being formed in the vicinity of the interface between martensite and bainite. In addition, if voids are formed, there is a risk of fine cracks occurring on the sheared end surface and the breaking limit strain to be described below decreasing. Therefore, the average diameter d_M of martensite is 0.70 μm or less. The average diameter d_M of martensite is preferably 0.65 μm or less, and more preferably 0.60 μm or less. On the other hand, if the average diameter d_M of martensite is less than 0.26 μm , there is a risk of martensite not contributing to the strength. In addition, if the average diameter d_M of martensite is less than 0.26 μm , the coverage may decrease. Therefore, the average diameter d_M of martensite is 0.26 μm or more. Preferably, the average diameter d_M of martensite is 0.30 μm or more.

[0086] Here, the ratio of the interface length between martensite and bainite to the total length of interfaces of martensite is the ratio of a total boundary length (interface length) between martensite and bainite to a total boundary length (interface length) between martensite and other metallographic structures adjacent thereto. A method for determining this ratio will be described below.

[0087] First, the total length of interfaces of martensite, that is, a sum of boundary lengths between martensite and other metallographic structures adjacent thereto, is a sum value obtained by measuring the lengths of boundaries (interface length) between martensite identified by the above method and other metallographic structures adjacent thereto. The total length of interfaces of martensite may be determined using a metallographic structure image captured by the same method as the method for measuring the average diameter d_M of martensite to be described below. Specifically, 300 martensite grains are selected from the captured metallographic structure image, and the interface length of these grains is determined. For individual martensite grains, the lengths of boundaries between martensite and other metallographic structures adjacent thereto are measured, and a sum of all length values is a sum of boundary lengths between martensite and other metallographic structures adjacent thereto, that is, the total length of interfaces of martensite.

[0088] Next, a sum of boundary lengths between martensite and bainite is obtained. The sum of boundary lengths between martensite and bainite is a sum of values obtained by measuring the lengths of boundaries between martensite identified by the above method and bainite in contact therewith. This value is a value measured using the same martensite as a measurement target when the total length of interfaces of martensite is measured, and the number of measurements

is also the same. That is, the "boundary between martensite and bainite" means the boundary between martensite and bainite among the boundaries between martensite identified by the above method and other metallographic structures adjacent thereto, and a sum of the lengths of boundaries is "the boundary length between martensite and bainite."

[0089] A value obtained by dividing a sum of boundary lengths between martensite and bainite obtained by the above method by a sum of boundary lengths between martensite and other metallographic structures adjacent thereto is a coverage of martensite with bainite, that is, a ratio of the interface length between martensite and bainite to the total length of interfaces of martensite.

[0090] Next, a method for determining the average diameter dM of martensite will be described.

[0091] The martensite of the hot-rolled steel sheet of the present embodiment has a sheet-like form. Therefore, martensite crystal grains are approximated to an ellipse, their long diameters and short diameters are measured, and the average value thereof is used as the average diameter of measured martensite grains. Then, the average value of all measured martensite diameters is calculated, and the average value of these values is defined as the average diameter dM of martensite of the hot-rolled steel sheet.

[0092] The number of martensite grains whose average diameter dM is measured is 300. Here, most martensite grains to be measured are fine (with a diameter of several μm or less). Therefore, it is preferable to perform measurement using a metallographic structure image captured at a magnification of 5,000. The field of view of the metallographic structure image used when the average diameter dM is measured and the measurement sample are the same as the field of view used when the area ratio of martensite is measured.

(Properties)

[0093] Next, properties of the hot-rolled steel sheet of the present embodiment will be described.

[0094] The hot-rolled steel sheet according to the present embodiment may have properties of a tensile strength of 780 MPa or more, a ductility (elongation at break) of 15.0% or more, and a hole expandability (hole expansion rate) of 60% or more. In addition, the breaking limit strain by the side bend test to be described below may be 0.5 or more. When these properties are satisfied in the hot-rolled steel sheet, it is possible to obtain a hot-rolled steel sheet that is suitable not only for automobile bodies but also for materials of automobile parts (particularly, chassis parts) processed into complicated shapes.

<Tensile strength>

[0095] The hot-rolled steel sheet according to the present embodiment may have a tensile strength of 780 MPa or more. If the tensile strength is set to 780 MPa or more, it is possible to contribute to reducing the weight of automobile bodies and parts. It is not necessary to particularly specify the upper limit, and the upper limit may be 950 MPa or less.

<Ductility (elongation at break)>

[0096] The hot-rolled steel sheet according to the present embodiment may have an elongation at break of 15.0% or more.

<Hole expandability>

[0097] The hot-rolled steel sheet according to the present embodiment may have a hole expandability (hole expansion rate) of 60% or more.

[0098] The tensile strength and the elongation at break are measured according to JIS Z 2241:2011 using No. 5 test piece of JIS Z 2241:2011. A tensile test piece is taken in the direction perpendicular to the rolling direction and the sheet thickness direction (sheet width direction) so that it includes a 1/4 part from the edge of the steel sheet. In this case, the tensile test piece is taken with the direction perpendicular to the rolling direction as the longitudinal direction. The crosshead speed in the tensile test may be set under conditions in which the strain rate is constant at 0.005 s^{-1} .

[0099] Hole expandability (hole expansion rate) is evaluated by the hole expansion rate (λ) specified in JIS Z 2256:2010. Specifically, using a $\phi 10 \text{ mm}$ punch, a die diameter is selected so that the clearance becomes 12.5%, and holes are punched out. Then, a hole expansion test is performed using a conical die with a tip angle of 60° with the burr on the outside and at a stroke speed of 10 mm/min . The test is stopped when cracks formed around the hole penetrate through the sheet thickness, and the hole diameters before and after the hole expansion test are compared.

<Elongation-flangeability (breaking limit strain)>

[0100] In the hot-rolled steel sheet of the present embodiment, as an index of elongation-flangeability, the breaking

limit strain evaluated by the side bend test to be described below is used. The breaking limit strain of the hot-rolled steel sheet of the present embodiment may be 0.5 or more.

[0101] Here, when an automobile part is molded, it is desirable to perform molding so that the vertical wall height (molding height) of the elongation-flanged part can be sufficiently secured in order to secure the rigidity of the part. That is, as a material steel sheet for parts, a material steel sheet that can withstand this increase in the molding height is desirable. Generally, for example, a material steel sheet that can secure a molding height of 18 mm or more is desirable. Therefore, the inventors examined the relationship between the molding height of the elongation-flanging molded part and the breaking limit strain according to the side bend test using a conventional hot-rolled steel sheet having a tensile strength of 340 to 780 MPa. The results are shown in FIG. 1. Here, in symbols in the graph shown in FIG. 1, white symbols indicate cases in which molding was possible, and black symbols indicate case in which cracks occurred. In addition, in the graph, for example, "780 material" indicates a 780 MPa material.

[0102] Based on the graph shown in FIG. 1, it can be understood that all 340 MPa, 440 MPa and 590 MPa materials with a limit strain of 0.5 or more could be molded to a molding height of 18 mm or more without breaking or cracking. However, it can be understood that the 780 MPa material with a limit strain of 0.35 could be molded up to a molding height of about 15 mm, but if this height was exceeded, cracks occurred. That is, it can be understood that, when the breaking limit strain of the steel sheet as a material is set to 0.5 or more, it can withstand molding in which the molding height of the elongation-flanging molded part is 18 mm or more.

[0103] Thus, in the hot-rolled steel sheet of the present embodiment, the breaking limit strain obtained by the following side bend test may be 0.5 or more, and is preferably 0.6 or more.

(Side bend test method)

[0104] The breaking limit strain, which is an index of elongation-flanging moldability, is a value measured in the following side bend test. Here, in the side bend test in the present embodiment, methods described in "Nippon Steel Technical Report No. 393, (2012) p. 18 to 24" and "Japanese Unexamined Patent Application, First Publication No. 2009-145138" are used.

[0105] The shape of the test piece for the side bend test is the shape shown in FIG. 2. The semicircular part of the test piece may be formed by shearing. Specifically, first, a sheet of 35 mm×100 mm is cut out from a steel sheet. Then, a semicircular hole is punched out in the sheet using a $\phi 30$ mm punch under conditions in which the sheet thickness clearance (a value obtained by dividing a gap between a punch and a die by a sheet thickness) is 12.5%. A test piece shown in FIG. 2 is prepared according to these processes. In addition, the radius of the semicircular part of the test piece is 15 mm. Here, before the side bend test is performed, it is preferable to draw a grid pattern of 2 mm on the surface of the test piece in order to measure the breaking limit strain.

[0106] Using the side bend test piece, devices and methods described in "Nippon Steel Technical Report No. 393, (2012) p. 18 to 24" and "Japanese Unexamined Patent Application, First Publication No. 2009-145138" are used to perform the test. Specifically, a test piece is deformed at a stroke speed of 10 mm/min, and formation of a crack at the edge of the hole is defined as "breakage." After breaking, the breaking limit strain with a gauge length of 6.0 mm is measured using a total of three elements including a determined element and elements adjacent thereto.

[0107] Here, from the hot-rolled steel sheet to be evaluated, three or more side bend test pieces are prepared, and the above breaking limit strains of these test pieces are measured. Then, the average value of these breaking limit strains is defined as the breaking limit strain according to the side bend test for the hot-rolled steel sheet.

(Sheet thickness)

[0108] The sheet thickness of the hot-rolled steel sheet according to the present embodiment is not particularly limited, but may be 1.6 to 8.0 mm. Particularly, in consideration of application to automobile chassis, the sheet thickness may be 1.6 mm or more in many cases. Therefore, the sheet thickness of the hot-rolled steel sheet according to the present embodiment may be 1.6 mm or more, and is preferably 1.8 mm or more, 2.0 mm or more. In addition, if the sheet thickness is set to 8.0 mm or less, the metallographic structure can be easily refined, and it is possible to easily secure the above metallographic structure. Therefore, the sheet thickness may be 8.0 mm or less, and is preferably 7.0 mm or less.

(Plating layer)

[0109] The hot-rolled steel sheet according to the present embodiment having the chemical composition and metallographic structure described above may have a plating layer on the surface in order to improve corrosion resistance, and may be used as a surface-treated steel sheet. The plating layer may be an electroplating layer or a melt plating layer. Examples of electroplating layers include electrogalvanizing and electro Zn-Ni alloy plating. Examples of melt plating layers include melt galvanizing, alloyed melt galvanizing, melt aluminum plating, melt Zn-Al alloy plating, melt

Zn-Al-Mg alloy plating, and melt Zn-Al-Mg-Si alloy plating. The amount of plating adhered is not particularly limited, and may be the same as in the related art. In addition, after plating, an appropriate chemical conversion treatment (for example, applying a silicate-based chromium-free chemical conversion treatment solution and drying) is performed, and it is possible to further increase corrosion resistance.

(Manufacturing conditions)

[0110] Next, a method for manufacturing a hot-rolled steel sheet according to the present embodiment will be described. Here, the temperature of the slab and the temperature of the steel sheet in the present embodiment refer to the surface temperature of the slab and the surface temperature of the steel sheet. In the present embodiment, the temperature of the hot-rolled steel sheet is measured with a contact type or noncontact type thermometer if it is the endmost part in the sheet width direction. If it is a part other than the endmost part of the hot-rolled steel sheet in the sheet width direction, it is measured by a thermocouple or calculated by heat transfer analysis.

[0111] A method for manufacturing a hot-rolled steel sheet according to the present embodiment that is performed on a slab having the above chemical composition, the method including a hot rolling process in which rolling is performed under conditions in which a final finishing temperature is 880°C or higher and 950°C or lower; a primary cooling process in which cooling is performed to a primary cooling stop temperature of 680°C or higher and 760°C or lower at an average cooling rate of 60 °C/sec or faster, after the hot rolling process; a secondary cooling process in which cooling is performed at an average cooling rate of 20 °C/sec or slower for 1.6 seconds or longer and 6.3 seconds or shorter, after the primary cooling process; a tertiary cooling process in which cooling is performed to a tertiary cooling stop temperature of 195°C or higher and 440°C or lower at an average cooling rate of 60 °C/sec or faster and 130 °C/sec or slower, after the secondary cooling process; a quaternary cooling process in which water cooling is performed at a water density of 2.0 m³/min/mm² or more and 7.2 m³/min/mm² or less for 0.33 seconds or longer and 1.50 seconds or shorter, after the tertiary cooling process; a quinary cooling process in which air cooling is performed for 3.0 seconds or longer and 5.0 seconds or shorter, after the quaternary cooling process; and a winding process in which winding is performed at lower than 180°C, after the quinary cooling process.

(Hot rolling process)

[0112] First, a hot slab having the above chemical composition is subjected to rough rolling, and final rolling is then performed under conditions in which the final rolling outlet temperature (final finishing temperature) is 880°C or higher and 950°C or lower. When final rolling is performed under such conditions, the area ratio of ferrite can be set to be within an appropriate range. If the final finishing temperature is lower than 880°C, the area ratio of ferrite becomes excessively large. In addition, if the final finishing temperature is higher than 950°C, it is difficult to secure a sufficient area ratio of ferrite. Therefore, the final finishing temperature is 880°C or higher and 950°C or lower, and the final finishing temperature is preferably 890°C or higher and 940°C or lower.

(Primary cooling process)

[0113] After the hot rolling process, cooling is performed at an average cooling rate of 60 °C/sec or faster to a primary cooling stop temperature of 680°C or higher and 760°C or lower (primary cooling process). In the primary cooling process, if the average cooling rate is slower than 60 °C/sec, pearlite is excessively formed, and it is difficult to improve hole expandability. Therefore, the average cooling rate in the primary cooling process is preferably 65 °C/sec or faster. Here, the upper limit of the average cooling rate in the primary cooling process is not particularly specified, and may be 150 °C/sec or slower or 110 °C/sec or slower. The cooling stop temperature (primary cooling stop temperature) in the primary cooling process may be 680°C or higher and 760°C or lower. If the primary cooling stop temperature is lower than 680°C, there is a risk of the area ratio of ferrite becoming insufficient. In addition, even if the primary cooling stop temperature is higher than 760°C, there is a risk of the area ratio of ferrite becoming insufficient and the area ratio of bainite increasing.

(Secondary cooling process)

[0114] After the primary cooling process, cooling is performed at an average cooling rate of 20 °C/sec or slower for 1.6 seconds or longer and 6.3 seconds or shorter (secondary cooling process). If the average cooling rate in the secondary cooling process is faster than 20 °C/sec, there is a risk of the area ratio of ferrite becoming insufficient. Therefore, the average cooling rate in the secondary cooling process is 20 °C/sec or slower, and preferably 18 °C/sec or slower. In addition, if the cooling time in the secondary cooling process is shorter than 1.6 seconds, there is a risk of the area ratio of ferrite becoming insufficient and additionally the area ratio of bainite increasing. On the other hand, if the cooling time in the secondary cooling process is longer than 6.3 seconds, there is a risk of the area ratio of ferrite excessively

increasing and the strength being improved. In addition, if the cooling time in the secondary cooling process is too long, the area ratio of bainite may be insufficient. Therefore, the cooling time in the secondary cooling process is preferably 1.8 seconds or longer and 6.1 seconds or shorter.

5 (Tertiary cooling process)

[0115] After the secondary cooling process, cooling is performed at an average cooling rate of 60 °C/sec or faster and 130 °C/sec or slower to a tertiary cooling stop temperature of 195°C or higher and 440°C or lower. In the present embodiment, when the quaternary cooling process to be described below and the tertiary cooling process are precisely controlled, a desired metallographic structure morphology is obtained. Therefore, the tertiary cooling process and the quaternary cooling process are important processes in order to secure elongation-flangeability. That is, by increasing the average cooling rate in the tertiary cooling process, a large amount of bainite can be formed from the interface between ferrite and austenite formed in the primary cooling process and the secondary cooling process or the austenite/austenite grain boundary, and the coverage of the remaining austenite with bainite can increase. After that, in the quaternary cooling process, the remaining austenite is transformed into martensite, and thus the coverage with bainite in the present embodiment can increase.

[0116] In the tertiary cooling process, if the average cooling rate is 60 °C/sec or faster, 130 °C/sec or slower, a desired amount of bainite can be secured. If the average cooling rate in the tertiary cooling process is slower than 60 °C/sec, a sufficient degree of supercooling cannot be secured, and a large amount of bainite is formed only from specific grain boundaries. As a result, after the quaternary cooling process, it is difficult to obtain a sufficient coverage of martensite with bainite. Therefore, in the tertiary cooling process, the average cooling rate is 60 °C/sec or faster, preferably 65 °C/sec or faster, and more preferably 70 °C/sec or faster. On the other hand, if the average cooling rate in the tertiary cooling process is faster than 130 °C/sec, formation of bainite does not proceed sufficiently, and it is difficult to obtain a sufficient coverage of martensite with bainite after the quaternary cooling process. Therefore, in the tertiary cooling process, the average cooling rate is 130 °C/sec or slower, preferably 125 °C/sec or slower, and more preferably 120 °C/sec or slower.

[0117] The temperature at which the tertiary cooling process is completed (tertiary cooling stop temperature) may be 195°C or higher and 440°C or lower. If the tertiary cooling stop temperature is lower than 195°C, the area ratio of bainite becomes insufficient. Therefore, the tertiary cooling stop temperature is preferably 220°C or higher and more preferably 250°C or higher. On the other hand, if the tertiary cooling stop temperature is higher than 440°C, the area ratio of bainite increases, and it is difficult to obtain a favorable elongation at break. Therefore, the tertiary cooling stop temperature is preferably 420°C or lower and more preferably 400°C or lower.

35 (Quaternary cooling process)

[0118] After the tertiary cooling process, water cooling is performed at a water density of 2.0 m³/min/mm² or more and 7.2 m³/min/mm² or less for 0.33 seconds or longer and 1.50 seconds or shorter.

[0119] Like the tertiary cooling process, this quaternary cooling process is an important process in controlling the coverage of martensite with bainite, the average diameter of martensite and the area ratio of martensite.

[0120] In the quaternary cooling process, if the water density is less than 2.0 m³/min/mm², there is a risk of the coverage of martensite with bainite not being secured. According to the examination by the inventors, it was found that the coverage of martensite with bainite increased as the water density in the quaternary cooling process increased. Although the detailed mechanism is unknown, it is thought that a decrease in the water density leads to a decrease in the driving force for bainite transformation, and as a result, bainite transformation around martensite is delayed. In the present embodiment, the coverage of martensite with bainite can be increased by setting the water density in the quaternary cooling process to 2.0 m³/min/mm² or more. Here, in consideration of the coverage of martensite with bainite, the upper limit of the water density is not particularly specified, but if the upper limit is 7.2 m³/min/mm² or more, sheet deformation due to a water pressure may occur. Therefore, the water density is less than 7.2 m³/min/mm², preferably 7.0 m³/min/mm² or less, and more preferably 6.8 m³/min/mm² or less.

[0121] In the quaternary cooling process, the water density is set to be within the above range, and the cooling time is set to 0.33 seconds or longer and 1.50 seconds or shorter. According to the examination by the inventors, it was found that the average diameter dM of martensite changed depending on the cooling time in the quaternary cooling process. Specifically, if the cooling time is shorter than 0.33 seconds, the average diameter dM of martensite becomes excessively small. On the other hand, if the cooling time is longer than 1.50 seconds, the average diameter dM of martensite becomes excessively large. Therefore, the cooling time in the quaternary cooling process is 0.33 seconds or longer and 1.50 seconds or shorter, and preferably 0.40 seconds or longer and 1.40 seconds or shorter.

(Quinary cooling process)

[0122] After the quaternary cooling process, air cooling is performed for 3.0 seconds or longer and 5.0 seconds or shorter and cooling is performed to lower than 180°C (quinary cooling process).

[0123] In the quinary cooling process, after the quaternary cooling process, air cooling is performed for a time of 3.0 seconds or longer and 5.0 seconds or shorter without performing water cooling. The time for which water cooling is not performed, that is, the air cooling time, influences the coverage of martensite with bainite. Although the detailed mechanism is unknown, it is estimated that the coverage of martensite is improved according to formation of bainite during air cooling in the quinary cooling process. If the air cooling time is shorter than 3.0 seconds, the coverage may be insufficient. On the other hand, if the air cooling time is longer than 5.0 seconds, the area ratio of bainite may excessively increase.

[0124] As a result of the examination by the inventors, if the air cooling time is shorter than 3.0 seconds or longer than 5.0 seconds, the coverage of martensite with bainite is less than 75.0%. In order to obtain a more sufficient effect, the air cooling time may be 4.0 seconds or longer and 4.8 seconds.

[0125] In the quinary cooling process, air cooling is performed to lower than 180°C, which is the winding temperature, and the steel sheet is then wound.

[0126] If the winding temperature is 180°C or higher, the area ratio of martensite becomes insufficient and it is difficult to obtain excellent strength. Therefore, the winding temperature is preferably lower than 180°C.

[0127] According to the method described above, the hot-rolled steel sheet according to the present embodiment can be manufactured.

[0128] Here, the sheet passing speed of the steel sheet in the quaternary cooling process may be 360 to 790 mpm (meter per minute).

[0129] In addition, the hot-rolled steel sheet is wound into a hot-rolled coil, and the hot-rolled coil is then unwound and may be pickled in order to remove the oxide film. In addition, skin pass rolling may be applied to the extent that ductility does not deteriorate.

[0130] In addition, in the present embodiment, a device for performing the above cooling processes is not limited. Industrially, it is preferable to use a water spray device that can precisely control the water density. For example, a water spray device may be arranged between transport rollers that transport a steel sheet, and cooling may be performed by spraying a predetermined amount of water from above and below the steel sheet. In addition, in this case, the thermal history of the supercooling process as described above can be achieved by controlling the density of the water amount to be sprayed or changing the opening/closing position of the valve.

[Examples]

[0131] Next, examples of the present invention will be described, and conditions in examples are one example of conditions used for confirming the feasibility and effects of the present invention, and the present invention is not limited to this one condition example. In the present invention, various conditions can be used without departing from the gist of the present invention and as long as the object of the present invention can be achieved.

[0132] Steel sheet coils having a width of 800 mm to 1,080 mm (hot-rolled steel sheets) were manufactured using casting slabs having chemical compositions shown in Table 1A and Table 1B under conditions shown in Table 2A to Table 2C. Here, in the quaternary cooling process, the sheet passing speed was in a range of 360 to 780 mpm (meter per minute). In addition, in each cooling process, a predetermined thermal history (cooling rate) was obtained by changing the opening/closing position of the valve on the run out table (ROT). In addition, the sheet thickness of the hot-rolled steel sheet was within a range of 2.0 mm to 6.0 mm. Here, in Table 1, "FT" indicates the final finishing temperature during final rolling in the hot rolling process.

[0133] Regarding the microstructure of the manufactured hot-rolled steel sheet, measurement of the area ratio of each structure, and measurement of the average particle size of martensite and the coverage of martensite with bainite were performed by the above measurement methods. In addition, the properties of the hot-rolled steel sheet were evaluated by the following methods. The evaluation results are shown in Table 3A to Table 3C.

"Tensile strength (TS)"

[0134] The tensile strength (TS) of the hot-rolled steel sheet was determined using a No. 5 test piece of JIS Z 2241:2011 and according to a test method described in JIS Z 2241:2011. A tensile test piece was taken in the direction perpendicular to the rolling direction and the sheet thickness direction (sheet width direction) so that it included a 1/4 part from the edge of the steel sheet. In this case, the tensile test piece was taken with the direction perpendicular to the rolling direction as the longitudinal direction. The crosshead speed in the tensile test was set under conditions in which the strain rate was constant at 0.005 s⁻¹. If the tensile strength was 780 MPa or more, it was determined to be satisfactory,

and if the tensile strength was less than 780 MPa, it was determined to be unsatisfactory.

"Elongation at break"

5 **[0135]** The elongation at break, which is an index of ductility, was determined according to the test method described in JIS Z 2241:2011 in the same manner as the method for evaluating the tensile strength (TS). If the elongation at break (%) was 15.0% or more, it was determined to be satisfactory, and if the elongation at break was less than 15.0%, it was determined to be unsatisfactory.

10 "Hole expandability"

[0136] The hole expandability was evaluated by the hole expansion rate λ (%) measured according to JIS Z 2256:2010. Specifically, using a $\phi 10$ mm punch, the die diameter was selected so that the clearance became 12.5%, and holes were punched out. Then, a hole expansion test was performed using a conical die with a tip angle of 60° with the burr on the outside and at a stroke speed of 10 mm/min. The test was stopped when cracks formed around the hole penetrated through the sheet thickness, and the hole diameters before and after the hole expansion test were compared, and the hole expansion rate (%) was calculated. If the hole expansion rate (%) was 60% or more, it was determined to be satisfactory, and if the hole expansion rate was less than 60%, it was determined to be unsatisfactory.

20 "Fine cracks on the sheared end surface"

[0137] The hot-rolled steel sheet was sheared, and the occurrence of fine cracks on the sheared end surface was visually observed. Specifically, for shearing, the edge of the punched semicircular part of the following side bend test piece was observed using a microscope at a magnification of 50, and cracks that did not penetrate the sheet thickness present only at the punched edge were defined as fine cracks. In this test, cracks that penetrated the sheet thickness were not occurred. The punched clearance in this case was 12.5%.

"Side bend test"

30 **[0138]** As an index of elongation-flangeability, the breaking limit strain evaluated by the side bend test was used. In the side bend test, methods described in "Nippon Steel Technical Report No. 393, (2012) p. 18 to 24" and "Japanese Unexamined Patent Application, First Publication No. 2009-145138" were used.

[0139] Specifically, first, a sheet of 35 mm×100 mm was cut out from a steel sheet. Then, a semicircular hole was punched out in the sheet using a $\phi 30$ mm punch under conditions in which the sheet thickness clearance (a value obtained by dividing a gap between a punch and a die by a sheet thickness) was 12.5%. A test piece shown in FIG. 2 was prepared according to these processes.

[0140] Next, the test piece was deformed at a stroke speed of 10 mm/min, and formation of a crack at the edge of the hole was defined as "breakage." After breaking, the breaking limit strain with a gauge length of 6.0 mm was measured using a total of three elements including a determined element and elements adjacent thereto. Here, in this example, three side bend test pieces were prepared, the above breaking limit strains of the test pieces were measured, and the average value of these breaking limit strains was evaluated. If the breaking limit strain was 0.5 or more, it was determined to be satisfactory, and if the breaking limit strain was less than 0.5, it was determined to be unsatisfactory.

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[Table 1A]

Steel No.	Chemical composition (mass%: remainder being made up of Fe and impurities)															
	C	Si	Mn	P	S	Al	Ti	Nb	N	Cr	B	Ca	Mo	Ni	Cu	REM
A	0.033	0.07	1.47	0.008	0.0031	0.22	0.104	0.012	0.0024	-	-	-	-	-	-	-
B	0.054	0.08	1.55	0.006	0.0017	0.36	0.112	0.014	0.0026	-	-	-	-	-	-	-
C	0.087	0.04	1.62	0.008	0.0044	0.38	0.092	0.015	0.0027	-	-	-	-	-	-	-
D	0.049	0.04	1.20	0.009	0.0032	0.12	0.132	0.014	0.0022	-	-	-	-	-	-	-
E	0.042	0.16	1.32	0.007	0.0036	0.35	0.121	0.011	0.0026	-	-	-	-	-	-	-
F	0.081	0.03	0.68	0.008	0.0024	0.12	0.079	0.044	0.0025	-	-	-	-	-	-	-
G	0.082	0.03	0.74	0.007	0.0016	0.14	0.091	0.048	0.0031	-	-	-	-	-	-	-
H	0.037	0.13	1.78	0.009	0.0029	0.39	0.138	0.034	0.0016	-	-	-	-	-	-	-
I	0.062	0.14	1.83	0.008	0.0020	0.34	0.134	0.032	0.0025	-	-	-	-	-	-	-
J	0.053	0.04	1.52	0.022	0.0022	0.32	0.128	0.014	0.0045	-	-	-	-	-	-	-
K	0.040	0.03	1.75	0.007	0.0063	0.36	0.132	0.033	0.0029	-	-	-	-	-	-	-
L	0.078	0.04	1.21	0.007	0.0033	0.08	0.128	0.015	0.0037	-	-	-	-	-	-	-
M	0.048	0.04	1.31	0.008	0.0029	0.32	0.133	0.012	0.0033	-	-	-	-	-	-	-
N	0.050	0.03	1.29	0.006	0.0023	0.42	0.128	0.010	0.0020	-	-	-	-	-	-	-
O	0.046	0.02	1.48	0.006	0.0027	0.32	0.073	0.015	0.0019	-	-	-	-	-	-	-
P	0.046	0.02	1.47	0.007	0.0022	0.34	0.105	0.015	0.0027	-	-	-	-	-	-	-
Q	0.048	0.03	1.49	0.006	0.0024	0.37	0.174	0.016	0.0023	-	-	-	-	-	-	-
R	0.043	0.02	1.43	0.005	0.0022	0.32	0.108	0.002	0.0026	-	-	-	-	-	-	-
S	0.045	0.02	1.44	0.006	0.0034	0.34	0.109	0.021	0.0029	-	-	-	-	-	-	-

[Table 1B]

Steel No.	Chemical composition (mass%: remainder being made up of Fe and impurities)															
	C	Si	Mn	P	S	Al	Ti	Nb	N	Cr	B	Ca	Mo	Ni	Cu	REM
T	0.046	0.02	1.48	0.007	0.0028	0.37	0.112	<u>0.053</u>	0.0032	-	-	-	-	-	-	-
U	0.056	0.06	1.58	0.007	0.0031	0.34	0.124	0.014	<u>0.0093</u>	-	-	-	-	-	-	-
V	0.038	0.02	1.68	0.005	0.0022	0.29	0.099	0.015	0.0027	0.06	-	-	-	-	-	-
W	0.040	0.03	1.72	0.005	0.0021	0.32	0.098	0.016	0.0026	0.17	-	0.0018	-	-	-	-
X	0.036	0.05	1.18	0.008	0.0030	0.38	0.168	0.015	0.0031	-	0.0003	-	-	-	-	-
Y	0.038	0.05	1.16	0.007	0.0039	0.32	0.135	0.015	0.0026	0.08	0.0004	0.0008	-	-	-	-
z	0.050	0.07	1.53	0.007	0.0017	0.34	0.115	0.017	0.0027	-	-	0.0015	-	-	-	-
a	0.044	0.04	1.22	0.006	0.0026	0.29	0.099	0.011	0.0021	-	-	-	0.08	-	-	-
b	0.051	0.03	1.32	0.006	0.0022	0.25	0.105	0.015	0.0032	-	-	-	-	0.26	-	-
c	0.049	0.06	1.39	0.007	0.0005	0.37	0.108	0.013	0.0019	-	-	-	-	-	0.19	-
d	0.048	0.08	1.51	0.007	0.0019	0.32	0.101	0.014	0.0020	-	-	-	-	-	-	0.0029
e	0.055	0.06	1.51	0.009	0.0027	0.29	0.134	0.049	0.0066	-	-	-	-	-	-	-
f	0.051	0.08	1.29	0.008	0.0021	0.31	0.111	0.015	0.0038	-	-	0.0003	-	-	-	-
g	0.053	0.03	1.55	0.007	0.0037	0.3	0.099	0.019	0.0033	-	-	0.0048	-	-	-	-
h	0.057	0.09	1.46	0.006	0.0009	0.26	0.097	0.017	0.0026	-	-	-	0.03	-	-	-
i	0.048	0.1	0.71	0.005	0.0025	0.37	0.088	0.016	0.0029	-	-	-	0.29	-	-	-
j	0.052	0.13	1.53	0.009	0.0022	0.24	0.102	0.013	0.0025	-	-	-	-	0.07	0.04	-
k	0.056	0.12	1.16	0.007	0.0021	0.29	0.099	0.024	0.0036	-	-	-	-	0.46	0.33	-
l	0.075	0.17	1.19	0.002	0.0002	0.33	0.103	0.011	0.0006	-	-	-	-	-	-	-

[Table 2A]

Test No	Steel No.	Hotrolling process	Primary cooling process		Secondary cooling process		Tertiary cooling process		Quaternary cooling process		Quinary cooling process	Winding temperature (°C)	Note
			Cooling rate (°C/sec)	Stop temperature (°C)	Cooling rate (°C/sec)	Cooling time (sec)	Cooling rate (°C/sec)	Stop temperature (°C)	Water density (m3/min/mm2)	Cooling time (sec)			
1	S	900	65	710	10	3.6	144	400	3.8	0.98	4.2	105	Comparative steel
2	G	925	70	755	15	4.2	58	300	3.3	0.48	3.1	150	Comparative steel
3	B	910	70	734	15	3.2	103	190	2.2	0.34	4.1	125	Comparative steel
4	H	935	70	705	15	3.8	111	225	1.2	0.52	3.6	155	Comparative steel
5	X	910	65	730	15	2.8	75	265	1.2	0.35	3.3	175	Comparative steel
6	Z	935	70	705	15	3.8	111	225	2.2	0.28	3.6	155	Comparative steel
7	M	915	65	710	10	2.2	68	430	2.4	1.52	3.6	85	Comparative steel
8	V	925	65	735	15	3.1	109	360	5.0	0.72	2.8	40	Comparative steel
9	P	910	65	725	15	2.7	84	305	2.2	0.72	5.3	160	Comparative steel
10	D	900	70	740	10	4.1	92	320	7.3	0.55	Could not be wound	-	Comparative steel
11	B	905	65	735	15	3.6	64	420	5.0	0.92	3.4	130	Invention steel
12	G	885	65	690	15	3.9	70	385	6.9	0.69	3.3	30	Invention steel
13	D	900	115	760	20	6.2	74	320	4.5	0.71	4.0	35	Invention steel
14	G	945	80	690	15	3.1	67	290	3.4	0.67	3.9	75	Invention steel

(continued)

Test No	Steel No.	Hotrolling process FT (°C)	Primary cooling process		Secondary cooling process		Tertiary cooling process		Quaternary cooling process		Quinary cooling process	Winding temperature (°C)	Note
			Cooling rate (°C/sec)	Stop temperature (°C)	Cooling rate (°C/sec)	Cooling time (sec)	Cooling rate (°C/sec)	Stop temperature (°C)	Water density (m3/min/mm2)	Cooling time (sec)			
15	S	900	65	740	10	1.6	61	430	2.8	1.47	4.5	35	Invention steel
16	B	910	75	725	10	3.6	114	260	3.6	0.52	3.5	85	Invention steel
17	D	930	65	710	10	4.1	121	205	3.9	0.42	3.6	50	Invention steel
18	H	915	65	725	10	2.6	97	330	4.5	1.08	3.6	35	Invention steel
19	P	890	65	755	10	3.6	116	315	3.0	0.59	3.3	150	Invention steel
20	X	910	60	725	5	3.5	64	380	3.0	1.23	4.8	45	Invention steel
21	B	890	65	720	15	4.2	97	310	3.8	1.23	3.3	25	Invention steel
22	M	930	80	690	20	3.8	107	220	2.5	0.52	3.1	70	Invention steel
23	S	925	85	700	10	5.3	86	265	3.1	0.54	4.1	105	Invention steel

[Table 2B]

Test No	Steel No.	Hot rolling process	Primary cooling process		Secondary cooling process		Tertiary cooling process		Quaternary cooling process		Quinary cooling process	Winding temperature (°C)	Note
			Cooling rate (°C/sec)	Stop temperature (°C)	Cooling rate (°C/sec)	Cooling time (sec)	Cooling rate (°C/sec)	Stop temperature (°C)	Water density (m ³ /min/mm ²)	Cooling time (sec)			
24	V	885	95	720	15	2.4	62	420	2.4	0.53	4.9	175	Invention steel
25	Z	890	70	740	20	3.2	120	375	2.1	1.33	3.0	85	Invention steel
26	H	875	70	715	10	4.3	82	415	5.0	0.71	3.4	75	Comparative steel
27	G	955	75	735	5	4.1	85	320	2.2	0.98	3.2	70	Comparative steel
28	P	915	55	705	10	3.8	64	420	5.0	0.88	3.3	100	Comparative steel
29	D	890	65	675	15	3.5	84	390	4.7	0.69	3.3	80	Comparative steel
30	B	945	80	765	15	2.7	79	370	4.7	0.78	3.8	25	Comparative steel
31	D	910	70	720	30	5.6	87	385	6.9	0.69	3.3	30	Comparative steel
32	H	885	70	720	15	1.5	79	410	5.0	0.71	3.4	70	Comparative steel
33	G	945	80	715	10	6.4	68	300	4.5	0.70	4.0	30	Comparative steel
34	S	910	65	720	5	2.7	59	280	4.7	0.63	4.5	35	Comparative steel
35	M	915	80	720	5	2.9	71	450	3.4	0.71	4.0	125	Comparative steel
36	M	880	65	735	5	4.9	63	435	2.2	0.53	3.4	184	Comparative steel

(continued)

Test No	Steel No.	Hot rolling process	Primary cooling process		Secondary cooling process		Tertiary cooling process		Quaternary cooling process		Quinary cooling process	Winding temperature (°C)	Note
			Cooling rate (°C/sec)	Stop temperature (°C)	Cooling rate (°C/sec)	Cooling time (sec)	Cooling rate (°C/sec)	Stop temperature (°C)	Water density (m ³ /min/mm ²)	Cooling time (sec)			
37	B	915	85	730	10	1.7	128	230	4.5	1.08	3.8	75	Invention steel
38	D	910	70	725	10	3.6	114	260	4.5	0.67	4.5	75	Invention steel
39	P	900	75	730	15	3.2	71	280	3.4	0.78	4.4	25	Invention steel
40	Z	935	85	705	15	3.8	111	425	4.7	0.72	3.7	135	Invention steel
41	X	930	80	710	10	4.1	121	205	2.8	1.47	4.5	35	Invention steel
42	A	900	70	695	5	2.9	95	305	3.1	0.67	4.8	80	Comparative steel
43	C	905	75	730	15	2.2	101	310	4.5	1.47	4.7	25	Comparative steel
44	E	900	80	700	10	4.9	74	330	2.2	0.93	4.9	115	Comparative steel
45	F	895	75	710	5	5.6	102	390	4.1	0.80	3.8	35	Comparative steel
46	I	900	75	705	10	5.8	85	235	3.1	0.57	3.7	85	Comparative steel

[Table 2C]

Test No	Steel No.	Hot rolling process	Primary cooling process		Secondary cooling process		Tertiary cooling process		Quaternary cooling process		Quinary cooling process	Winding temperature (°C)	Note	
			Cooling rate (°C/sec)	Stop temperature (°C)	Cooling rate (°C/sec)	Cooling time (sec)	Cooling rate (°C/sec)	Stop temperature (°C)	Water density (m³/min/mm²)	Cooling time (sec)				Time from water stop to winding (sec)
47	J	Rolling was stopped due to cracks in casting corner												Comparative steel
48	K	Rolling was stopped due to flaws during rough rolling												Comparative steel
49	L	910	70	750	20	3.7	129	320	2.6	0.79	3.4	95	Comparative steel	
50	N	890	65	695	5	5.1	61	255	3.8	0.63	4.6	25	Comparative steel	
51	O	895	120	705	10	4.4	101	290	3.3	0.52	4.1	165	Comparative steel	
52	Q	Rolling was stopped due to cracks in casting slab												Comparative steel
53	R	915	90	700	5	3.7	86	305	2.8	0.55	4.9	70	Comparative steel	
54	T	Rolling was stopped due to flaws during rough rolling												Comparative steel
55	U	Rolling was stopped due to cracks in casting corner												Comparative steel
56	W	915	110	710	5	5.2	90	400	6.8	0.78	3.3	30	Invention steel	
57	Y	895	85	715	5	3.6	105	435	5.5	0.79	3.4	20	Invention steel	
58	a	900	95	705	5	4.8	110	420	5.6	0.80	3.5	25	Invention steel	
59	b	905	100	695	10	2.9	105	400	4.9	0.78	4.0	25	Invention steel	
60	c	900	95	700	5	4.2	100	390	5.5	0.80	3.8	20	Invention steel	
61	d	910	95	700	5	3.6	110	410	5.1	0.80	3.7	25	Invention steel	

(continued)

Test No	Steel No.	Hot rolling process	Primary cooling process		Secondary cooling process		Tertiary cooling process		Quaternary cooling process		Quinary cooling process	Winding temperature (°C)	Note
			Cooling rate (°C/sec)	Stop temperature (°C)	Cooling rate (°C/sec)	Cooling time (sec)	Cooling rate (°C/sec)	Stop temperature (°C)	Water density (m ³ /min/mm ²)	Cooling time (sec)			
62	e	900	100	690	10	3.8	105	390	4.8	0.89	Time from water stop to winding (sec) 4.1	25	Invention steel
63	f	915	105	700	15	3.2	100	390	4.2	0.92	3.8	30	Invention steel
64	g	890	110	690	10	4.3	95	370	4.5	0.88	4.2	25	Invention steel
65	h	910	100	710	10	4	110	380	4.4	0.88	3.6	25	Invention steel
66	i	905	95	720	10	3.8	90	370	3.8	0.90	3.5	25	Invention steel
67	j	890	105	700	15	4.2	100	400	4.2	0.92	3.8	25	Invention steel
68	k	900	100	710	10	4	100	370	4.2	0.90	4	30	Invention steel
69	l	920	<u>35</u>	670	15	3.8	95	410	3.9	0.91	4	35	Comparative steel

[Table 3A]

Test No	Steel No.	Metallographic structure (area%)					Average diameter of martensite (μm)	Coverage (%)	Property evaluation					Note
		Ferrite	Pearlite	Bainite	Martensite	Retained austenite			TS (MPa)	Elongation at break (%)	Hole expandability (%)	Occurrence of fine cracks on sheared end surface	Breaking limit strain	
1	S	73.4	2.4	13.8	8.6	1.8	0.59	66.7	804	18.9	61	Occurred	0.3	Comparative steel
2	G	50.3	1.1	40.4	6.4	1.8	0.38	70.6	734	13.8	80	Occurred	0.4	Comparative steel
3	B	75.6	0.0	12.6	9.6	2.2	0.49	83.4	782	20.8	71	Occurred	0.4	Comparative steel
4	H	71.1	0.0	19.6	7.7	1.6	0.37	66.8	823	23.1	72	Occurred	0.3	Comparative steel
5	X	70.3	0.0	22.2	4.4	3.1	0.47	65.2	798	19.3	88	Occurred	0.3	Comparative steel
6	Z	73.4	0.0	17.3	7.7	1.6	0.24	66.8	773	23.1	89	Occurred	0.3	Comparative steel
7	M	62.4	0.0	30.4	6.8	0.4	0.73	80.2	809	19.2	83	Occurred	0.4	Comparative steel
8	V	70.3	0.0	24.2	5.3	0.2	0.43	68.4	810	22.3	82	Occurred	0.3	Comparative steel
9	P	53.2	0.0	43.0	3.8	0.0	0.42	69.3	771	17.8	80	Occurred	0.4	Comparative steel
10	D	Test number that could not be evaluated												
11	B	71.8	0.0	21.3	5.8	1.1	0.58	79.4	784	23.2	80	Not occurred	0.8	Invention steel
12	G	67.4	0.0	27.7	4.8	0.1	0.31	84.6	803	18.6	77	Not occurred	0.7	Invention steel
13	D	75.8	0.0	14.3	9.8	0.1	0.48	86.4	798	20.6	70	Not occurred	0.9	Invention steel

(continued)

Test No	Steel No.	Metallographic structure (area%)					Average diameter of martensite (μm)	Coverage (%)	Property evaluation					Note
		Ferrite	Pearlite	Bainite	Martensite	Retained austenite			TS (MPa)	Elongation at break (%)	Hole expandability (%)	Occurrence of fine cracks on sheared end surface	Breaking limit strain	
14	G	66.3	0.0	28.4	5.2	0.1	0.48	83.4	794	17.3	86	Not occurred	0.8	Invention steel
15	S	64.3	0.0	32.3	3.2	0.2	0.69	81.4	783	15.4	68	Not occurred	0.7	Invention steel
16	B	74.1	0.0	21.4	4.2	0.3	0.44	83.1	794	22.1	92	Not occurred	0.8	Invention steel
17	D	73.2	0.0	17.6	9.0	0.2	0.38	79.4	842	24.2	61	Not occurred	0.8	Invention steel
18	H	67.9	0.0	26.3	5.6	0.2	0.62	80.2	803	20.8	82	Not occurred	0.7	Invention steel
19	P	73.3	0.0	18.6	6.8	1.3	0.36	78.2	802	22.1	78	Not occurred	0.7	Invention steel
20	X	70.5	1.7	22.4	5.1	0.3	0.60	77.5	788	23.1	70	Not occurred	0.7	Invention steel
21	B	70.1	0.0	25.1	4.8	0.0	0.44	80.3	806	22.4	82	Not occurred	1.0	Invention steel
22	M	66.0	0.0	29.6	4.0	0.4	0.37	76.5	824	17.9	78	Not occurred	0.7	Invention steel
23	S	70.9	1.2	17.9	9.5	0.5	0.48	81.3	852	18.3	68	Not occurred	0.6	Invention steel

[Table 3B]

Test No	Steel No.	Metallographic structure (area%)					Average diameter of martensite (μm)	Coverage (%)	Property evaluation					Note
		Ferrite	Pearlite	Bainite	Martensite	Retained austenite			TS (MPa)	Elongation at break (%)	Hole expandability (%)	Occurrence of fine cracks on sheared end surface	Breaking limit strain	
24	V	54.0	0.0	34.5	8.7	2.8	0.46	76.0	820	18.2	83	Not occurred	0.7	Invention steel
25	Z	74.4	0.0	19.6	5.8	0.2	0.64	75.4	796	19.6	81	Not occurred	0.6	Invention steel
26	H	78.3	0.0	17.2	4.1	0.4	0.39	79.6	754	21.9	79	Not occurred	0.8	Comparative steel
27	G	51.6	0.0	38.8	9.2	0.4	0.58	76.4	846	14.3	66	Not occurred	0.6	Comparative steel
28	P	73.4	3.2	14.5	7.5	1.4	0.58	78.2	796	19.3	56	Not occurred	0.7	Comparative steel
29	D	52.4	0.0	38.4	9.1	0.1	0.38	82.1	832	14.8	64	Not occurred	0.7	Comparative steel
30	B	50.6	1.2	44.7	3.5	0.0	0.39	80.9	783	14.3	87	Not occurred	0.7	Comparative steel
31	D	50.9	0.0	38.9	9.9	0.3	0.54	78.9	813	14.6	62	Not occurred	0.6	Comparative steel
32	H	52.0	0.0	39.0	8.6	0.4	0.57	83.1	820	14.8	64	Not occurred	0.7	Comparative steel
33	G	76.5	1.2	13.7	8.6	0.0	0.39	79.7	738	18.9	72	Not occurred	0.7	Comparative steel
34	S	54.0	0.0	42.1	3.9	0.0	0.52	65.3	783	13.1	75	Not occurred	0.9	Comparative steel
35	M	53.4	0.0	42.3	3.1	1.2	0.39	81.4	783	13.9	68	Not occurred	0.7	Comparative steel
36	M	61.9	0.0	32.3	2.0	3.8	0.33	82.3	742	20.1	75	Not occurred	0.7	Comparative steel

(continued)

Test No	Steel No.	Metallographic structure (area%)					Average diameter of martensite (μm)	Coverage (%)	Property evaluation					Note
		Ferrite	Pearlite	Bainite	Martensite	Retained austenite			TS (MPa)	Elongation at break (%)	Hole expandability (%)	Occurrence of fine cracks on sheared end surface	Breaking limit strain	
37	B	71.8	0.0	21.3	5.8	1.1	0.58	79.4	784	23.2	80	Not occurred	0.8	Invention steel
38	D	67.4	0.0	27.7	4.8	0.1	0.31	84.6	803	18.6	77	Not occurred	0.7	Invention steel
39	P	75.8	0.0	14.3	9.8	0.1	0.48	86.4	798	20.6	70	Not occurred	0.9	Invention steel
40	Z	66.3	0.0	26.4	5.2	2.1	0.48	83.4	794	17.3	86	Not occurred	0.8	Invention steel
41	X	58.3	0.0	38.3	3.2	0.2	0.69	81.4	882	15.4	68	Not occurred	0.6	Invention steel
42	A	75.3	0.0	21.6	2.8	0.3	0.31	77.5	758	21.2	78	Not occurred	0.7	Comparative steel
43	C	60.8	0.0	26.5	12.6	0.1	0.69	78.4	899	18.3	54	Not occurred	0.6	Comparative steel
44	E	77.9	0.0	17.5	3.8	0.8	0.54	76.1	742	26.3	91	Not occurred	0.8	Comparative steel
45	F	80.2	1.6	14.8	3.4	0.0	0.46	79.4	731	24.1	108	Not occurred	0.8	Comparative steel
46	I	50.2	0.0	39.9	9.4	0.5	0.47	82.5	811	14.1	69	Not occurred	0.8	Comparative steel

[Table 3C]

Test No	Steel No.	Metallographic structure (area%)					Average diameter of martensite (μm)	Coverage (%)	Property evaluation					Note
		Ferrite	Pearlite	Bainite	Martensite	Retained austenite			TS (MPa)	Elongation at break (%)	Hole expandability (%)	Occurrence of fine cracks on sheared end surface	Breaking limit strain	
47	J	Rolling was stopped due to cracks in casting corner												Comparative steel
48	K	Rolling was stopped due to flaws during rough rolling												Comparative steel
49	L	48.8	1.7	38.1	9.8	1.6	0.44	78.2	821	12.9	70	Not occurred	0.7	Comparative steel
50	N	82.2	0.0	14.4	3.4	0.0	0.43	78.7	699	24.9	118	Not occurred	0.9	Comparative steel
51	O	70.6	0.0	24.6	3.7	1.1	0.43	82.4	768	19.2	89	Not occurred	0.8	Comparative steel
52	Q	Rolling was stopped due to cracks in casting slab												Comparative steel
53	R	72.0	0.0	18.3	9.4	0.3	0.44	77.3	778	18.2	96	Not occurred	0.9	Comparative steel
54	T	Rolling was stopped due to flaws during rough rolling												Comparative steel
55	U	Rolling was stopped due to cracks in casting corner												Comparative steel
56	W	58.8	0.0	3.80	3.2	0.0	0.41	77.9	835	16.8	69	Not occurred	0.7	Invention steel
57	Y	53.9	0.0	37.6	8.5	0.0	0.37	80.4	878	15.2	74	Not occurred	0.8	Invention steel
58	a	58.6	0.0	36.8	4.6	0.0	0.42	81.6	823	20.9	81	Not occurred	0.9	Invention steel
59	b	57.5	0.0	37.2	5.3	0.0	0.57	79.9	817	22.3	80	Not occurred	0.8	Invention steel

(continued)

Test No	Steel No.	Metallographic structure (area%)					Average diameter of martensite (μm)	Coverage (%)	Property evaluation					Note
		Ferrite	Pearlite	Bainite	Martensite	Retained austenite			TS (MPa)	Elongation at break (%)	Hole expandability (%)	Occurrence of fine cracks on sheared end surface	Breaking limit strain	
60	c	57.4	0.0	36.4	6.2	0.0	0.49	80.4	833	21.4	81	Not occurred	0.8	Invention steel
61	d	62.7	0.0	32.4	4.9	0.0	0.45	84.9	805	21.5	85	Not occurred	0.9	Invention steel
62	e	59.2	0.0	35.2	5.6	0.0	0.52	86.7	799	22.6	84	Not occurred	0.7	Invention steel
63	f	60.2	0.0	33.6	6.2	0.0	0.49	83.5	826	21.3	97	Not occurred	0.8	Invention steel
64	g	59.2	0.0	34.6	5.9	0.0	0.51	88.2	816	20.9	66	Not occurred	0.6	Invention steel
65	h	62.8	0.0	31.9	5.3	0.0	0.49	84.6	802	21.8	92	Not occurred	0.9	Invention steel
66	i	59.6	0.0	34.5	5.9	0.0	0.37	88.3	846	19.2	76	Not occurred	0.9	Invention steel
67	j	63.0	0.0	32.8	4.2	0.0	0.46	79.2	792	22.6	89	Not occurred	0.8	Invention steel
68	k	65.2	0.0	27.3	7.5	0.0	0.41	84.9	821	21.3	81	Not occurred	0.8	Invention steel
69	l	61.5	2.8	26.8	8.9	0.0	0.39	82.4	801	20.8	48	Not occurred	0.7	Comparative steel

[0141] Based on Table 3A to Table 3C, it can be understood that Test Nos. 11 to 25, and 37 to 41 and Test Nos. 56 to 68, which were invention examples, had high strength, and excellent ductility, hole expandability and elongation-flangeability.

[0142] FIG. 5 shows the relationship between the breaking limit strain and the coverage in Test Nos. 2, 4, 5, 8, 9, and 11 to 25. Here, all of Test Nos. 11 to 25 had the average diameter of martensite and the area ratio of bainite within the scope of the present invention. As shown in FIG. 5, it can be understood that, when a hot-rolled steel sheet in which the average diameter of martensite and the area ratio of bainite were within the scope of the present invention, and the coverage of martensite with bainite was 75.0% or more was used, the breaking limit strain according to the side bend could be 0.5 or more. In other words, it can be understood that, even if the average diameter of martensite and the area ratio of bainite were within the scope of the present invention, if the coverage of martensite with bainite was less than 75.0%, it was difficult to increase the breaking limit strain.

[0143] In addition, FIG. 6 shows the relationship between the breaking limit strain and the average diameter d_M of martensite in Test Nos. 6, 7, and 11 to 25. Here, all of Test Nos. 11 to 25, the area ratio of bainite and the coverage of martensite with bainite were within the scope of the present invention. As shown in FIG. 6, it can be understood that, when a hot-rolled steel sheet in which the area ratio of bainite and the coverage were within the scope of the present invention and the average diameter d_M of martensite was within the scope of the present invention was used, the breaking limit strain according to the side bend could be 0.5 or more. In other words, it can be understood that, even if the area ratio of bainite and the coverage were within the scope of the present invention, if the average diameter d_M of martensite was outside the scope, it was difficult to increase the breaking limit strain.

[0144] In addition, FIG. 7 shows the relationship between the coverage and the water density in the quaternary cooling process in Test Nos. 4, 5, and 11 to 25. Here, in all of Test Nos. 11 to 25, manufacturing conditions other than the water density in the quaternary cooling process were within the scope of the present invention. As shown in FIG. 7, it can be understood that, when a hot-rolled steel sheet was manufactured under conditions in which all manufacturing conditions including the water density in the quaternary cooling process were within the scope of the present invention, it was possible to sufficiently improve the coverage of the hot-rolled steel sheet. In other words, it can be understood that, even if manufacturing conditions other than the water density in the quaternary cooling process were within the scope of the present invention, if the water density in the quaternary cooling process was outside the scope, it was difficult to increase the coverage.

[0145] In addition, FIG. 8 shows the relationship between the average diameter d_M of martensite and the cooling time in the quaternary cooling process in Test Nos. 6, 7, and 11 to 25. Here, in all of Test Nos. 11 to 25, manufacturing conditions other than the cooling time in the quaternary cooling process were within the scope of the present invention. As shown in FIG. 8, it can be understood that, when a hot-rolled steel sheet was manufactured under conditions in which all manufacturing conditions including the cooling time in the quaternary cooling process were within the scope of the present invention, it was possible to sufficiently improve the average diameter d_M of martensite. In other words, it can be understood that, even if manufacturing conditions other than the cooling time in the quaternary cooling process were within the scope of the present invention, if the cooling time in the quaternary cooling process was outside the scope, it was difficult to increase the average diameter d_M of martensite.

[0146] In addition, FIG. 9 shows the relationship between the coverage of martensite with bainite and the air cooling time in Test Nos. 8, 9, and 11 to 25. Here, in all of Test Nos. 11 to 25, manufacturing conditions other than the air cooling time were within the scope of the present invention. As shown in FIG. 9, it can be understood that, when a hot-rolled steel sheet was manufactured under conditions in which all manufacturing conditions including the air cooling time were within the scope of the present invention, it was possible to sufficiently improve the coverage. In other words, it can be understood that, even if manufacturing conditions other than the air cooling time were within the scope of the present invention, if the air cooling time was outside the scope, it was difficult to increase the coverage of martensite with bainite.

[0147] As described above, it can be understood that all properties of Test Nos. 11 to 25, and 37 to 41 and Test Nos. 56 to 68, which were invention examples within the scope of the present invention, were excellent.

[0148] For example, when the microstructure of Test No. 21, which was an invention example, was observed, the microstructure shown in FIG. 10A was obtained. As clearly shown in FIG. 10A, it can be understood that, in Test No. 21, which was an invention example, martensite was sufficiently covered with bainite (dotted line area in the drawing).

[0149] In addition, in order to perform the side bend test on Test No. 21, shearing was performed on Test No. 21, and the structure in the vicinity of the sheared end surface was observed. As a result, a structure image shown in FIG. 10B was obtained. Based on FIG. 10B, it can be understood that no cracks were observed in the deformed martensite itself or at the interface between martensite and other structures, and voids were formed within ferrite with large deformation. That is, it was thought that, when bainite was arranged to cover the vicinity of martensite, and this bainite had a role such as a cushion that reduces a difference in the amount of deformation between ferrite and martensite, cracking in martensite could be restricted.

[0150] As described above, it can be understood that any one or more properties of Test Nos. 1 to 10, and 26 to 36 and Test Nos. 42 to 55, which were comparative examples, were poor.

[0151] For example, in Test Nos. 4 and 5, which were comparative examples, since the water density in the quaternary cooling process was less than $2.0 \text{ m}^3/\text{min}/\text{mm}^2$, the coverage of martensite with bainite was less than 75.0%. In addition, fine cracks were observed on the sheared end surface, and the breaking limit strain according to the side bend test could not reach a desired value.

[0152] In Test Nos. 26 to 36, which were comparative examples, although the coverage of martensite with bainite and the average diameter d_M of martensite were within the scope of the invention, other requirements for the metallographic structure were not satisfied, any one or more properties were not satisfied. For example, in Test No. 27 using a steel type G having an appropriate chemical composition, since the final finishing temperature during final rolling was higher than 950°C , the area ratio of ferrite was less than 53.0%. As a result, the ductility decreased.

[0153] In addition, although Test No. 50, which was a comparative example, was manufactured under manufacturing conditions within the scope of the present invention, since the Al content in the chemical composition was large, the area ratio of ferrite increased. As a result, the tensile strength was less than 780 MPa. Here, like the case of Test No. 50, if conditions in the quaternary cooling process were appropriate and the area ratio of bainite was more than 14.0%, the breaking limit strain according to the side bend reached a desired value. Accordingly, it can be understood that it was very important to control conditions in the quaternary cooling process to be within the scope of the present invention in order to reduce fine cracks on the sheared end surface, and accordingly, improve the breaking limit strain according to the side bend.

[0154] In addition, FIG. 11A shows a structure image (SEM image) of Test No. 6, which was a comparative example in which a holding time was shorter than 0.33 seconds. In addition, FIG. 11B shows an enlarged view of an area A indicated by FIG. 11A. In the part indicated by the arrow in FIG. 11B, linear contrast different from that of the grain boundary was observed. The contrast was considered to be the interface with austenite after bainite transformation according to tertiary cooling was completed. It can be understood that martensite transformation proceeded at the interface between austenite and ferrite and a part close thereto, and as a result, the coverage of martensite with bainite decreased.

Claims

1. A hot-rolled steel sheet having a chemical composition containing, in mass%,

C: 0.035% or more and 0.085% or less,

Si: 0.001% or more and 0.15% or less,

Mn: 0.70% or more and 1.80% or less,

P: 0.020% or less,

S: 0.0050% or less,

Ti: 0.075% or more and 0.170% or less,

Nb: 0.003% or more and 0.050% or less,

Al: 0.10% or more and 0.40% or less,

N: 0.0080% or less,

Cr: 0% or more and 0.27% or less,

B: 0% or more and 0.0050% or less,

Ca: 0% or more and 0.0050% or less,

Mo: 0% or more and 0.40% or less,

Ni: 0% or more and 0.50% or less,

Cu: 0% or more and 0.50% or less, and

REM: 0% or more and 0.0300% or less,

with the remainder consisting of Fe and impurities, and

having a metallographic structure containing,

ferrite with an area ratio of 53.0% or more and 76.0% or less,

martensite with an area ratio of 3.0% or more and 10.0% or less,

bainite with an area ratio of 14.0% or more and 39.0% or less, and

pearlite with an area ratio of 2.6% or less,

with an average diameter of martensite of $0.26 \mu\text{m}$ or more and $0.70 \mu\text{m}$ or less,

wherein, among all interfaces of the martensite, a total length of the interfaces between the martensite and the bainite is 75.0% or more with respect to a total length of all interfaces of the martensite.

2. The hot-rolled steel sheet according to claim 1,

wherein the chemical composition contains, in mass,
one, or two or more selected from the group consisting of

Cr: 0.06% or more and 0.27% or less,
B: 0.0003% or more and 0.0050% or less,
Ca: 0.0003% or more and 0.0050% or less,
Mo: 0.01% or more and 0.40% or less,
Ni: 0.01% or more and 0.50% or less,
Cu: 0.01% or more and 0.50% or less, and
REM: 0.0003% or more and 0.0300% or less.

3. A method for manufacturing a hot-rolled steel sheet that is performed on a slab having the chemical composition according to claim 1 or 2, the method comprising:

a hot rolling process in which rolling is performed under conditions in which a final finishing temperature is 880°C or higher and 950°C or lower;
a primary cooling process in which cooling is performed to a primary cooling stop temperature of 680°C or higher and 760°C or lower at an average cooling rate of 60 °C/sec or faster, after the hot rolling process;
a secondary cooling process in which cooling is performed at an average cooling rate of 20 °C/sec or slower for 1.6 seconds or longer and 6.3 seconds or shorter, after the primary cooling process;
a tertiary cooling process in which cooling is performed to a tertiary cooling stop temperature of 195°C or higher and 440°C or lower at an average cooling rate of 60 °C/sec or faster and 130 °C/sec or slower, after the secondary cooling process;
a quaternary cooling process in which water cooling is performed at a water density of 2.0 m³/min/mm² or more and 7.2 m³/min/mm² or less for 0.33 seconds or longer and 1.50 seconds or shorter, after the tertiary cooling process;
a quinary cooling process in which air cooling is performed for 3.0 seconds or longer and 5.0 seconds or shorter, after the quaternary cooling process; and
a winding process in which winding is performed at lower than 180°C, after the quinary cooling process.

FIG. 1

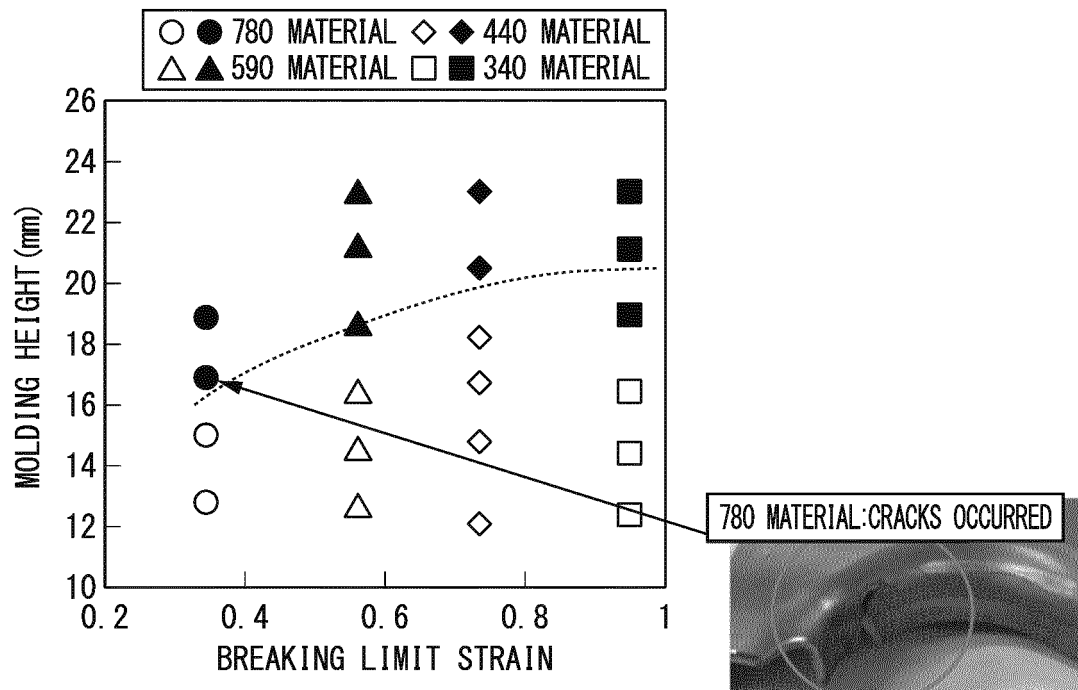


FIG. 2

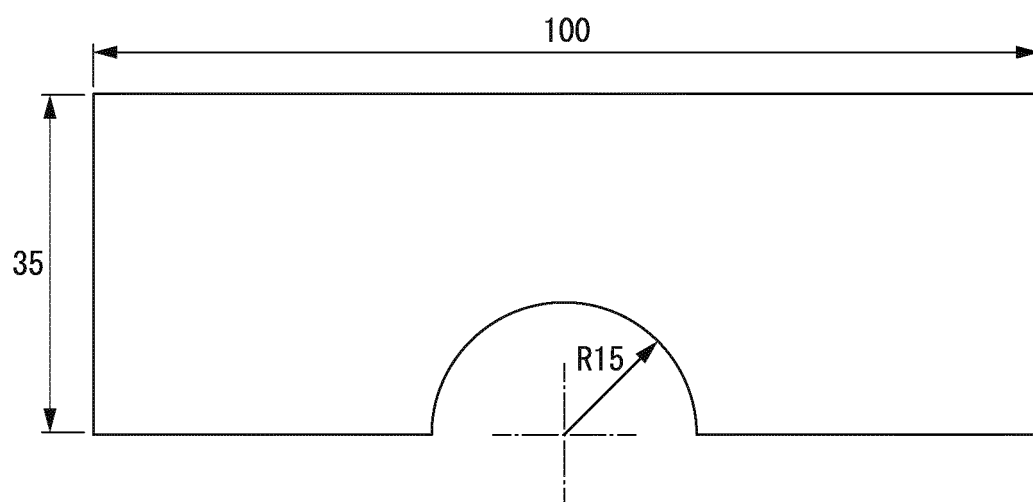


FIG. 3

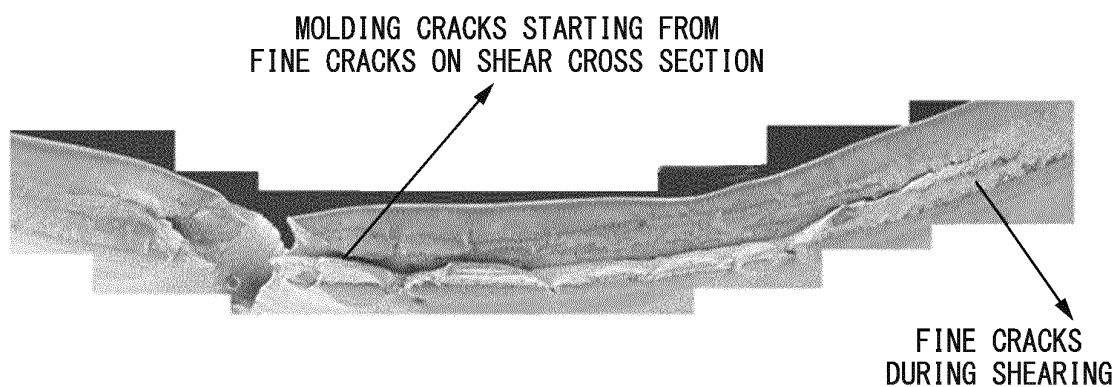


FIG. 4A

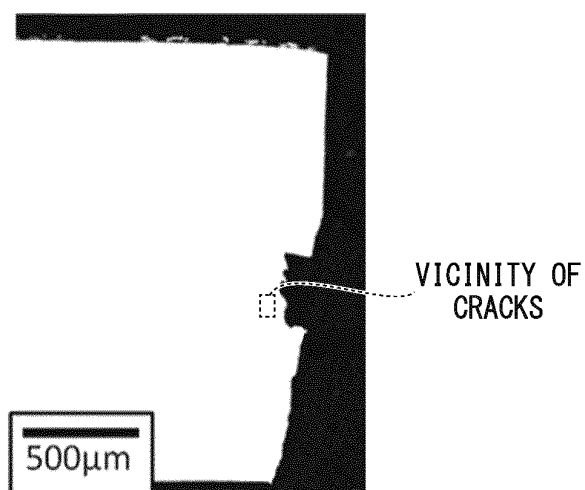


FIG. 4B

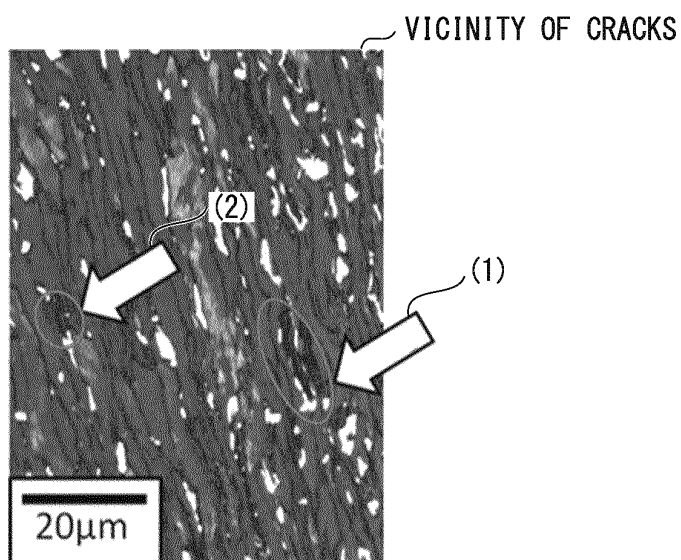


FIG. 5

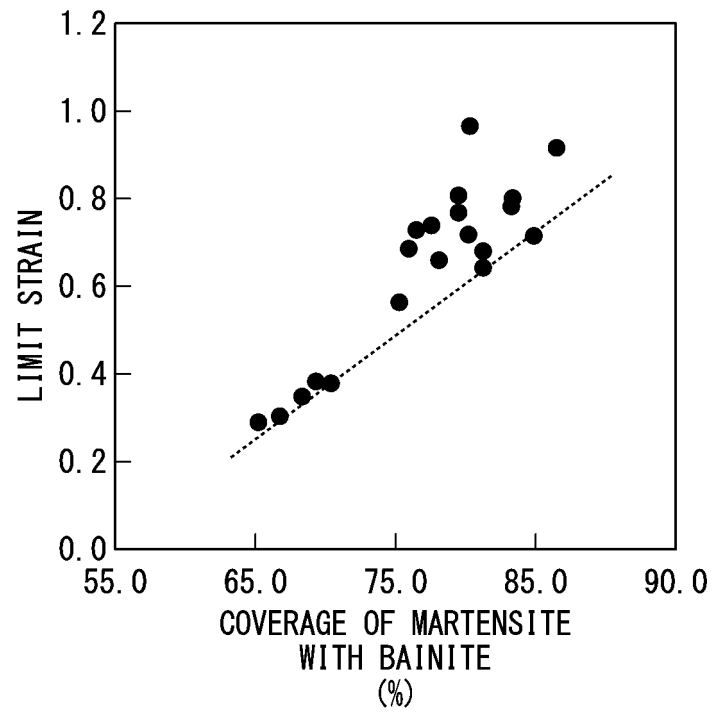


FIG. 6

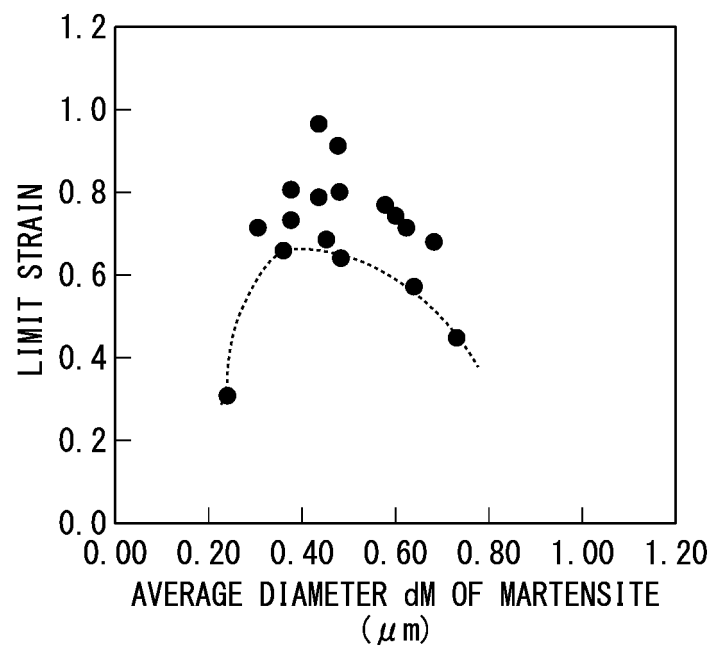
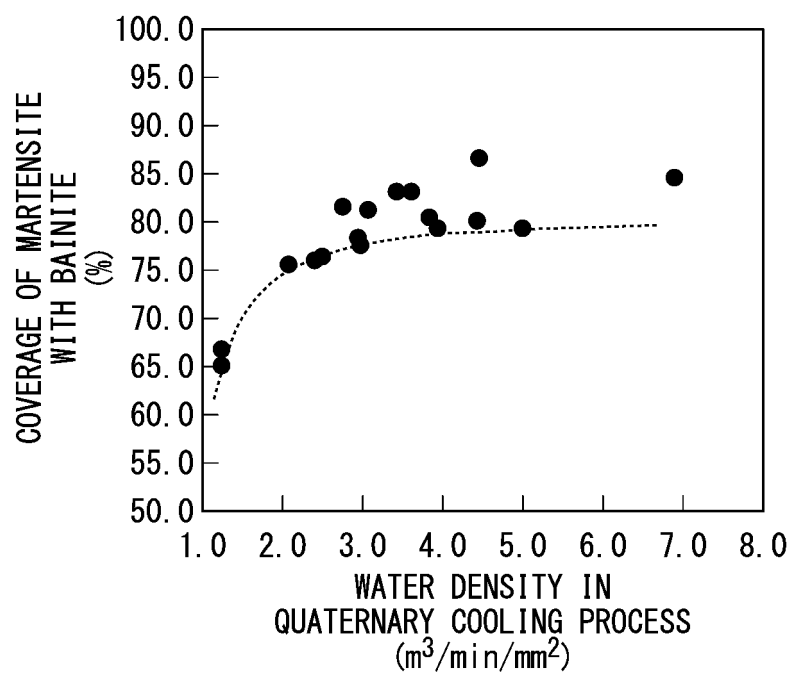


FIG. 7



[FIG. 8]

FIG. 8

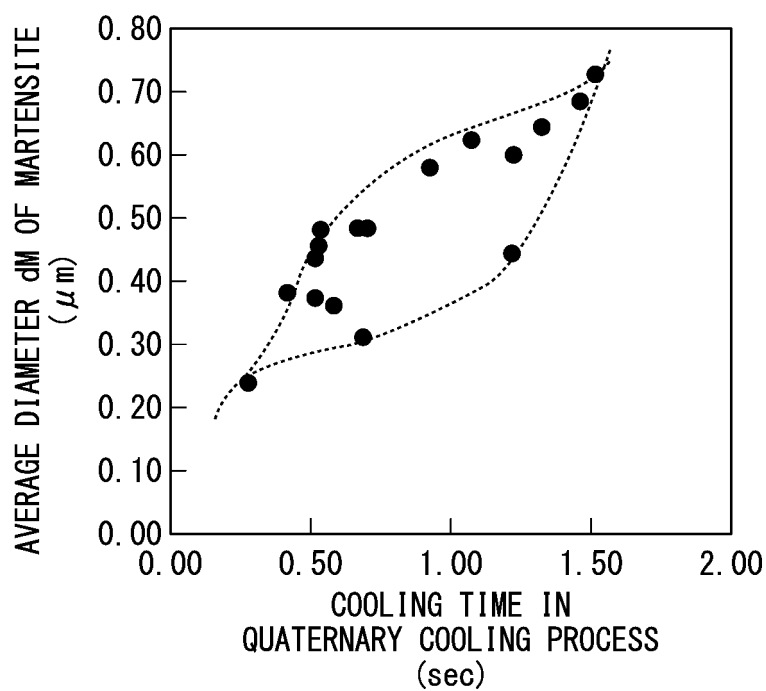


FIG. 9

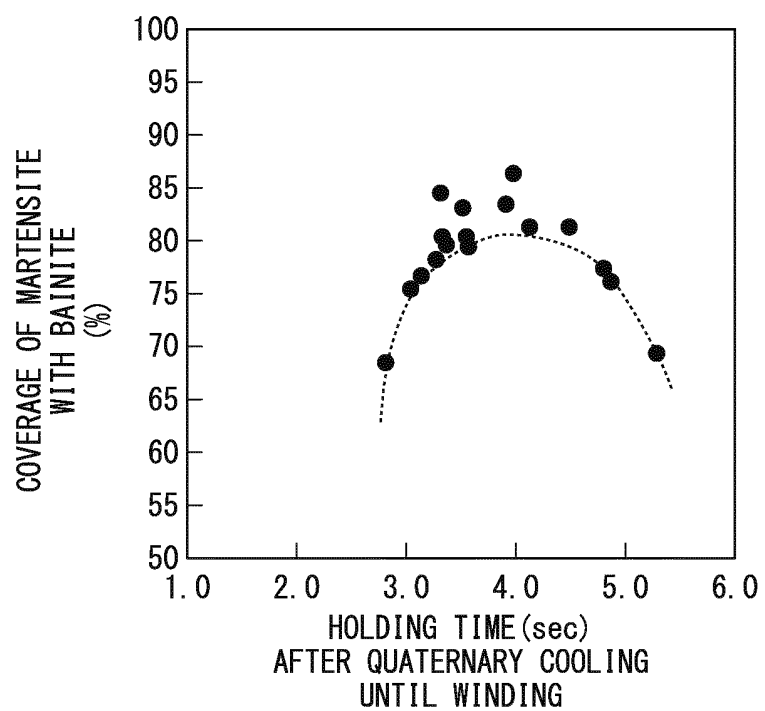


FIG. 10A

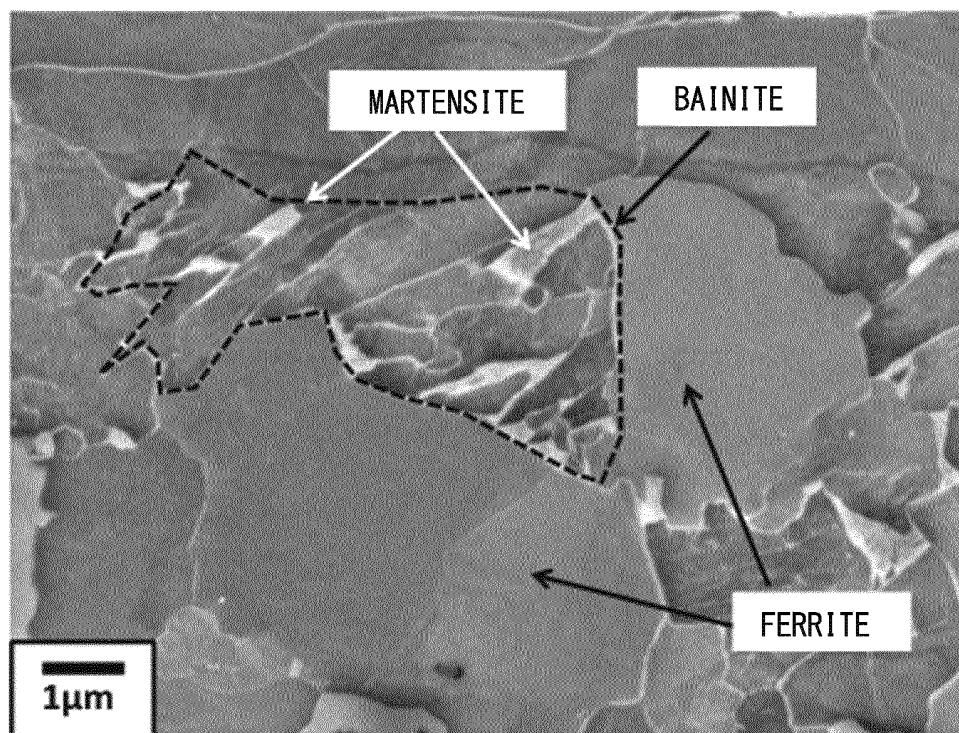


FIG. 10B

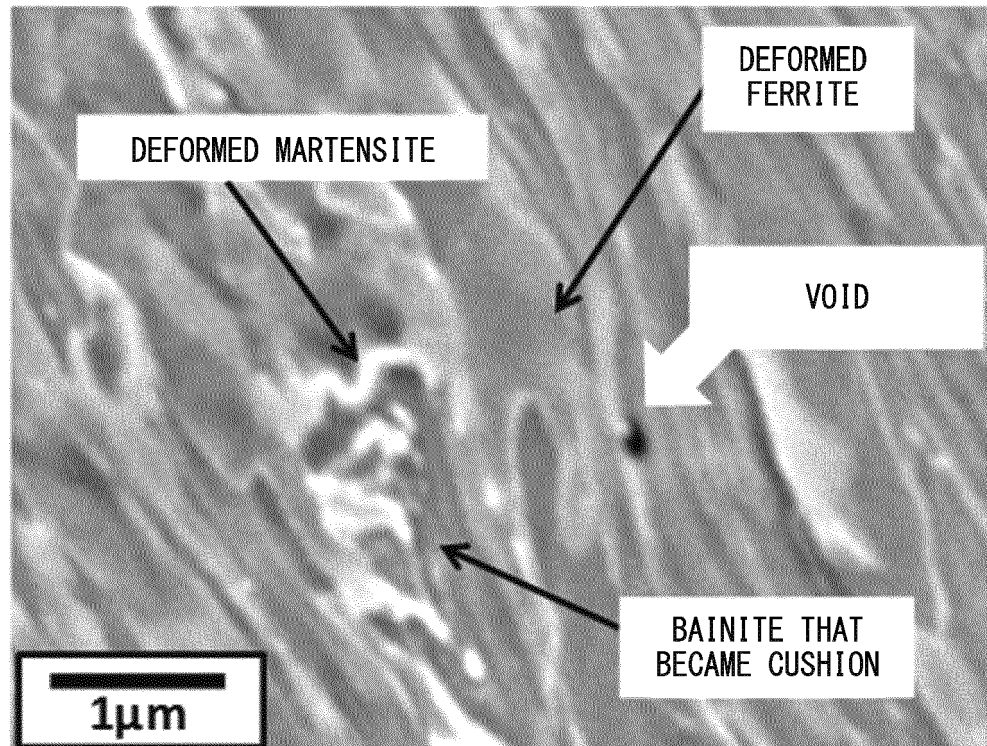


FIG. 11A

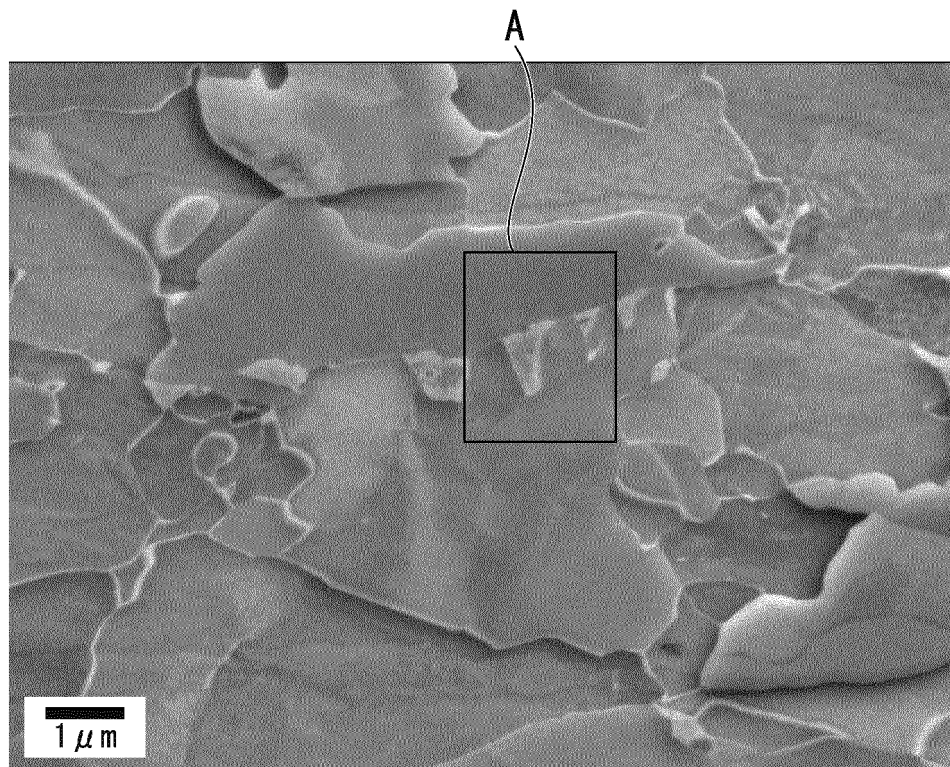
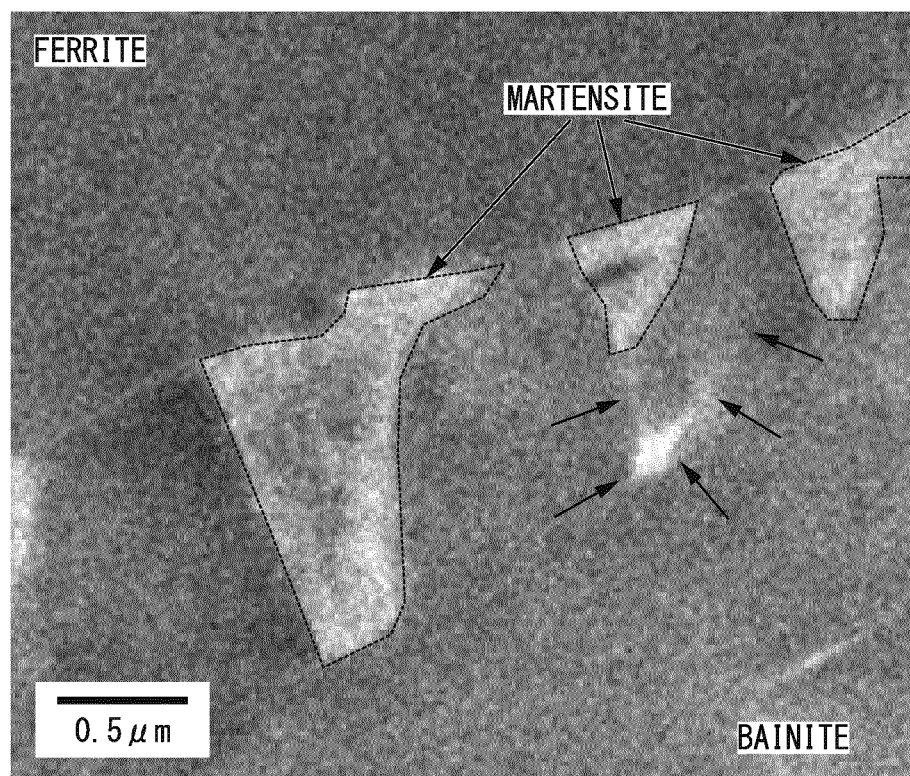


FIG. 11B



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/023549

A. CLASSIFICATION OF SUBJECT MATTER

C21D 9/46(2006.01)i; C22C 38/00(2006.01)i; C22C 38/58(2006.01)i
FI: C22C38/00 301W; C22C38/58; C21D9/46 T

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; C22C38/58

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2021/065346 A1 (NIPPON STEEL CORP) 08 April 2021 (2021-04-08)	1-3
A	WO 2020/170710 A1 (JFE STEEL CORP) 27 August 2020 (2020-08-27)	1-3
A	JP 2015-199987 A (NIPPON STEEL & SUMITOMO METAL CORP) 12 November 2015 (2015-11-12)	1-3
A	JP 2015-63731 A (NIPPON STEEL & SUMITOMO METAL CORP) 09 April 2015 (2015-04-09)	1-3



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"G" document member of the same patent family

Date of the actual completion of the international search
02 September 2021 (02.09.2021)Date of mailing of the international search report
14 September 2021 (14.09.2021)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2021/023549

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2021/065346 A1	08 Apr. 2021	(Family: none)	
WO 2020/170710 A1	27 Aug. 2020	(Family: none)	
JP 2015-199987 A	12 Nov. 2015	(Family: none)	
JP 2015-63731 A	09 Apr. 2015	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- WO 2014051005 A [0007]
- JP 2009145138 A [0104] [0106] [0138]

Non-patent literature cited in the description

- *Nippon Steel Technical Report*, 2012, (393), 18-24
[0104] [0106] [0138]