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

(57) A hot-rolled steel sheet has a predetermined chemical composition, a microstructure of an inner region includes 40% to 80% of one or two of martensite and bainite in total and 20% to 60% of ferrite by area ratio, an area ratio of a remainder in microstructure is less than 5%, α_s/α_c , which is a ratio of a ferrite area ratio α_s of a

surface layer region to a ferrite area ratio α_c of the inner region, is in a range of 1.15 to 2.50, (1 - Hvs/Hvc), which is a hardness difference ratio between a Vickers hardness Hvs of the surface layer region and a Vickers hardness Hvc of the inner region, is 0.20 or less, and a tensile strength is 980 MPa or more.

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Description

[Technical Field of the Invention]

5 **[0001]** The present invention relates to a hot-rolled steel sheet. Specifically, the present invention relates to a hot-rolled steel sheet that has high strength and excellent fatigue strength, toughness, and ductility.

[Background Art]

10 **[0002]** In recent years, the application of a high strength steel sheet to vehicle members has been actively studied for the purpose of improving the durability and collision safety of a vehicle. However, in a case where a steel sheet is highly strengthened, the toughness of the steel sheet generally deteriorates. For this reason, in the development of a high strength steel sheet, it is an important problem to highly strengthen a steel sheet without the deterioration of material properties. In particular, it is important to ensure the fatigue durability of components in a case of a high strength steel sheet applied to vehicle members. In a case where a steel sheet is worked into a component, cracks propagate from a punched surface or the like. Even if a high strength steel sheet is used, the fatigue durability of the component is not necessarily improved.

15 **[0003]** In this regard, Patent Document 1 proposes a high-strength hot-rolled steel sheet which is excellent in bending workability and in which a microstructure includes a surface layer region having a ferrite phase as a primary phase and an inner region having a bainite phase as a primary phase and a ratio of the surface layer region to the steel sheet in a thickness direction is set in the range of 1.0% to 5.0% of the total sheet thickness on each of the surface and back of the steel sheet.

20 **[0004]** Patent Document 2 proposes a high-strength hot-rolled steel sheet which is excellent in workability and includes a central part mainly including bainite and a surface layer area mainly including polygonal ferrite and in which the surface layer area is formed in a region present from at least each of both surfaces of the steel sheet to a depth of 0.2 mm from each of both surfaces of the steel sheet.

25 **[0005]** Patent Document 3 proposes a high strength steel sheet that is excellent in bendability and in which an average Vickers hardness from a surface layer to a position corresponding to 1/2 of a sheet thickness and a standard deviation of hardnesses are kept low.

30 **[0006]** Patent Document 4 proposes a hot-rolled steel sheet in which the area fraction of martensite and Vickers hardness are controlled within predetermined ranges in each depth direction of a sheet thickness to improve fatigue properties and surface layer machinability.

[Prior Art Document]

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[Patent Document]

[0007]

40 [Patent Document 1] PCT International Publication No. WO2014/171057

[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2001-279378

[Patent Document 3] PCT International Publication No. WO2018/151331

[Patent Document 4] Japanese Unexamined Patent Application, First Publication No. 2017-186634

45 [Disclosure of the Invention]

[Problems to be Solved by the Invention]

50 **[0008]** However, since a surface layer has ferrite as a primary phase and is softened in the hot-rolled steel sheets disclosed in Patent Documents 1 to 3, there is room for further improvement in fatigue properties.

[0009] Further, since a surface layer is softened in the invention disclosed in Patent Document 4, there is room for further improvement in fatigue strength. Furthermore, since the hot-rolled steel sheet is precipitation-strengthened inside the sheet thickness, a dislocation motion in ferrite is inhibited. From this viewpoint, there is room for further improvement in toughness.

55 **[0010]** In recent years, there has been a demand for a high-strength hot-rolled steel sheet having higher fatigue strength and toughness against a background of a demand for a further reduction in the weight of a vehicle, the complication of the shape of a component, and the like.

[0011] The present invention has been made in consideration of the above-mentioned problems, and an object of the

present invention is to provide a hot-rolled steel sheet that has high strength and excellent fatigue strength and toughness. Further, another object of the present invention is to provide a hot-rolled steel sheet that has various properties described above and has excellent ductility which is a property generally required for a hot-rolled steel sheet applied to a vehicle member.

[Means for Solving the Problem]

[0012] A precipitation-strengthened structure is excellent in fatigue strength since inhibiting a dislocation motion. For this reason, a precipitation-strengthened structure is often used for suspension components of a vehicle. On the other hand, in a case where a dislocation motion is suppressed, plastic deformation is less likely to occur. For this reason, impact properties (particularly, toughness) deteriorate. Accordingly, it is presumed that fatigue strength and impact properties are in a contradictory relationship. The present inventors have analyzed in detail the deformation mechanisms of fatigue strength and impact strength to improve both fatigue strength and toughness. As a result, the present inventors have found that the microstructure and hardness of a surface layer region of a hot-rolled steel sheet greatly affect fatigue strength and the microstructure and hardness of an inner region of a hot-rolled steel sheet greatly affect the propagation of cracks.

[0013] The gist of the present invention made on the basis of the above findings is as follows.

(1) A hot-rolled steel sheet according to an aspect of the present invention comprising, as a chemical composition, by mass%:

C: 0.02% to 0.30%;

Si: 0.10% to 2.00%;

Mn: 0.5% to 3.0%;

sol. Al: 0.10% to 1.00%;

Ti: 0.06% to 0.20%;

P: 0.1000% or less;

S: 0.0100% or less;

N: 0.0100% or less;

Nb: 0% to 0.100%;

Ca: 0% to 0.0060%;

Mo: 0% to 0.50%;

Cr: 0% to 1.00%;

V: 0% to 0.40%;

Ni: 0% to 0.40%;

Cu: 0% to 0.40%;

B: 0% to 0.0020%; and

Sn: 0% to 0.20%,

in which a remainder consists of Fe and impurities,

a microstructure of an inner region includes 40% to 80% of one or two of martensite and bainite in total and 20% to 60% of ferrite by area ratio, and an area ratio of a remainder in microstructure is less than 5%,

α_s/α_c , which is a ratio of a ferrite area ratio α_s of a surface layer region to a ferrite area ratio α_c of the inner region, is in a range of 1.15 to 2.50,

$(1 - H_{vs}/H_{vc})$, which is a hardness difference ratio between a Vickers hardness H_{vs} of the surface layer region and a Vickers hardness H_{vc} of the inner region, is 0.20 or less, and

a tensile strength is 980 MPa or more.

(2) In the hot-rolled steel sheet according to (1), the chemical composition may include, by mass%, one or two or more selected from the group consisting of

Nb: 0.010% to 0.100%,

Ca: 0.0005% to 0.0060%,

Mo: 0.02% to 0.50%,

Cr: 0.02% to 1.00%,

V: 0.01% to 0.40%,

Ni: 0.01 % to 0.40%,

Cu: 0.01% to 0.40%,

B: 0.0001 % to 0.0020%, and

Sn: 0.01% to 0.20%.

[Effects of the Invention]

[0014] According to the aspect of the present invention, it is possible to provide a hot-rolled steel sheet that has high strength and excellent fatigue strength, toughness, and ductility. According to this hot-rolled steel sheet, since it is possible to reduce the weight of a vehicle body of a vehicle or the like and to improve the durability thereof, the industrial value of the hot-rolled steel sheet is high.

[Embodiments of the Invention]

[0015] A hot-rolled steel sheet according to an embodiment of the present invention (hereinafter, referred to as a hot-rolled steel sheet according to the present embodiment) will be described. However, the present invention is not limited to only configuration disclosed in the present embodiment, and can have various modifications without departing from the scope of the present invention.

[0016] Individual configuration requirements of the present invention will be described in detail below. First, reasons for limiting the chemical composition of the hot-rolled steel sheet according to the present embodiment will be described.

[0017] A limited numerical range described below using "to" includes a lower limit and an upper limit. Numerical values represented using "less than" or "exceed" are not included in a numerical range. In the following description, % regarding the chemical composition is mass% unless otherwise specified.

[0018] The hot-rolled steel sheet according to the present embodiment contains, as a chemical composition, by mass%, C: 0.02% to 0.30%, Si: 0.10% to 2.00%, Mn: 0.5% to 3.0%, sol. Al: 0.10% to 1.00%, Ti: 0.06% to 0.20%, P: 0.1000% or less, S: 0.0100% or less, N: 0.0100% or less, and a remainder: Fe and impurities. Each element will be described in detail below.

<C: 0.02% to 0.30%>

[0019] C is an important element for improving the strength of the hot-rolled steel sheet. In order to obtain a desired strength, the C content is set to 0.02% or more. The C content is preferably 0.04% or more.

[0020] On the other hand, in a case where the C content exceeds 0.30%, the toughness of the hot-rolled steel sheet deteriorates. For this reason, the C content is set to 0.30% or less. The C content is preferably 0.20% or less.

<Si: 0.10% to 2.00%>

[0021] Si is an element that has an effect of suppressing the generation of carbide during ferritic transformation and improving the toughness of the hot-rolled steel sheet. In order to obtain this effect, the Si content is set to 0.10% or more. The Si content is preferably 0.20% or more or 0.50% or more.

[0022] On the other hand, in a case where the Si content exceeds 2.00%, the toughness of the hot-rolled steel sheet deteriorates. For this reason, the Si content is set to 2.00% or less. The Si content is preferably 1.50% or less.

<Mn: 0.5% to 3.0%>

[0023] Mn is an element effective in improving hardenability and improving the strength of the hot-rolled steel sheet using solid solution strengthening. In order to obtain this effect, the Mn content is set to 0.5% or more. The Mn content is preferably 1.0% or more.

[0024] On the other hand, in a case where the Mn content exceeds 3.0%, MnS harmful to toughness and fatigue strength is generated. For this reason, the Mn content is set to 3.0% or less. The Mn content is preferably 2.5% or less or 2.0% or less.

<sol. Al: 0.10% to 1.00%>

[0025] Al is an important element for controlling ferritic transformation. In order to obtain this effect, the sol. Al content is set to 0.10% or more. The sol. Al content is preferably 0.15% or more or 0.20% or more.

[0026] On the other hand, in a case where the sol. Al content exceeds 1.00%, alumina precipitated in the form of a cluster is generated and the toughness of the hot-rolled steel sheet deteriorates. For this reason, the sol. Al content is set to 1.00% or less. The sol. Al content is preferably 0.80% or less or 0.50% or less.

[0027] The sol. Al means acid-soluble Al and refers to solute Al present in steel in a solid solution state.

<Ti: 0.06% to 0.20%>

[0028] Ti is an element for precipitation-strengthening ferrite and is an important element for controlling ferritic transformation to obtain a desired amount of ferrite. In order to obtain excellent fatigue strength using precipitation-strengthening and the control of ferritic transformation, the Ti content is set to 0.06% or more. The Ti content is preferably 0.08% or more.

[0029] On the other hand, in a case where the Ti content exceeds 0.20%, inclusions caused by TiN are generated and the toughness of the hot-rolled steel sheet deteriorates. For this reason, the Ti content is set to 0.20% or less. The Ti content is preferably 0.16% or less or 0.13% or less.

<P: 0.1000% or less>

[0030] P is an impurity and it is more preferable that the P content is lower. In particular, in a case where the P content exceeds 0.1000%, the workability and weldability of the hot-rolled steel sheet significantly deteriorate and fatigue strength is also reduced. For this reason, the P content is set to 0.1000% or less. The P content is preferably 0.0500% or less or 0.0200% or less.

[0031] The lower limit of the P content does not need to be particularly specified, but it is preferable that the lower limit of the P content is set to 0.0010% or more from the viewpoint of refining cost.

<S: 0.0100% or less>

[0032] S is an impurity and it is more preferable that the S content is lower. In particular, in a case where the S content exceeds 0.0100%, a large amount of inclusions, such as MnS harmful to the isotropy of toughness, is generated. For this reason, the S content is set to 0.0100% or less. In a case where more excellent toughness is required, it is preferable that the S content is set to 0.0060% or less. The S content is more preferably 0.0050% or less.

[0033] The lower limit of the S content does not need to be particularly specified, but it is preferable that the lower limit of the S content is set to 0.0001% or more from the viewpoint of refining cost.

<N: 0.0100% or less>

[0034] N is an impurity. Since coarse Ti nitride is formed in a high-temperature range in a case where the N content exceeds 0.0100%, the toughness of the hot-rolled steel sheet deteriorates. For this reason, the N content is set to 0.0100% or less. The N content is preferably 0.0060% or less or 0.0050% or less.

[0035] The lower limit of the N content does not need to be particularly specified, but it is preferable that the lower limit of the N content is set to 0.0001% or more from the viewpoint of refining cost.

[0036] The hot-rolled steel sheet according to the present embodiment may contain the above-mentioned chemical composition and a remainder may consist of Fe and impurities. In the present embodiment, the impurities mean substances that are incorporated from ore as a raw material, a scrap, manufacturing environment, or the like and/or substances that are permitted to an extent that the hot-rolled steel sheet according to the present embodiment is not adversely affected.

[0037] Although not essential to impart desired properties, the following optional elements may be contained to reduce manufacturing variations or to further improve the strength of the hot-rolled steel sheet. However, since it is not essential that these elements are contained, the lower limits of the contents of these elements are 0%. In a case where the content of each optional element is less than the lower limit of the content to be described below, the optional element can be regarded as an impurity.

<Nb: 0.010% to 0.100%>

[0038] Nb is an element that has an effect of increasing the strength of the hot-rolled steel sheet using the refinement of the grain size of the hot-rolled steel sheet and the precipitation-strengthening of NbC. In a case where this effect is to be reliably obtained, it is preferable that the Nb content is set to 0.010% or more.

[0039] On the other hand, in a case where the Nb content exceeds 0.100%, the above-mentioned effect is saturated. For this reason, even in a case where Nb is to be contained, the Nb content is set to 0.100% or less. The Nb content is preferably 0.060% or less.

<Ca: 0.0005% to 0.0060%>

[0040] Ca is an element that has an effect of refining the structure of the hot-rolled steel sheet by causing a number

of fine oxides to be dispersed during the deoxidation of molten steel. Further, Ca is an element that fixes S in the steel as spherical CaS and suppresses the generation of elongated inclusions, such as MnS, to improve the hole expansibility of the hot-rolled steel sheet. In a case where these effects are to be reliably obtained, it is preferable that the Ca content is set to 0.0005% or more.

[0041] On the other hand, even though the Ca content exceeds 0.0060%, the above-mentioned effects are saturated. For this reason, even in a case where Ca is to be contained, the Ca content is set to 0.0060% or less. The Ca content is preferably 0.0040% or less.

<Mo: 0.02% to 0.50%>

[0042] Mo is an element effective in the precipitation-strengthening of ferrite. In a case where this effect is to be reliably obtained, it is preferable that the Mo content is set to 0.02% or more. The Mo content is more preferably 0.10% or more.

[0043] On the other hand, in a case where the Mo content is excessively high, the crack sensitivity of a slab is increased, so that it is difficult to handle the slab. For this reason, even in a case where Mo is to be contained, the Mo content is set to 0.50% or less. The Mo content is preferably 0.30% or less.

<Cr: 0.02% to 1.00%>

[0044] Cr is an element effective in improving the strength of the hot-rolled steel sheet. In a case where this effect is to be reliably obtained, it is preferable that the Cr content is set to 0.02% or more. The Cr content is more preferably 0.10% or more.

[0045] On the other hand, in a case where the Cr content is excessively high, the ductility of the hot-rolled steel sheet deteriorates. For this reason, even in a case where Cr is to be contained, the Cr content is set to 1.00% or less. The Cr content is preferably 0.80% or less.

<V: 0.01% to 0.40%>

[0046] V improves the strength of the hot-rolled steel sheet via strengthening caused by precipitates, grain refinement strengthening caused by the suppression of the growth of ferrite crystal grains, and dislocation strengthening caused by the suppression of recrystallization. In a case where this effect is to be reliably obtained, it is preferable that the V content is set to 0.01% or more.

[0047] On the other hand, in a case where the V content is excessively high, a large amount of carbonitride is precipitated, so that the formability of the hot-rolled steel sheet deteriorates. For this reason, the V content is set to 0.40% or less. The V content is preferably 0.20% or less.

<Ni: 0.01% to 0.40%>

[0048] Ni suppresses phase transformation at a high temperature and improves the strength of the hot-rolled steel sheet. In a case where this effect is to be reliably obtained, it is preferable that the Ni content is set to 0.01 % or more.

[0049] On the other hand, in a case where the Ni content is excessively high, the weldability of the hot-rolled steel sheet deteriorates. For this reason, the Ni content is set to 0.40% or less. The Ni content is preferably 0.20% or less.

<Cu: 0.01% to 0.40%>

[0050] Cu is present in steel in the form of fine grains and improves the strength of the hot-rolled steel sheet. In a case where this effect is to be reliably obtained, it is preferable that the Cu content is set to 0.01% or more.

[0051] On the other hands, in a case where the Cu content is excessively high, the weldability of the hot-rolled steel sheet deteriorates. For this reason, the Cu content is set to 0.40% or less. The Cu content is preferably 0.20% or less.

<B: 0.0001% to 0.0020%>

[0052] B suppresses phase transformation at a high temperature and improves the strength of the hot-rolled steel sheet. In a case where this effect is to be reliably obtained, it is preferable that the B content is set to 0.0001% or more.

[0053] On the other hand, in a case where the B content is excessively high, a B precipitate is generated, so that the strength of the hot-rolled steel sheet is reduced. For this reason, the B content is set to 0.0020% or less. The B content is preferably 0.0005% or less.

<Sn: 0.01% to 0.20%>

[0054] Sn is an element that suppresses the coarsening of crystal grains and improves the strength of the hot-rolled steel sheet. In a case where this effect is to be reliably obtained, it is preferable that the Sn content is set to 0.01 % or more.

[0055] On the other hand, in a case where the Sn content is excessively high, steel is embrittled. Accordingly, the steel is likely to be fractured during the rolling. For this reason, the Sn content is set to 0.20% or less. The Sn content is preferably 0.10% or less.

[0056] The chemical composition of the hot-rolled steel sheet described above may be measured by a general analysis method. For example, the chemical composition of the hot-rolled steel sheet described above may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). sol. Al may be measured by the ICP-AES using a filtrate that is obtained after a sample is decomposed with an acid by heating. C and S may be measured using a combustion-infrared absorption method, and N may be measured using an inert gas melting-thermal conductivity method.

[0057] Next, the microstructure of the hot-rolled steel sheet according to the present embodiment will be described.

[0058] In the hot-rolled steel sheet according to the present embodiment, the microstructure of an inner region contains 40% to 80% of one or two of martensite and bainite in total and 20% to 60% of ferrite by area ratio, an area ratio of a remainder in microstructure is less than 5%, α_s/α_c , which is a ratio of a ferrite area ratio α_s of a surface layer region to a ferrite area ratio α_c of the inner region, is in the range of 1.15 to 2.50, and $(1 - H_{vs}/H_{vc})$, which is a hardness difference ratio between a Vickers hardness H_{vs} of the surface layer region and a Vickers hardness H_{vc} of the inner region, is 0.20 or less.

[0059] The inner region refers to a region that is centered on a position having a depth of 1/4 of a sheet thickness from a surface of the hot-rolled steel sheet and is present from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface. Further, the surface layer region refers to a region that is present from the surface of the hot-rolled steel sheet to a depth of 20 μm from the surface.

[0060] The structure mainly including martensite and bainite is excellent in toughness since being fine. Further, although there are many unclear points about the mechanism, it is known that steel having a structure mainly including martensite and bainite is inferior to precipitation-strengthened steel and dual-phase (DP) steel of ferrite and martensite in terms of fatigue strength. On the other hand, in precipitation-strengthened steel and DP steel, fatigue strength and toughness are inferior since a highspeed dislocation motion in ferrite is inhibited. In the related art, a steel sheet structure has been made according to required properties for a component for a vehicle. However, as the high-strengthening of a component for a vehicle further progresses, it has been difficult to obtain both high fatigue strength and high toughness. Accordingly, in the hot-rolled steel sheet according to the present embodiment, unlike in the related art, the amount of ferrite in the surface layer region is increased to use dual-phase of ferrite and martensite, which are excellent in fatigue strength, and precipitation-strengthening in the surface layer region, and a microstructure mainly including one or two of martensite and bainite excellent in toughness is used in the inner region. Therefore, a high strength of 980 MPa or more, excellent fatigue strength, toughness, and ductility can be obtained.

Microstructure of inner region

[0061] The microstructure of the inner region of the hot-rolled steel sheet greatly affects the toughness of the hot-rolled steel sheet. For this reason, the microstructure of the inner region mainly includes a low-temperature transformation structure. The low-temperature transformation structure is martensite and bainite. In a case where a total area ratio of these structures is less than 40%, the toughness of the hot-rolled steel sheet is inferior. For this reason, the total area ratio of martensite and bainite is set to 40% or more. The total area ratio of martensite and bainite is preferably 45% or more and is more preferably 50% or more.

[0062] On the other hand, in a case where the total area ratio of martensite and bainite exceeds 80%, a hardness difference between the microstructure of the inner region and the microstructure of the surface layer region is increased. Accordingly, the fatigue strength of the hot-rolled steel sheet is inferior. For this reason, the total area ratio of martensite and bainite is set to 80% or less. The total area ratio of martensite and bainite is preferably 75% or less and is more preferably 70% or less.

[0063] In the present embodiment, the amount of only either martensite or bainite may be in the above-mentioned range in a case where the microstructure of the inner region includes only either martensite or bainite, and a total content of both martensite and bainite may be in the above-mentioned range in a case where the microstructure of the inner region includes both martensite and bainite.

[0064] In a case where the area ratio of ferrite is less than 20%, a hardness difference between the microstructure of the inner region and the microstructure of the surface layer region is increased. Accordingly, the fatigue strength of the hot-rolled steel sheet is inferior. For this reason, the area ratio of ferrite is set to 20% or more. The area ratio of ferrite is preferably 25% or more and is more preferably 30% or more.

[0065] On the other hand, in a case where the area ratio of ferrite exceeds 60%, there are cases where strain is not

relieved due to precipitation-strengthened ferrite grains and workability cannot be ensured. As a result, the toughness of the hot-rolled steel sheet deteriorates. For this reason, the area ratio of ferrite is set to 60% or less. The area ratio of ferrite is preferably 55% or less and is more preferably 50% or less.

[0066] The remainder in microstructure of the microstructure of the inner region is less than 5% by area ratio. The remainder in microstructure is one or more of pearlite and residual austenite. The area ratio of the remainder in microstructure is preferably less than 3%, is more preferably 2.5% or less, and is still more preferably 2% or less.

Microstructure of surface layer region

[0067] In a case where α_s/α_c , which is a ratio of the ferrite area ratio α_s of the surface layer region to the ferrite area ratio α_c of the inner region, is less than 1.15 in the microstructure of the surface layer region of the hot-rolled steel sheet, the suppression of a dislocation motion in ferrite is insufficient. As a result, the fatigue strength of the hot-rolled steel sheet is inferior. For this reason, α_s/α_c is set to 1.15 or more. α_s/α_c is preferably 1.20 or more or 1.30 or more, and is more preferably 1.50 or more.

[0068] On the other hand, in a case where α_s/α_c exceeds 2.50, carbon is concentrated inside the sheet thickness during ferritic transformation, so that a hardness difference between the microstructure of the inner region and the microstructure of the surface layer region is increased. As a result, the toughness and/or fatigue strength of the hot-rolled steel sheet is inferior. For this reason, α_s/α_c is set to 2.50 or less. α_s/α_c is preferably 2.20 or less, and is more preferably 2.00 or less.

[0069] It is preferable that β_s/β_c , which is a ratio of a total area ratio β_s of martensite and bainite of the surface layer region to a total area ratio β_c of martensite and bainite of the inner region, is in the range of 0.30 to 0.90 in the microstructure of the surface layer region of the hot-rolled steel sheet. Since β_s/β_c is 0.90 or less, a dislocation motion in martensite and bainite is sufficiently suppressed. As a result, the fatigue strength of the hot-rolled steel sheet is increased. β_s/β_c is more preferably 0.85 or less and is still more preferably 0.80 or less.

[0070] On the other hand, in a case where β_s/β_c is 0.30 or more, carbon is concentrated inside the sheet thickness during martensitic transformation and bainitic transformation, so that an increase in a hardness difference between the microstructure of the inner region and the microstructure of the surface layer region is suppressed. As a result, the toughness and fatigue strength of the hot-rolled steel sheet are increased. β_s/β_c is more preferably 0.40 or more, is still more preferably 0.45 or more, and is even more preferably 0.50 or more.

[0071] The microstructure of the surface layer region may include 30% to 80% of ferrite by area ratio. Further, the microstructure of the surface layer region may include 20% to 70% of one or two or more of bainite, martensite, pearlite, and residual austenite in total by area ratio as a remainder in microstructure other than ferrite.

Method of measuring microstructure

[0072] A sample is cut out from the hot-rolled steel sheet so that a cross-section of the sample taken in a sheet thickness direction perpendicular to the surface of the hot-rolled steel sheet can be observed. After the cross-section of the sample taken in the sheet thickness direction is polished using silicon carbide paper having a grit of #600 to #1500, the cross-section of the sample is finished as a mirror surface using liquid in which diamond powder having a grain size of 1 to 6 μm is dispersed in a diluted solution of alcohol or the like or pure water and Nital etching is performed on the cross-section of the sample. After that, photographs having a plurality of visual fields are taken at an arbitrary position in a longitudinal direction of the cross-section of the sample using a schottky emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd.). Evenly spaced grids are drawn in the taken photographs, and structures at grid points are identified. The number of grid points corresponding to each structure is obtained and is divided by the total number of grid points, so that the area ratio of each structure is obtained. The area ratio can be more accurately obtained as the total number of grid points is larger. In the present embodiment, grid spacings are set to 2 μm $\times$ 2 μm and the total number of grid points is set to 1500.

[0073] A region where cementite is precipitated in a lamellar shape in the grains is determined as pearlite. A region in which luminance is low and no substructure is observed is determined as ferrite. A region in which luminance is high and a substructure is not exposed by etching is determined as martensite or residual austenite. A region that does not correspond to any of the above-described structures is determined as bainite. The area ratio of residual austenite obtained by EBSD analysis described later is subtracted from the area ratio of martensite and residual austenite obtained from the taken photographs, so that the area ratio of martensite is obtained.

[0074] A sample is cut out from the same position as the above-mentioned measurement so that a cross-section of the sample taken in a sheet thickness direction perpendicular to the surface of the hot-rolled steel sheet can be observed. After the cross-section of the sample taken in the sheet thickness direction is polished using silicon carbide paper having a grit of #600 to #1500, the cross-section of the sample is finished as a mirror surface using liquid in which diamond powder having a grain size of 1 to 6 μm is dispersed in a diluted solution of alcohol or the like or pure water. Next, the

cross-section of the sample is polished for eight minutes at room temperature using colloidal silica containing no alkaline solution to remove strain introduced into the surface layer of the sample. Measurement is performed at a measurement interval of 0.1 μm with an electron backscatter diffraction method at an arbitrary position in the longitudinal direction of the cross-section of the sample to obtain crystal orientation information. An EBSD including a schottky emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd.) and an EBSD detector (DVC5 detector manufactured by TSL Solutions) is used for the measurement. In this case, the degree of vacuum in the EBSD device is set to 9.6×10^{-5} Pa or less, an accelerating voltage is set to 15 kV, an irradiation current level is set to 13, and the irradiation level of an electron beam is set to 62. The area ratio of residual austenite is calculated from the obtained crystal orientation information using "Phase Map" function of software "OIM Analysis (registered trademark)" included in an EBSD analysis device. A region where a crystal structure is an fcc structure is determined as residual austenite.

[0075] Each measurement is performed in a region that is present from a depth of 1/8 of the sheet thickness from a surface of the hot-rolled steel sheet to a depth of 3/8 of the sheet thickness from the surface and a region that is present from the surface of the hot-rolled steel sheet to a depth of 20 μm from the surface. As a result, the area ratio of the microstructure in each of the inner region and the surface layer region is obtained.

[0076] Hardness difference ratio between Vickers hardness of surface layer region and Vickers hardness of inner region: 0.20 or less

[0077] In a case where $(1 - H_{vs}/H_{vc})$, which is a hardness difference ratio between the Vickers hardness H_{vs} of the surface layer region and the Vickers hardness H_{vc} of the inner region, exceeds 0.20, the surface layer region is softened. As a result, the fatigue strength of the hot-rolled steel sheet is inferior. For this reason, $(1 - H_{vs}/H_{vc})$, which is a hardness difference ratio between H_{vs} and H_{vc} , is set to 0.20 or less. $(1 - H_{vs}/H_{vc})$ is preferably 0.15 or less and is more preferably 0.10 or less.

[0078] It is more preferable that $(1 - H_{vs}/H_{vc})$, which is a hardness difference ratio between H_{vs} and H_{vc} , is smaller, but $(1 - H_{vs}/H_{vc})$ may be -0.10 or more, 0.00 or more, or 0.01 or more from the viewpoint of manufacture.

Method of measuring Vickers hardness

[0079] A test piece is cut out from the hot-rolled steel sheet so that a cross-section of the test piece taken in a sheet thickness direction perpendicular to the surface of the hot-rolled steel sheet can be observed. After the cross-section of the test piece taken in the sheet thickness direction is polished using silicon carbide paper having a grit of #600 to #1500, the cross-section of the test piece is finished as a mirror surface using liquid in which diamond powder having a grain size of 1 to 6 μm is dispersed in a diluted solution of alcohol or the like or pure water. This cross-section of the test piece taken in the sheet thickness direction is defined as a measurement surface. A micro-Vickers hardness tester is used to measure Vickers hardnesses at intervals of three or more times an indentation under a load of 1 kgf in a region of the measurement surface that is present from a depth of 1/8 of the sheet thickness from a surface of the hot-rolled steel sheet to a depth of 3/8 of the sheet thickness from the surface. Vickers hardnesses are measured at 20 points in total and an average value of the measured Vickers hardnesses is calculated, so that the Vickers hardness H_{vc} of the microstructure of the inner region is obtained. Likewise, Vickers hardnesses are measured in a region of the measurement surface that is present from the surface of the hot-rolled steel sheet to a depth of 20 μm from the surface and an average value of the Vickers hardnesses measured at 20 points is calculated, so that the Vickers hardness H_{vs} of the microstructure of the surface layer region is obtained. $(1 - H_{vs}/H_{vc})$ is calculated using the obtained H_{vs} and H_{vc} , so that a height difference ratio between the Vickers hardnesses is obtained.

[0080] The tensile (maximum) strength of the hot-rolled steel sheet according to the present embodiment is 980 MPa or more. The tensile (maximum) strength of the hot-rolled steel sheet is preferably 1000 MPa or more. Since components to which the hot-rolled steel sheet can be applied are limited in a case where the tensile strength of the hot-rolled steel sheet is less than 980 MPa, the hot-rolled steel sheet less contributes to a reduction in the weight of a vehicle body. An upper limit of the tensile strength of the hot-rolled steel sheet does not need to be particularly limited, and may be set to 1500 MPa or less or 1300 MPa or less from the viewpoint of suppressing the wear of a die.

[0081] Further, the hot-rolled steel sheet according to the present embodiment may have a total elongation of 10% or more, may have an absorbed energy of 80 J/cm² or more at a temperature of -20°C, and may have a fatigue limit ratio (fatigue strength/tensile strength) of 0.48 or more.

[0082] A tensile test is performed according to JIS Z 2241:2011 to evaluate a tensile strength and total elongation. No. 5 test piece of JIS Z 2241:2011 is used as a test piece. The sampling position of the tensile test piece may be set to a 1/4 portion from the end portion in the sheet width direction, and a direction perpendicular to the rolling direction may be set to the longitudinal direction.

[0083] For toughness, first, a V-notch test piece having a subsize of 2.5 mm specified in JIS Z 2242:2018 is collected from a position adjacent to the sampling position of the test piece used in the tensile test. A Charpy impact test for a notch in a C direction is performed using this test piece at a temperature of -20°C, so that absorbed energy is measured. For a hot-rolled steel sheet having a sheet thickness of less than 2.5 mm, the test is performed over the entire thickness.

[0084] Fatigue strength is measured according to JIS Z 2275:1978 using a Schenck type plane bending fatigue tester. The speed of a test for a stress load at the time of measurement is set to 30 Hz with both oscillations and fatigue strength is measured over 10^7 cycle. Then, the fatigue strength over 10^7 cycle is divided by the tensile strength measured in the above-mentioned tensile test, so that a fatigue limit ratio (fatigue strength/tensile strength) is calculated.

[0085] The sheet thickness of the hot-rolled steel sheet according to the present embodiment is not particularly limited and may be set to 1.2 to 8.0 mm. In a case where the sheet thickness of the hot-rolled steel sheet according to the present embodiment is less than 1.2 mm, it is difficult to ensure a rolling completion temperature and a rolling force is excessively large. For this reason, it may be difficult to perform hot rolling. Accordingly, the sheet thickness of the hot-rolled steel sheet according to the present embodiment may be set to 1.2 mm or more. The sheet thickness of the hot-rolled steel sheet according to the present embodiment is preferably 1.4 mm or more. On the other hand, in a case where the sheet thickness exceeds 8.0 mm, it may be difficult to obtain the above-mentioned microstructure after hot rolling. Accordingly, the sheet thickness may be set to 8.0 mm or less. The sheet thickness is preferably 6.0 mm or less.

[0086] The hot-rolled steel sheet according to the present embodiment having the chemical composition and the microstructure described above may be provided with a plating layer on the surface thereof for the purpose of improving corrosion resistance and the like to be made into a surface-treated steel sheet. The plating layer may be an electroplating layer or a hot-dip plating layer. Electroplating, electro-Zn-Ni alloy plating, and the like are exemplary examples as the electroplating layer. Hot-dip galvanizing, hot-dip galvannealing, hot-dip aluminizing, hot-dip Zn-Al alloy plating, hot-dip Zn-Al-Mg alloy plating, hot-dip Zn-Al-Mg-Si alloy plating, and the like are exemplary examples as the hot-dip plating layer. The plating adhesion amount is not particularly limited and may be the same as the related art. In addition, it is also possible to further increase corrosion resistance by performing appropriate chemical conversion treatment (for example, the application and drying of silicate-based chromium-free chemical conversion liquid) after plating.

[0087] Since the hot-rolled steel sheet according to the present embodiment has the chemical composition and the microstructure regardless of a manufacturing method, the effects are obtained. However, according to a manufacturing method to be described below, the hot-rolled steel sheet according to the present embodiment is stably obtained.

Accordingly, the manufacturing method to be described below is preferable.

[0088] In a preferred method of manufacturing the hot-rolled steel sheet according to the present embodiment, bending is performed during the finish rolling of hot rolling. Accordingly, strain is applied to the surface layer region and ferritic transformation in the surface layer region is promoted. In a case where precipitation-strengthened ferrite is crystallized in the surface layer region and then cooled rapidly, martensite and bainite are generated in the inner region in addition to ferrite. For this reason, it is possible to reduce a hardness difference between the precipitation-strengthened surface layer region and the inner region which is not precipitation-strengthened and in which a low-temperature transformation structure is generated.

Hot rolling

[0089] The heating temperature of a slab greatly affects the relief of solutionization and element segregation. In a case where the heating temperature of a slab is set to 1100°C or higher, the insufficient relief of solutionization and element segregation can be suppressed. As a result, it is possible to suppress the deterioration of tensile properties and toughness of a product. Further, in a case where the heating temperature of a slab is set to 1350°C or lower, an effect of relieving solutionization and element segregation can be saturated. Accordingly, it is preferable that the heating temperature of a slab is set to 1100°C to 1350°C. The heating temperature of a slab is more preferably 1150°C to 1300°C.

[0090] The temperature of a slab and the temperature of a steel sheet in the present embodiment refer to the surface temperature of a slab and the surface temperature of a steel sheet.

[0091] In the finish rolling, rolling for causing a slab to continuously pass through a rolling stand for finish rolling a plurality of times is performed. In the finish rolling, it is preferable that the temperature (finishing temperature) of the hot-rolled steel sheet after a final pass is set to Ar_3 point or higher and a rolling reduction of the final pass is set to 12% to 45%.

[0092] The temperature of the hot-rolled steel sheet after the final pass is a lowest temperature in the finish rolling that is performed using a plurality of stands. In a case where an inlet sheet thickness before the final pass is denoted by t_0 and an outlet sheet thickness after the final pass is denoted by t_i , a rolling reduction after the final pass can be represented by $\{(t_0 - t_i)/t_0\} \times 100(\%)$. Further, the Ar_3 point is represented by Equation (1).

$$Ar_3 \text{ point} = 901 - 325 \times C + 33 \times Si - 92 \times Mn + 287 \times P + 40 \times \text{sol. Al} \dots (1)$$

[0093] Each element symbol in Equation (1) denotes the content (mass%) of each element. In a case where the element is not contained, the element symbol is substituted with 0.

[0094] In a case where the temperature (finishing temperature) of the hot-rolled steel sheet after the final pass of the finish rolling is set to Ar_3 point or higher, it is possible to suppress the generation of ferrite during the finish rolling. As a

result, a desired microstructure and desired properties can be obtained.

[0095] In a case where the rolling reduction of the final pass of the finish rolling is set to 12% or more, it is possible to promote recrystallization in the finish rolling and to preferably control the microstructures of the inner region and the surface layer region. As a result, excellent fatigue strength can be obtained. Further, in a case where the rolling reduction of the final pass is set to 45% or less, it is possible to suppress an increase in a load of the rolling stand and the deterioration of the shape of the hot-rolled steel sheet after the finish rolling. Accordingly, it is preferable that the rolling reduction of the final pass of the finish rolling is set to 12% to 45%. The rolling reduction of the final pass of the finish rolling is more preferably 15% to 45%.

[0096] It is preferable that bending is performed between the final pass of the finish rolling and a pass immediately before the final pass to apply strain of 0.002 to 0.020 to the surface layer region of the hot-rolled steel sheet (a region present from a surface of the hot-rolled steel sheet to a depth of 20 μm from the surface). In a case where strain during bending is set to 0.002 or more, a desired microstructure can be formed in the surface layer region. For this reason, it is preferable that strain during bending is set to 0.002 or more. Strain during bending is more preferably 0.003 or more or 0.004 or more.

[0097] Further, in a case where strain during bending is set to 0.020 or less, buckling is likely to occur during the finish rolling and the loss of manufacturing stability can be suppressed. Furthermore, in a case where strain during bending is set to 0.020 or less, it is possible to preferably control the microstructures of the surface layer region and the inner region. For this reason, it is preferable that strain during bending is set to 0.020 or less. Strain during bending is more preferably 0.015 or less or 0.010 or less.

[0098] Bending can be performed with a method, such as a method of pushing up the steel sheet from below between stands with a roller, and strain during bending can be controlled by the adjustment of a bending angle using the push-up distance of the roller or the diameter of the roller.

[0099] For example, in a case where bending is performed with a method of pushing up the steel sheet from below between stands with a roller, a strain amount during bending can be obtained from Equation (2).

$$\text{Strain amount} = 1.5 \times (\text{sheet thickness}) \times (\text{push-up distance}) / (\text{diameter of leading end of push-up device})^2 \quad (2)$$

[0100] It is preferable that an elapsed time from the end of the finish rolling to the start of cooling is set to 1.6 seconds or less. In a case where an elapsed time from the completion of the finish rolling to the start of cooling is set to 1.6 seconds or less, it is possible to suppress the recovery of the strain of bending and rolling and to preferably control the microstructure of the surface layer region.

[0101] After the completion of the finish rolling, it is preferable that, as primary cooling, the hot-rolled steel sheet is cooled to a temperature range of 600°C to 750°C at an average cooling rate of 40°C/sec or faster and is then air-cooled for 2 to 6 seconds. In general, a cooling rate during air cooling is 2 to 10°C/sec.

[0102] In a case where the stop temperature of cooling performed at an average cooling rate of 40°C/sec or faster is set in a temperature range of 600°C to 750°C and the hot-rolled steel sheet is then air-cooled, ferritic transformation can be promoted and a desired amount of ferrite can be obtained.

[0103] After the air cooling, it is preferable that, as secondary cooling, the hot-rolled steel sheet is cooled to a temperature range of 200°C or lower at an average cooling rate of 60°C/sec or faster and is then coiled in a coil shape. In a case where an average cooling rate to a temperature range of 200°C or lower is set to 60°C/sec or faster, martensitic transformation can be promoted and a desired amount of martensite and bainite can be obtained.

[0104] The average cooling rate is defined as a value obtained in a case where a temperature drop width of the steel sheet from the start of cooling to the end of the cooling is divided by a time required from the start of the cooling to the end of the cooling.

[0105] Examples of cooling equipment include equipment having no air-cooling section and equipment having at least one air-cooling section. In the present embodiment, any cooling equipment may be used. Even in a case where cooling equipment having an air-cooling section is used, an average cooling rate from the start of cooling to the end of cooling may be in the above-mentioned range.

[0106] Since the hot-rolled steel sheet is coiled immediately after the secondary cooling, a coiling temperature is substantially equal to the cooling stop temperature of the secondary cooling. In a case where the coiling temperature is set to 200°C or lower, the generation of a large amount of polygonal ferrite or bainite can be suppressed. As a result, a desired microstructure and desired properties can be obtained.

[0107] After the coiling, temper rolling may be performed on the hot-rolled steel sheet according to a usual method or pickling may be performed on the hot-rolled steel sheet to remove scale formed on the surface of the hot-rolled steel sheet. Alternatively, plating, such as hot-dip galvanizing or electrogalvanizing described above, may be formed and chemical conversion treatment may be further performed.

[0108] According to the above-mentioned manufacturing method, a hot-rolled steel sheet having the above-mentioned microstructure can be stably manufactured. For this reason, a hot-rolled steel sheet that has high strength and excellent fatigue strength and toughness can be stably manufactured.

5 [Examples]

[0109] Next, the effect of one aspect of the present invention will be more specifically described using examples. However, conditions in the examples are simply examples of the conditions employed to confirm the feasibility and effects of the present invention, and the present invention is not limited to these examples of the conditions. The present invention may employ various conditions to achieve the object of the present invention without departing from the scope of the present invention.

[0110] Steels having chemical compositions shown in Table 1 were melted, and slabs having a thickness of 240 to 300 mm were manufactured using continuous casting. Hot-rolled steel sheets shown in Tables 4 and 5 were obtained using the obtained slabs under manufacturing conditions shown in Tables 2 and 3.

[0111] The steel sheet was pushed up from below between stands with a roller to perform bending. A strain amount during bending was controlled by the adjustment of a bending angle using the push-up distance of the roller or the diameter of the roller. In this case, a strain amount during bending was obtained from Equation (2).

[0112] For the obtained hot-rolled steel sheets, area fractions and Vickers hardnesses of microstructures of an inner region and a surface layer region, a tensile strength, total elongation, absorbed energy at a temperature of -20°C, and a fatigue limit ratio were obtained by the above-mentioned method. Obtained measurement results are shown in Tables 4 and 5.

Method of evaluating properties of hot-rolled steel sheet

[0113] In a case where a tensile strength TS was 980 MPa or more, a hot-rolled steel sheet was considered to be excellent in strength and determined to be acceptable. On the other hand, in a case where the tensile strength TS was less than 980 MPa, a hot-rolled steel sheet was not considered to be excellent in strength and determined to be unacceptable.

[0114] In a case where total elongation was 10% or more, a hot-rolled steel sheet was considered to be excellent in ductility and determined to be acceptable. On the other hand, in a case where total elongation was less than 10%, a hot-rolled steel sheet was not considered to be excellent in ductility and determined to be unacceptable.

[0115] In a case where absorbed energy at a temperature of -20°C was 80 J/cm² or more, a hot-rolled steel sheet was considered to be excellent in toughness and determined to be acceptable. On the other hand, in a case where absorbed energy at a temperature of -20°C was less than 80 J/cm², a hot-rolled steel sheet was not considered to be excellent in toughness and determined to be unacceptable.

[0116] In a case where a fatigue limit ratio was 0.48 or more, a hot-rolled steel sheet was considered to be excellent in fatigue strength and determined to be acceptable. On the other hand, in a case where a fatigue limit ratio was less than 0.48, a hot-rolled steel sheet was not considered to be excellent in fatigue strength and determined to be unacceptable.

[Table 1]

Steel type	Chemical composition (mass%) Remainder: Fe and impurities																	Ars	Note
	C	Si	Mn	sol. Al	Ti	P	S	N	Nb	Ca	Mo	Cr	V	Ni	Cu	B	Sn	(°C)	
A	0.10	1.10	1.4	0.17	0.09	0.0150	0.0033	0.0036	-	-	-	-	-	-	-	-	-	792	Steel of present invention
B	0.06	0.22	1.1	0.18	0.10	0.0126	0.0038	0.0040	-	0.0011	-	-	-	-	-	-	-	798	Steel of present invention
C	0.07	0.33	1.1	0.20	0.06	0.0126	0.0033	0.0030	-	0.0008	0.35	-	-	-	-	-	-	803	Steel of present invention
D	0.14	1.43	1.5	0.29	0.13	0.0135	0.0010	0.0040	0.015	-	-	-	-	-	-	-	-	775	Steel of present invention
E	0.15	0.12	1.8	0.25	0.10	0.0135	0.0014	0.0033	-	-	0.20	-	-	-	-	-	-	704	Steel of present invention
F	0.08	0.72	1.2	0.30	0.07	0.0154	0.0030	0.0044	0.035	-	-	0.30	-	-	-	-	-	805	Steel of present invention
G	0.04	0.30	2.2	0.44	0.14	0.0130	0.0066	0.0030	-	0.0018	-	-	-	-	-	-	-	717	Steel of present invention
H	0.12	1.00	0.6	<u>0.06</u>	0.10	0.0135	0.0055	0.0036	-	-	-	-	-	-	-	-	-	846	Comparative steel
I	0.20	0.44	2.0	0.34	<u>0.04</u>	0.0150	0.0027	0.0036	-	0.0021	0.05	-	-	-	-	-	-	685	Comparative steel
J	0.28	1.20	2.5	0.35	0.11	0.0135	0.0033	0.0044	-	-	0.10	-	0.10	0.04	-	-	-	637	Steel of present invention
K	0.26	1.50	1.8	0.25	0.12	0.0154	0.0010	0.0030	-	-	-	-	-	0.10	0.20	0.0001	-	715	Steel of present invention
L	0.18	1.80	2.8	0.55	0.17	0.0130	0.0014	0.0033	-	-	0.02	0.10	0.15	0.05	0.10	-	0.01	670	Steel of present invention
M	0.18	1.76	2.2	0.22	-	0.0130	0.0016	0.0036	-	-	0.06	-	-	-	-	0.0018	-	712	Comparative steel
N	0.18	<u>2.01</u>	2.0	<u>0.03</u>	<u>0.01</u>	0.0130	0.0009	0.0041	-	-	-	-	-	-	-	-	-	733	Comparative steel

An underline represents that a condition is out of the range of the present invention.

[Table 2]

Test No.	Steel type	Heating temperature	Finishing temperature	Rolling reduction of final pass	Strain during bending	Cooling start time	Primary cooling		Air-cooling time	Secondary cooling		Coiling temperature	Sheet thickness	Note
		°C	°C	%	-	Sec.	Cooling stop temperature	Average cooling rate	Sec.	Cooling stop temperature	Average cooling rate	°C	mm	
1	A	1200	962	24	0.008	1.3	639	222	6	100	220	100	1.6	Example of present invention
2	A	1200	1019	20	<u>0.040</u>	1.0	747	72	4	100	266	100	2.3	Comparative Example
3	A	1200	991	33	0.014	1.1	662	222	6	100	179	100	2.3	Example of present invention
4	A	1200	967	25	0.013	0.4	656	80	6	100	295	100	2.3	Example of present invention
5	A	1200	936	16	<u>0.001</u>	0.7	736	226	2	100	322	100	2.6	Comparative Example
6	B	1200	981	32	0.016	0.7	718	169	3	100	390	100	2.6	Example of present invention
7	B	1200	1017	21	0.010	1.0	710	220	6	100	154	100	1.6	Example of present invention
8	B	1200	992	29	0.016	0.7	<u>554</u>	103	3	100	390	100	2.9	Comparative Example
9	B	1200	943	19	0.013	1.2	634	151	2	100	357	100	2.9	Example of present invention
10	C	1200	940	28	0.006	0.4	715	185	2	100	374	100	2.9	Example of present invention
11	C	1200	948	29	0.014	1.1	720	79	5	100	93	100	2.0	Example of present invention
12	C	1200	966	26	0.004	0.1	622	<u>20</u>	6	100	128	100	3.2	Comparative Example
13	C	1250	978	32	0.012	0.9	664	99	2	100	91	100	3.2	Example of present invention
14	C	1250	1020	35	0.016	0.4	680	218	5	100	138	100	2.6	Example of present invention
15	D	1250	973	31	0.008	0.4	707	210	2	100	142	100	4.5	Example of present invention
16	D	1250	1006	15	0.002	0.5	<u>780</u>	131	4	100	434	100	3.9	Comparative Example
17	D	1250	918	39	0.011	1.1	650	204	6	100	371	100	3.9	Example of present invention
18	D	1250	920	33	0.017	1.2	745	97	5	100	234	100	2.3	Example of present invention
19	E	1200	966	37	0.004	1.1	625	109	4	100	88	100	2.3	Example of present invention
20	E	1200	1013	17	0.006	1.1	657	85	<u>1</u>	100	303	100	2.3	Comparative Example

An underline represents that a manufacturing condition is not preferable.

[Table 3]

Test No.	Steel type	Heating temperature	Finishing temperature	Rolling reduction of final pass	Strain during bending	Cooling start time	Primary cooling		Air-cooling time	Secondary cooling		Coiling temperature	Sheet thickness	Note
		°C	°C	%	-	Sec.	Cooling stop temperature	Average cooling rate		Cooling stop temperature	Average cooling rate			
21	E	1200	920	39	0.014	1.6	654	62	2	100	389	100	2.9	Example of present invention
22	E	1200	973	23	0.010	0.8	725	50	<u>12</u>	100	288	100	2.9	Comparative Example
23	F	1200	956	33	0.005	0.5	748	77	3	100	262	100	2.9	Example of present invention
24	F	1200	956	22	0.018	0.8	719	63	3	<u>530</u>	243	<u>500</u>	2.6	Comparative Example
25	F	1200	964	33	0.006	1.3	651	130	2	100	193	100	2.6	Example of present invention
26	F	1200	927	31	0.006	0.6	733	153	6	100	130	100	1.6	Example of present invention
27	G	1250	1000	33	0.006	<u>2.4</u>	666	114	4	100	403	100	2.0	Comparative Example
28	G	1250	987	24	0.018	1.2	695	120	2	100	419	100	1.8	Example of present invention
29	G	1250	954	39	0.007	1.1	731	154	6	100	211	100	1.8	Example of present invention
30	G	1250	912	20	0.002	1.6	668	84	4	100	109	100	2.0	Example of present invention
31	G	1250	1004	<u>7</u>	0.004	1.5	725	205	5	100	247	100	1.6	Comparative Example
32	G	1200	1020	27	0.017	1.4	701	91	6	100	196	100	1.6	Example of present invention
<u>33</u>	<u>H</u>	1200	1020	25	0.004	0.6	740	145	6	100	295	100	3.6	Comparative Example
<u>34</u>	<u>I</u>	1230	968	33	0.008	0.5	709	57	4	100	93	100	3.6	Comparative Example
35	J	1200	964	28	0.006	0.4	715	130	2	100	374	100	2.6	Example of present invention
36	K	1200	941	32	0.006	1.3	731	185	3	100	193	100	2.6	Example of present invention
37	L	1250	954	38	0.007	1.2	651	154	6	100	211	100	1.8	Example of present invention
<u>38</u>	<u>M</u>	1250	918	39	0.011	1.1	666	114	4	100	403	100	3.9	Comparative Example
<u>39</u>	<u>N</u>	1200	900	20	0.006	1.3	695	120	5	100	419	100	2.6	Comparative Example
40	K	1250	954	39	<u>0.024</u>	1.5	725	205	5	100	247	100	1.8	Comparative Example
41	L	1200	941	32	0.006	1.3	651	130	2	100	193	<u>250</u>	2.0	Comparative Example

An underline represents that a manufacturing condition is not preferable.

[Table 4]

Test No.	Steel type	Inner region			Surface layer region				Hardness difference ratio	Tensile strength	Total elongation	Absorbed energy (-20°C)	Fatigue limit ratio	Note
		Ferrite α_c	Martensite + bainite β_c	Remainder	Ferrite α_s	Remainder	α_s/α_c	β_s/β_c						
		Area%	Area%	Area%	Area%	Area%	-	-	-	MPa	%	J/cm ²	-	
1	A	22	78	0	31	69	1.40	0.89	0.14	1018	16	158	0.50	Example of present invention
2	A	32	43	<u>25</u>	95	5	<u>2.97</u>	0.12	<u>0.32</u>	1148	16	<u>65</u>	0.59	Comparative Example
3	A	33	67	0	46	54	1.40	0.80	0.12	1003	15	115	0.59	Example of present invention
4	A	33	67	0	46	54	1.40	0.80	0.16	1209	16	217	0.54	Example of present invention
5	A	25	75	0	24	76	<u>0.96</u>	1.01	0.15	1116	18	83	<u>0.41</u>	Comparative Example
6	B	40	60	0	56	44	1.40	0.73	0.17	1162	19	171	0.55	Example of present invention
7	B	44	56	0	62	38	1.40	0.69	0.02	1034	14	93	0.58	Example of present invention
8	B	<u>12</u>	77	<u>11</u>	32	68	<u>2.68</u>	0.77	0.09	1187	11	99	<u>0.35</u>	Comparative Example
9	B	35	65	0	49	51	1.40	0.78	0.09	1100	13	127	0.55	Example of present invention
10	C	26	74	0	36	64	1.40	0.86	0.02	997	14	90	0.50	Example of present invention
11	C	36	64	0	64	36	1.78	0.56	0.15	1072	13	226	0.56	Example of present invention
12	C	<u>15</u>	80	<u>5</u>	50	50	<u>3.33</u>	0.54	0.11	1147	12	162	<u>0.42</u>	Comparative Example
13	C	28	72	0	52	48	1.86	0.67	0.09	1127	15	219	0.52	Example of present invention
14	C	28	72	0	52	48	1.86	0.67	0.05	1188	14	183	0.48	Example of present invention
15	D	53	47	0	75	25	1.42	0.53	0.06	987	13	202	0.55	Example of present invention
16	D	<u>18</u>	68	<u>14</u>	68	32	<u>3.78</u>	0.22	0.12	1137	12	145	<u>0.39</u>	Comparative Example
17	D	37	63	0	63	37	1.70	0.59	0.06	1054	17	160	0.60	Example of present invention
18	D	33	67	0	67	33	2.03	0.49	0.06	1007	16	158	0.49	Example of present invention
19	E	46	54	0	54	46	1.17	0.85	0.12	1079	11	163	0.57	Example of present invention
20	E	<u>18</u>	60	<u>22</u>	60	40	<u>3.33</u>	0.37	0.18	1093	11	206	<u>0.46</u>	Comparative Example

An underline means that a condition is out of the range of the present invention or a property is not preferable.

[Table 5]

Test No.	Steel type	Inner region			Surface layer region				Hardness difference ratio	Tensile strength	Total elongation	Absorbed energy (-20°C)	Fatigue limit ratio	Note
		Ferrite α_c	Martensite + bainite β_c	Remainder	Ferrite α_s	Remainder	α_s/α_c	β_s/β_c						
		Area %	Area%	Area%	Area%	Area%	-	-	-	MPa	%	J/cm ²	-	
21	E	47	53	0	62	38	1.32	0.72	0.09	996	15	211	0.57	Example of present invention
22	E	<u>70</u>	<u>25</u>	<u>5</u>	72	28	<u>1.03</u>	0.92	0.07	1157	15	<u>65</u>	<u>0.45</u>	Comparative Example
23	F	45	55	0	55	45	1.22	0.82	0.09	1189	15	141	0.50	Example of present invention
24	F	25	55	<u>20</u>	75	25	<u>3.00</u>	0.45	0.03	<u>850</u>	18	<u>75</u>	0.60	Comparative Example
25	F	40	60	0	60	40	1.50	0.67	0.04	1159	13	91	0.52	Example of present invention
26	F	30	70	0	70	30	2.33	0.43	0.13	1070	12	232	0.59	Example of present invention
27	G	25	75	0	28	72	<u>1.12</u>	0.96	0.07	1133	18	126	<u>0.42</u>	Comparative Example
28	G	34	66	0	66	34	1.94	0.52	0.06	1011	14	184	0.49	Example of present invention
29	G	33	67	0	67	33	2.03	0.49	0.09	1159	17	226	0.58	Example of present invention
30	G	51	49	0	73	27	1.43	0.55	0.10	1121	15	158	0.58	Example of present invention
31	G	<u>15</u>	61	<u>24</u>	16	84	<u>1.07</u>	0.98	0.03	1153	18	122	<u>0.42</u>	Comparative Example
32	G	24	76	0	52	48	2.17	0.32	0.04	1163	12	187	0.56	Example of present invention
33	H	<u>15</u>	72	<u>13</u>	20	80	1.33	0.80	0.07	1206	15	124	<u>0.40</u>	Comparative Example
34	I	<u>75</u>	<u>17</u>	<u>8</u>	76	24	<u>1.01</u>	0.61	0.17	1034	15	<u>72</u>	<u>0.41</u>	Comparative Example
35	J	33	67	0	60	40	1.82	0.60	0.09	1159	13	158	0.52	Example of present invention
36	K	28	72	0	65	35	2.32	0.49	0.08	1012	14	191	0.50	Example of present invention
37	L	39	61	0	67	33	1.72	0.54	0.03	1189	16	214	0.57	Example of present invention
38	M	34	66	0	66	34	1.94	0.52	<u>0.25</u>	997	14	90	<u>0.42</u>	Comparative Example
39	N	33	67	0	67	33	2.03	0.49	<u>0.22</u>	1072	13	226	<u>0.46</u>	Comparative Example
40	K	52	42	<u>6</u>	91	9	1.75	0.21	0.06	987	13	<u>57</u>	0.56	Comparative Example
41	L	45	55	0	84	16	1.87	0.29	0.18	<u>875</u>	13	<u>62</u>	<u>0.46</u>	Comparative Example

An underline means that a condition is out of the range of the present invention or a property is not preferable.

[0117] From Tables 4 and 5, it is found that hot-rolled steel sheets according to examples of the present invention have high strength and excellent toughness, fatigue strength, and ductility.

[0118] On the other hand, it is found that hot-rolled steel sheets according to comparative examples are inferior in any one or more of strength, toughness, and fatigue strength.

[Industrial Applicability]

[0119] According to the aspect of the present invention, it is possible to provide a hot-rolled steel sheet that has high strength and excellent fatigue strength, toughness, and ductility. According to this hot-rolled steel sheet, since it is possible to reduce the weight of a vehicle body of a vehicle or the like, to integrally form components, to shorten a working step, and the like, to improve fuel efficiency, and to reduce manufacturing costs, the industrial value of the hot-rolled steel sheet is high.

Claims

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

C: 0.02% to 0.30%;
 Si: 0.10% to 2.00%;
 Mn: 0.5% to 3.0%;
 sol. Al: 0.10% to 1.00%;
 Ti: 0.06% to 0.20%;
 P: 0.1000% or less;
 S: 0.0100% or less;
 N: 0.0100% or less;
 Nb: 0% to 0.100%;
 Ca: 0% to 0.0060%;
 Mo: 0% to 0.50%;
 Cr: 0% to 1.00%;
 V: 0% to 0.40%;
 Ni: 0% to 0.40%;
 Cu: 0% to 0.40%;
 B: 0% to 0.0020%; and
 Sn: 0% to 0.20%,

with a remainder of Fe and impurities,

a microstructure of an inner region includes 40% to 80% of one or two of martensite and bainite in total and 20% to 60% of ferrite by area ratio, and an area ratio of a remainder in microstructure is less than 5%,

α_s/α_c , which is a ratio of a ferrite area ratio α_s of a surface layer region to a ferrite area ratio α_c of the inner region, is in a range of 1.15 to 2.50,

$(1 - H_{vs}/H_{vc})$, which is a hardness difference ratio between a Vickers hardness H_{vs} of the surface layer region and a Vickers hardness H_{vc} of the inner region, is 0.20 or less, and

a tensile strength is 980 MPa or more.

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

wherein the chemical composition comprises, by mass%, one or two or more selected from the group consisting of

Nb: 0.010% to 0.100%,
 Ca: 0.0005% to 0.0060%,
 Mo: 0.02% to 0.50%,
 Cr: 0.02% to 1.00%,
 V: 0.01% to 0.40%,
 Ni: 0.01% to 0.40%,
 Cu: 0.01% to 0.40%,
 B: 0.0001% to 0.0020%, and
 Sn: 0.01% to 0.20%.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/032729

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 S

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)

C21D8/02; C21D9/46; C22C38/00-C22C38/60

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2021
 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 2020/196326 A1 (NIPPON STEEL CORP) 01 October 2020 (2020-10-01) entire text, all drawings	1-2
A	JP 2016-50335 A (NIPPON STEEL & SUMITOMO METAL CORP) 11 April 2016 (2016-04-11) entire text	1-2
A	JP 2015-124410 A (NIPPON STEEL & SUMITOMO METAL CORP) 06 July 2015 (2015-07-06) entire text	1-2
A	WO 2021/124203 A1 (ARCELORMITTAL) 24 June 2021 (2021-06-24) entire text	1-2

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

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Date of the actual completion of the international search

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Patent documents cited in the description

- WO 2014171057 A [0007]
- JP 2001279378 A [0007]
- WO 2018151331 A [0007]
- JP 2017186634 A [0007]