

DESCRIPTION

HOT-ROLLED STEEL SHEET AND METHOD FOR PRODUCING SAME

Technical Field

[0001]

The present invention relates to a hot-rolled steel sheet having an oxide scale on a surface thereof, and a method for producing the hot-rolled steel sheet, the hot-rolled steel sheet being used for automobiles, home appliances, building materials, and other applications. More particularly, the present invention relates to a hot-rolled steel sheet that exhibits excellent blackness and scale adhesion suitable as a material for building materials, truck frames, Chinese woks, and other products, and that has small variations in blackness and scale adhesion in the width direction of the steel sheet, and a method for producing the hot-rolled steel sheet.

Background Art

[0002]

Hot-rolled steel sheets are usually hot-rolled at high temperatures in an oxidizing atmosphere, and therefore scale (iron oxides) is unavoidably formed on surfaces thereof. When hot-rolled steel sheets with scale remaining adhered thereto (hereinafter referred to as mill scale hot-rolled steel sheets) are subjected to processing operations

including skin-pass rolling, bending, press forming, and laser cutting, portions of the scale peel off. As a result, processing defects, contamination of processing lines, surface defects in processed products, and other defects occur. To avoid this issue, hot-rolled steel sheets having excellent scale adhesion on steel sheet surfaces have been desired, and demand for such steel sheets has been increasing.

[0003]

In certain regions, such as Southeast Asia, where black color is culturally preferred, a beautiful black color provides additional value to products including building materials. For this reason, demand for mill scale hot-rolled steel sheets having high blackness has been increasing.

[0004]

When a steel sheet has variations in scale adhesion or blackness in the width direction thereof and includes portions having inferior adhesion or blackness, it is necessary to remove such portions before use. In particular, in coils of mill scale hot-rolled steel sheets, whitening of the scale and deterioration of scale adhesion tend to occur at edge portions. Accordingly, there has been a strong demand for hot-rolled steel sheets having excellent uniformity in scale adhesion and blackness in the width

direction of the coils in order to improve yield.

[0005]

In the related art, various proposals have been made to improve scale adhesion. For example, Patent Literature 1 discloses a hot-rolled steel sheet having excellent scale adhesion, the hot-rolled steel sheet being produced by subjecting a steel material having a composition containing, in mass%, C: 0.01% to 0.3%, Si: 0.20% or less, Mn: 0.01% to 2.0%, P: 0.10% or less, S: 0.10% or less, Al: 0.10% or less, and Cr: 0.01% to 2.0%, with the balance being Fe and unavoidable impurities, to: rough rolling; descaling; finish rolling satisfying formula (1) below at a finish rolling delivery temperature of 800°C to 950°C; cooling at an average cooling rate of 3 °C/s or more and 80 °C/s or less from finish rolling to start of coiling; and then coiling at a coiling temperature of 430°C to 580°C. The hot-rolled steel sheet has, from a steel substrate side, a magnetite layer and magnetite grains and/or a eutectoid transformation microstructure containing iron and magnetite on the magnetite layer, wherein an average grain size of the magnetite grains and/or an average block size of the eutectoid transformation microstructure is 3 μm or more and 8 μm or less, and a mass fraction of wustite contained in the scale layer is 10% or less.

$$|T_2 - T_1| \leq 50^\circ\text{C}, \text{ and } |T_3 - T_2| \leq 50^\circ\text{C} \cdots (1)$$

In formula (1),

T₁: the temperature (°C) of the steel sheet at a central portion in the width direction at a position 30 m from a leading end in the longitudinal direction after finish rolling,

T₂: the temperature (°C) of the steel sheet at a central portion in the width direction at the center in the longitudinal direction after finish rolling, and

T₃: the temperature (°C) of the steel sheet at a central portion in the width direction at a position 30 m from a trailing end in the longitudinal direction after finish rolling.

[0006]

Patent Literature 2 discloses a method in which a slab containing, in mass%, C: 0.02% to 0.20%, Mn: 0.1% to 2.0%, Si: 0.3% or less, P: 0.03% or less, S: 0.03% or less, Ni: 0.03% to 0.3%, Cu: 0.04% to 0.5%, and Cr: 0.03% to 0.3%, with the balance being Fe and unavoidable impurities, is heated to 1100°C or higher, then hot-rolled in a temperature range of 800°C to 950°C, and coiled at 400°C to 650°C. This method provides a hot-rolled steel sheet having excellent tight scale adhesion, wherein the number of unevenness heights of 0.5 μm or more per inch of length is 300 or more as an index of surface roughness at the interface between the scale on the steel sheet surface and the steel substrate

of the steel sheet.

[0007]

Patent Literature 3 discloses a hot-rolled steel sheet having excellent scale adhesion, the hot-rolled steel sheet having a scale, wherein the scale at a portion within 30 mm from the end surface of a coil has: at the interface between a steel substrate and the scale, a magnetite layer in contact with the steel substrate at an area fraction of 90% or more; a eutectoid microstructure layer containing iron and magnetite on the magnetite layer in contact with the steel substrate; a magnetite layer on the eutectoid microstructure layer containing iron and magnetite; and a hematite layer on the magnetite layer, wherein a total thickness of the hematite layer and the magnetite layer on the eutectoid microstructure layer containing iron and magnetite is 30% or less of a total thickness of the scale, and a difference between a thickness of the scale at a position 30 mm from the end surface of the coil and a thickness of the scale at the center of the coil is 2 μm or less.

[0008]

Patent Literature 4 discloses a mill scale hot-rolled steel sheet excellent in high blackness, the mill scale hot-rolled steel sheet having scale with a thickness of more than 4 μm on a surface of a hot-rolled steel sheet having a

chemical composition containing C: 0.001 to 0.20 mass%, Si: 0.001 to 0.50 mass%, Mn: 0.05 to 2.0 mass%, P: 0.05 mass% or less, S: 0.05 mass% or less, and sol. Al: 0.01 to 0.10 mass%, with the balance being Fe and unavoidable impurities, characterized in that the scale has a composition containing Fe_3O_4 at a volume ratio of 50% or more, and a region extending at least to a depth of 2 μm in the thickness direction from the surface of the scale contains no precipitated Fe.

[0009]

Patent Literature 5 discloses a mill scale hot-rolled steel sheet including a base hot-rolled steel sheet and scale on the surface of the base hot-rolled steel sheet, wherein the scale contains Fe_3O_4 and Fe and has a thickness of 3.0 to 20 μm . The average grain size in a surface layer of the scale is 3.0 μm or less, and the Fe area fraction in the cross-section of the scale is less than 1.0% in a region of 0 to 1.0 μm in the thickness direction of the scale from the outermost layer of the scale. The Fe area fraction is 1.0% or more in a region of 0 to 1.0 μm in the thickness direction of the scale from the interface between the scale and the base hot-rolled steel sheet.

Citation List

Patent Literature

[0010]

PTL 1: Japanese Unexamined Patent Application
Publication No. 2019-183267

PTL 2: Japanese Unexamined Patent Application
Publication No. 2004-027312

PTL 3: Japanese Unexamined Patent Application
Publication No. 2012-148286

PTL 4: Japanese Unexamined Patent Application
Publication No. 2004-043888

PTL 5: International Publication No. WO 2018-186265

Summary of Invention

Technical Problem

[0011]

In the technique described in Patent Literature 1, a steel material having a predetermined chemical composition is used, and the finish rolling delivery temperature during hot rolling, the cooling rate after rolling, and the coiling temperature are controlled. Accordingly, the average grain size of magnetite grains and/or the average block size of the eutectoid transformation microstructure containing iron and magnetite on the magnetite layer on the steel substrate side in the scale layer is optimized. Furthermore, the temperature of the steel sheet in the longitudinal direction immediately after finish rolling is controlled to improve uniform scale adhesion in the longitudinal direction. However, no method for uniformly improving scale adhesion in

the width direction is mentioned. In addition, no method for enhancing scale blackness is mentioned.

[0012]

In the technique described in Patent Literature 2, a hot-rolled steel sheet having excellent tight scale adhesion is produced by hot-rolling a steel containing predetermined amounts of Ni, Cu, and Cr and controlling the surface roughness at the interface between the scale on the steel sheet surface and the steel substrate of the steel sheet within a predetermined range. However, no method for enhancing scale blackness is mentioned. Furthermore, no method for uniformly improving scale adhesion and blackness in the width direction is mentioned.

[0013]

The technique described in Patent Literature 3 discloses a method for producing a hot-rolled steel sheet by hot-rolling a steel material and coiling the resulting steel sheet into a coil shape. The rough-rolled steel sheet is finish-rolled at 850°C to 1050°C, and then the finish-rolled hot-rolled steel sheet is coiled into a coil shape at a coiling temperature of 500°C to 650°C, while both end surfaces of the hot-rolled steel sheet are cooled so that the temperature at the end surfaces decreases to 480°C or lower within 5 minutes from start of coiling. Thereafter, the temperature at the end surfaces is maintained at 480°C

or lower, and the steel sheet is subsequently gradually cooled, while being maintained in a coil shape, from a time point at which the temperature at the end surfaces is 400°C to 480°C. This process achieves excellent scale adhesion in the width direction of the hot-rolled coil, particularly at the edge portions. However, no method for uniformly enhancing blackness of the hot-rolled coil in the width direction is mentioned.

[0014]

In the techniques described in Patent Literature 4 and Patent Literature 5, hot-rolled steel sheets having excellent blackness and scale adhesion are proposed; however, uniform scale adhesion and blackness in the width direction of the hot-rolled coils are not always obtained. In particular, at the edge portions of the coils, there is a problem of whitening of the scale and deterioration of scale adhesion.

[0015]

An object of the present invention is to solve the above-described problems and to provide a hot-rolled steel sheet having excellent uniformity in scale adhesion and blackness in the width direction of the hot-rolled steel sheet, and a method for producing the hot-rolled steel sheet.

Solution to Problem

[0016]

The inventors of the present invention have first investigated the causes of the failure to obtain excellent uniformity in scale adhesion and blackness in the width direction in hot-rolled steel sheets known in the related art. During hot rolling, scale is formed in the order of hematite (Fe_2O_3), magnetite (Fe_3O_4), and wustite (FeO) from the scale surface side at high temperatures. Among these oxides, wustite undergoes eutectoid transformation during cooling after coiling to form a eutectoid transformation microstructure containing magnetite and precipitated Fe ($4\text{FeO} \rightarrow \text{Fe}_3\text{O}_4 + \text{Fe}$). The eutectoid transformation microstructure containing magnetite and precipitated Fe contributes to improvement in scale adhesion because the eutectoid transformation microstructure has high coherency with the surrounding magnetite grains and the surrounding steel substrate. Magnetite is an iron-based oxide having a black color and therefore contributes to blackening of the surface of a mill scale hot-rolled steel sheet. However, the inventors of the present invention have found that precipitated Fe formed along with the eutectoid transformation and hematite formed on the scale surface at high temperatures during hot rolling are factors that inhibit blackening of the surface.

[0017]

In the related art, scale adhesion and blackness have tended to deteriorate particularly at the edge portions in the width direction. It has been found that the decrease in adhesion at the edge portions is attributable to the following factors. Specifically, the decrease in adhesion is attributable to reoxidation caused by air penetrating from the edges after coiling, which excessively increases the amount of hematite on the scale surface and the amount of a magnetite layer containing columnar magnetite grains, decreases the proportion of a eutectoid transformation microstructure, and increases scale thickness at the edge portions. The inventors of the present invention have further found that the decrease in blackness at the edge portions is attributable to an excessive increase in the amount of hematite formed on the scale surface.

[0018]

In the related art, after the steel sheet is coiled into a hot-rolled coil, central portions of the steel sheet in the width direction may come into close contact with each other and be shielded from an oxidizing atmosphere, whereby hematite and magnetite on the scale surface may be reduced to wustite, and eutectoid transformation may also proceed at the scale surface. In this case, scale adhesion is improved; however, there is a problem in that blackness deteriorates because the amount of precipitated Fe on the

scale surface increases.

[0019]

Furthermore, under ordinary production conditions, transformation expansion after coiling occurs non-uniformly in the longitudinal direction of the coil. This induces loosening of the hot-rolled coil and causes air to penetrate even into a central portion in the width direction, whereby reoxidation proceeds, the amount of the eutectoid transformation microstructure decreases, and the amount of hematite increases. As a result, there are cases in which adhesion and blackness deteriorate, as has been found.

[0020]

Accordingly, the inventors of the present invention have intensively studied means for solving the above-described problems to obtain a hot-rolled steel sheet having excellent uniformity in scale adhesion and blackness in the width direction of a coil. As a result, the following findings have been obtained.

[0021]

(i) A steel material having a predetermined chemical composition is descaled after hot rough rolling, finish-rolled at a finish rolling delivery temperature of 800°C to 950°C, and then cooled to a coiling temperature at a predetermined cooling rate. This process appropriately controls scale thickness and suppresses formation of cracks

in the scale that cause a decrease in adhesion. This process also sufficiently forms magnetite grains in a surface layer that contribute to blackening of the surface. [0022]

(ii) Coiling is performed at a coiling temperature of 450°C or higher and 600°C or lower to appropriately control the amount of a eutectoid transformation microstructure that contributes to improvement in adhesion and suppresses formation of precipitated Fe on a steel sheet surface that causes whitening. After start of coiling, the entire coil is cooled such that the temperature of the edge portions of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling stop temperature of 300°C or higher and 430°C or lower. This process decreases the temperature of the edge portions of the coil, increases coil rigidity, and prevents coil loosening. The edge portions of the coil refer to regions within 200 mm from the edges of the coil in the width direction. As a result, at a central portion in the width direction, shielding from an oxidizing atmosphere suppresses hematite formation caused by reoxidation and suppresses deterioration of adhesion and whitening. In the edge portions of the coil in the width direction, complete shielding from an oxidizing atmosphere is difficult; however, cooling of the edge portions suppresses

reoxidation, and recuperation from the central portion in the width direction promotes eutectoid transformation, thereby ensuring excellent adhesion and blackness.

[0023]

The present invention is based on the above findings and specifically provides the following.

[1] A hot-rolled steel sheet having: a chemical composition containing, in mass%, C: 0.01% to 0.30%, Si: 0.50% or less, Mn: 0.01% to 2.0%, P: 0.10% or less, S: 0.10% or less, sol. Al: 0.10% or less, and N: 0.015% or less, with the balance being Fe and unavoidable impurities; and a scale on a surface of the steel sheet, wherein the scale in a width direction of the steel sheet has a microstructure containing, in terms of area fraction, magnetite grains: 30% or more, a eutectoid transformation microstructure containing iron and magnetite: 20% or more and 60% or less, wherein magnetite includes the magnetite grains and the magnetite contained in the eutectoid transformation microstructure, and wustite: 20% or less, and, in terms of mass fraction, hematite: 5% or less, an area fraction of precipitated Fe on a surface of the scale is 15% or less, and an average thickness of the scale in the width direction of the steel sheet is 3 μm or more and 20 μm or less.

[2] The hot-rolled steel sheet according to [1], wherein the chemical composition further contains, in mass%, at least

one selected from Cu: 1.0% or less, Ni: 0.50% or less, and Cr: 2.0% or less.

[3] The hot-rolled steel sheet according to [1] or [2], wherein the chemical composition further contains, in mass%, at least one selected from Mo: 1.0% or less, Nb: 0.1% or less, V: 0.1% or less, Ti: 0.03% or less, B: 0.01% or less, and Sb: 0.03% or less.

[4] A method for producing a hot-rolled steel sheet, the method including: subjecting a steel material having the chemical composition according to any one of [1] to [3] to: descaling after hot rough rolling; finish rolling at a finish rolling delivery temperature of 800°C or higher and 950°C or lower; cooling at an average cooling rate of 5 °C/s or higher in a temperature range from the finish rolling delivery temperature to 750°C; then cooling at an average cooling rate of 1 °C/s or higher and 30 °C/s or lower in a range from 750°C to a temperature at start of coiling; coiling at a coiling temperature of 450°C or higher and 600°C or lower; and after start of coiling, cooling such that an entire coil is cooled so that a temperature of an edge portion of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling stop temperature of 300°C or higher and 430°C or lower.

Advantageous Effects of Invention

[0024]

According to the present invention, a hot-rolled steel sheet having excellent scale adhesion and blackness can be easily and inexpensively produced, yielding remarkable industrial advantages. According to the present invention, variations in scale adhesion in the width direction of a coil can be reduced, which also produces advantageous effects that greatly contribute to improvement in the surface quality of products, prevention of processing defects in products, and improvement in the working environment.

[0025]

The hot-rolled steel sheet according to the present invention has a thickness of more than 2.0 mm and 25 mm or less, preferably more than 5.0 mm and 25 mm or less.

Description of Embodiments

[0026]

A hot-rolled steel sheet according to the present invention and a method for producing the hot-rolled steel sheet will be described below in detail. The present invention is not limited to the following embodiments. The embodiments described below include those that can be easily replaced by a person skilled in the art, or those that are substantially identical.

[0027]

The hot-rolled steel sheet of the present invention has a chemical composition described below. Unless otherwise specified, the unit "%" for the amount of each component in the chemical composition means "mass%."

[0028]

C: 0.01% to 0.30%

C is an element useful for ensuring strength. When the C content is less than 0.01%, the effect of ensuring strength is small; therefore, the C content is set to 0.01% or more. When the C content exceeds 0.30%, CO gas is generated at the interface between the scale and the steel substrate to cause peeling at the interface between the scale and the steel substrate during rolling, resulting in scale defects; therefore, the C content is set to 0.30% or less. From the viewpoint of scale adhesion, the C content is preferably 0.20% or less.

[0029]

Si: 0.50% or Less

Si is an element that functions as a deoxidizing agent. Although Si is not necessarily required to be contained, the Si content is preferably 0.01% or more in order to obtain such a deoxidizing effect. When the Si content exceeds 0.50%, however, Si enriches at the interface between the scale and the steel substrate to form a Si oxide layer. As a result, the scale easily peels off at the interface

between the Si oxide layer and the scale layer formed on the Si oxide layer. In addition, descaling properties at high temperatures before finish rolling deteriorate, and primary scale formed before rough rolling is crushed during finish rolling, resulting in easy formation of so-called red scale as well as inferior blackness. For this reason, the Si content is set to 0.50% or less. The Si content is preferably 0.20% or less.

[0030]

Mn: 0.01% to 2.0%

Mn is an element that has the effect of neutralizing dissolved S, which causes embrittlement during hot working, by converting S into MnS, and also has the effect of improving strength. When the Mn content is less than 0.01%, such effects are small. When the Mn content exceeds 2.0%, toughness is reduced, and Mn-based oxides are formed at the interface between the scale and the steel substrate, causing a decrease in scale adhesion. In addition, transformation after finish rolling is delayed, transformation is not completed until coiling, and transformation proceeds partially and non-uniformly in the longitudinal direction after coiling. This induces loosening of the hot-rolled coil after coiling, and even at a central portion in the width direction of the coil, reoxidation occurs due to contact between the steel sheet surface and an oxidizing

atmosphere, that is, the amount of hematite and magnetite grains increases, and the amount of the eutectoid transformation microstructure decreases, resulting in deterioration of scale adhesion. For these reasons, the Mn content is set to 0.01% to 2.0%. The lower limit is preferably 0.05% or more. The upper limit is preferably 1.5% or less.

[0031]

P: 0.10% or Less

P is an element that is preferably reduced as much as possible because P adversely affects grain boundary embrittlement. In addition, P forms a very brittle oxide layer at the interface between the scale and the steel substrate and lowers scale adhesion. When the P content exceeds 0.10%, these adverse effects increase; therefore, the P content is set to 0.10% or less. The upper limit is preferably 0.05% or less. P may be absent; however, from the viewpoint of production cost, the lower limit is preferably 0.001% or more.

[0032]

S: 0.10% or Less

S is an element that significantly degrades hot workability and toughness. In addition, S enriches at the interface between the scale and the steel substrate and lowers scale adhesion. When the S content exceeds 0.10%,

these adverse effects increase; therefore, the S content is set to 0.10% or less. The S content is preferably 0.05% or less. S may be absent; however, from the viewpoint of production cost, the lower limit is preferably 0.0001% or more.

[0033]

Sol. Al: 0.10% or Less

sol. Al is an element that functions as a deoxidizing agent. The sol. Al content may be 0.00%; however, the sol. Al content is preferably 0.01% or more in order to obtain such a deoxidizing effect. When the sol. Al content exceeds 0.10%, the amount of oxide inclusions increases, and cleanliness decreases. For this reason, the sol. Al content is set to 0.10% or less. The sol. Al content is preferably 0.06% or less.

[0034]

N: 0.015% or Less

N is an element that forms nitrides, such as BN, AlN, and TiN, in steel, lowers hot ductility of steel, and lowers surface quality. When the N content exceeds 0.015%, surface quality markedly deteriorates. Therefore, the N content is set to 0.015% or less. The N content is preferably 0.010% or less. N may be absent; however, from the viewpoint of production cost, the N content is preferably 0.0001% or more. More preferably, the N content is 0.001% or more.

[0035]

The chemical components described above are essential components of the hot-rolled steel sheet of the present invention. To improve various properties, the hot-rolled steel sheet of the present invention may contain at least one selected from Cu: 1.0% or less, Ni: 0.50% or less, and Cr: 2.0% or less as needed, in addition to the above chemical components.

[0036]

Cu: 1.0% or Less

Cu is an element that enriches at the interface between the scale and the steel substrate to promote grain boundary oxidation and also to promote unevenness of the interface between the scale and the steel substrate, thereby enhancing adhesion at the interface between the scale and the steel substrate. To obtain these effects, the Cu content is preferably 0.01% or more. When the Cu content exceeds 1.0%, however, there is a concern that molten Cu penetrates into austenite grain boundaries of the steel substrate during heating, resulting in deterioration in surface properties due to hot embrittlement. Therefore, when copper is contained, the Cu content is set to 1.0% or less. The Cu content is preferably 0.8% or less.

[0037]

Ni: 0.50% or Less

Like Cu, Ni is an element that enriches at the interface between the scale and the steel substrate to promote grain boundary oxidation and also to promote unevenness of the interface between the scale and the steel substrate, thereby enhancing adhesion at the interface between the scale and the steel substrate. To obtain these effects, the Ni content is preferably 0.01% or more. When the Ni content exceeds 0.50%, however, the above effects reach saturation, and an increase in cost is a concern. Therefore, when Ni is contained, the Ni content is set to 0.50% or less. The Ni content is preferably 0.40% or less.

[0038]

Cr: 2.0% or Less

Cr has the effect of enhancing strength, hardenability, and corrosion resistance. Cr enriches at the interface between the scale and the steel substrate, and the unevenness of the interface causes the scale to bite into the steel substrate, which also provides the effect of improving scale adhesion. To obtain such effects, the Cr content is preferably 0.01% or more. When the Cr content exceeds 2.0%, the above effects reach saturation; therefore, when Cr is contained, the Cr content is set to 2.0% or less. The lower limit is more preferably 0.07% or more, still more preferably 0.12% or more. The upper limit is more preferably 1.0% or less, still more preferably 0.8% or less.

[0039]

In the present invention, the hot-rolled steel sheet may further contain at least one selected from Mo: 1.0% or less, Nb: 0.1% or less, V: 0.1% or less, Ti: 0.03% or less, B: 0.01% or less, and Sb: 0.03% or less as needed.

[0040]

Mo: 1.0% or Less

Mo has the effect of enhancing strength and hardenability and suppressing softening associated with tempering. To obtain such an effect, the Mo content is preferably 0.1% or more. When the Mo content exceeds 1.0%, the strength may excessively increase, and the toughness and formability may deteriorate. Therefore, when Mo is contained, the Mo content is set to 1.0% or less.

[0041]

Nb: 0.1% or Less

Nb is an element that enhances the strength and toughness of base steel. To obtain such an effect, the Nb content is preferably 0.003% or more. When the Nb content exceeds 0.1%, the toughness may conversely deteriorate. Therefore, when Nb is contained, the Nb content is set to 0.1% or less.

[0042]

V: 0.1% or Less

V is an element that enhances the strength and

toughness of base steel. To obtain such an effect, the V content is preferably 0.003% or more. When the V content exceeds 0.1%, the toughness may conversely deteriorate. Therefore, when V is contained, the V content is set to 0.1% or less.

[0043]

Ti: 0.03% or Less

Ti is an element that enhances the strength and toughness of base steel and also has the effect of ensuring toughness in a weld heat affected zone. To obtain such effects, the Ti content is preferably 0.001% or more. When the Ti content exceeds 0.03%, the toughness may conversely deteriorate. Therefore, when Ti is contained, the Ti content is set to 0.03% or less.

[0044]

B: 0.01% or Less

B is an element that has the effect of enhancing hardenability of steel. This effect can increase strength. To obtain such an effect, the B content is preferably 0.0005% or more. When the B content exceeds 0.01%, this effect reaches saturation; therefore, when B is contained, the B content is set to 0.01% or less.

[0045]

Sb: 0.03% or Less

Sb enriches in the surface layer of the steel sheet

during heating of a material and has the effect of suppressing a decrease in the C content of the surface layer of the steel sheet caused by decarburization during heating. To obtain such an effect, the Sb content is preferably 0.001% or more. When the Sb content exceeds 0.03%, Sb may become a liquid metal during heating of the material and may penetrate into prior-austenite grain boundaries to lower scale adhesion. Therefore, when Sb is contained, the Sb content is set to 0.03% or less.

[0046]

The balance other than the chemical components described above is Fe and unavoidable impurities. As unavoidable impurities, O: 0.005% or less, Mg: 0.003% or less, Sn: 0.1% or less, and Ca: 0.01% or less are allowable. When the above-described optional elements are contained in amounts less than the preferable lower limits, these elements are regarded as unavoidable impurities.

[0047]

Next, the scale microstructure in the width direction of the hot-rolled steel sheet of the present invention will be described. The scale microstructure in the width direction of the steel sheet means the scale microstructure at a central portion in the width direction of the steel sheet and at a position 5 mm from an edge in the width direction. It is sufficient that the microstructure at each

position falls within the following ranges.

[0048]

Area Fraction of Magnetite Grains: 30% or More

Magnetite of the present invention includes magnetite grains and magnetite contained in the eutectoid transformation microstructure. These are microstructures that can be distinguished from each other as described below. The magnetite grains in the present invention include a magnetite layer located near a scale surface and containing columnar magnetite grains, and massive pre-eutectoid magnetite grains formed inside or adjacent to the eutectoid transformation microstructure prior to progress of eutectoid transformation. The magnetite grains further include a so-called magnetite seam, which is a thin layer of fine magnetite grains formed at the interface between the scale and the steel substrate. The magnetite seam is distinguished from magnetite contained in the eutectoid transformation microstructure containing iron and magnetite. The magnetite grains have higher ductility at room temperature than wustite and hematite and contribute to improvement in scale adhesion. In particular, the magnetite seam has high coherency with the steel substrate, and thus contributes to improvement in scale adhesion by suppressing peeling of scale from the interface between the scale and the steel substrate. In addition, the magnetite layer

adjacent to the scale surface containing columnar magnetite grains is a microstructure that contributes to blackening. When the area fraction of the magnetite grains is less than 30%, these effects cannot be sufficiently obtained; therefore, the area fraction of the magnetite grains is set to 30% or more, preferably 40% or more. When the area fraction of the magnetite grains exceeds 80%, cracks may occur in magnetite, and scale adhesion may deteriorate. Therefore, the area fraction of the magnetite grains is preferably 80% or less, more preferably 70% or less.

[0049]

Area Fraction of Eutectoid Transformation

Microstructure Containing Iron and Magnetite: 20% or More and 60% or Less

The eutectoid transformation microstructure containing iron and magnetite contributes to improvement in scale adhesion because magnetite and precipitated Fe have high coherency with the steel substrate. When the area fraction is less than 20%, this effect cannot be sufficiently obtained. Therefore, the area fraction of the eutectoid transformation microstructure containing iron and magnetite is set to 20% or more, preferably 25% or more, more preferably 30% or more. When the area fraction of the eutectoid transformation microstructure containing iron and magnetite exceeds 60%, precipitated Fe derived from

eutectoid transformation is also formed near the scale surface to cause whitening. Therefore, the area fraction of the eutectoid transformation microstructure containing iron and magnetite is set to 60% or less, preferably 55% or less, more preferably 50% or less.

[0050]

Area Fraction of Wustite: 20% or Less

Wustite is a phase that is stable at high temperatures, and most of the wustite disappears by undergoing eutectoid transformation during cooling after coiling; however, when the cooling rate is high, wustite may remain at room temperature in an untransformed state. In particular, near the edge portions in the width direction of the coil, the cooling rate is relatively high, and wustite tends to remain at room temperature. Wustite is more brittle than magnetite at room temperature, and cracks in the scale impair scale adhesion. Therefore, the area fraction of wustite is set to 20% or less, preferably 15% or less, more preferably 10% or less. The area fraction of wustite may be 0%.

[0051]

Mass Fraction of Hematite: 5% or Less

Hematite may be formed in a layered form on the surface of the scale, in addition to the magnetite grains, the eutectoid transformation microstructure containing iron and magnetite, and wustite. Hematite leads to deterioration in

adhesion as well as whitening and also causes surface defects, such as red scale. Therefore, the mass fraction of hematite is set to 5% or less.

[0052]

Area Fraction of Precipitated Fe on Scale Surface: 15% or Less

Precipitated Fe on the scale surface is a factor that inhibits blackening of the scale surface. Therefore, when the area fraction of precipitated Fe on the scale surface exceeds 15%, sufficient blackness cannot be obtained. Accordingly, the area fraction of precipitated Fe on the scale surface is set to 15% or less. The area fraction of precipitated Fe on the scale surface may be 0%.

[0053]

Average Thickness of Scale in Width Direction of Steel Sheet: 3 μm or More and 20 μm or Less

When the average thickness of the scale is less than 3 μm , the color tone of the eutectoid transformation microstructure formed in the scale on the steel substrate side and the gloss and color tone of the steel substrate affect the color tone of the surface layer, which causes the scale to appear white. Therefore, the average thickness of the scale is set to 3 μm or more, preferably 4 μm or more. When the average thickness of the scale exceeds 20 μm , the strain applied to the scale surface during processing of the

steel sheet increases, and the occurrence of cracks in the scale reduces scale adhesion. Therefore, the average thickness of the scale is set to 20 μm or less, preferably 18 μm or less, more preferably 15 μm or less.

[0054]

Next, a method for measuring the scale microstructure and the scale thickness of the hot-rolled steel sheet according to the present invention will be described.

[0055]

The scale microstructure is measured in a central portion and an edge portion of the steel sheet in the width direction. Specifically, a central portion in the width direction of the hot-rolled coil and a portion 5 mm from an edge in the width direction are evaluated as observation positions.

[0056]

The area fractions of the magnetite grains, the eutectoid transformation microstructure containing iron and magnetite, and the wustite can be determined as follows. Cross-sections in the sheet thickness direction that are perpendicular to the steel sheet surface and parallel to the rolling direction are cut out from the above observation positions as observation surfaces, and the cross-sections are mirror-polished. Subsequently, the area fractions can be measured by observing a backscattered electron image of

each cross-section of the scale using a scanning electron microscope (SEM). With respect to the field of view of the SEM, the entire scale thickness from the scale surface to the interface between the scale and the steel sheet is targeted for observation. Accordingly, the backscattered electron image of each scale cross-section is observed at an observation magnification at which the entire scale thickness fits within the field of view. In the backscattered electron image obtained using the SEM, magnetite appears as the darkest region, the steel substrate and the precipitated Fe in the eutectoid transformation microstructure appear as the brightest regions, and wustite appears as a region having intermediate contrast. The eutectoid transformation microstructure containing iron and magnetite is a region containing magnetite and iron in a layered form.

[0057]

Hematite is formed as an extremely thin layer on the scale surface and easily detaches during mirror polishing; therefore, it is difficult to quantitatively evaluate the area fraction of hematite using the SEM. Accordingly, the integrated intensities of diffraction peaks of respective phases in the scale are measured using an X-ray diffractometer with a Co K α radiation source. From the ratios of the integrated intensities of the respective

phases between a standard sample and a test sample, the mass fraction can be obtained using the following formula (2).

The standard sample is a mixture of Fe, FeO (wustite), Fe₂O₃ (hematite), and Fe₃O₄ (magnetite) at equal weights. The mass fraction of hematite can be regarded as an area fraction.

$$\text{Mass fraction of hematite (Fe}_2\text{O}_3) = (I_{\text{Fe}_2\text{O}_3}/R_{\text{Fe}_2\text{O}_3}) \times 100 / ((I_{\text{Fe}}/R_{\text{Fe}}) + (I_{\text{FeO}}/R_{\text{FeO}}) + (I_{\text{Fe}_2\text{O}_3}/R_{\text{Fe}_2\text{O}_3}) + (I_{\text{Fe}_3\text{O}_4}/R_{\text{Fe}_3\text{O}_4})) \cdots$$

(2)

In formula (2),

I_A: the integrated intensity of phase A in the test sample,

R_A: the integrated intensity of phase A in the standard sample, and

A: Fe, FeO, Fe₂O₃, or Fe₃O₄.

[0058]

The area fraction of precipitated Fe on the scale surface can be measured by observing a backscattered electron image of the surface at the observation positions described above using an SEM at a magnification of 3000×, and determining the area fraction of precipitated Fe appearing with the brightest contrast by image analysis.

[0059]

The average thickness of the scale in the width direction of the coil can be measured as follows. For example, cross-sections in the sheet thickness direction that are perpendicular to the steel sheet surface and

parallel to the rolling direction are cut out from a central portion in the width direction of the hot-rolled steel sheet and from a portion 5 mm from an edge in the width direction of the hot-rolled steel sheet, and the cross-sections are mirror-polished. Subsequently, the scale thickness is measured at three locations for each cross-section using an SEM, and the measured values are averaged to obtain the average thickness. The average thickness of the scale in the width direction according to the present invention being 3 μm or more and 20 μm or less means that the average thickness of the scale is 3 μm or more and 20 μm or less at each of the central portion in the width direction of the hot-rolled steel sheet and the portion 5 mm from the edge in the width direction.

[0060]

Next, a method for producing a hot-rolled steel sheet according to the present invention will be described.

[0061]

In the present invention, the temperature specified in each step refers to the surface temperature of a slab (steel slab) or a steel sheet, and the surface temperatures can be measured using a radiation thermometer or other devices. Unless otherwise specified, the average cooling rate is defined as "(cooling start temperature - cooling stop temperature)/cooling time."

[0062]

In the present invention, a method for producing a steel material having the chemical composition described above is not limited, and any commonly used method can be employed. For example, a molten steel having the chemical composition described above is preferably melted in a converter, an electric arc furnace, or the like and formed into a steel material, such as a slab, by a casting method, such as continuous casting. An ingot casting-blooming rolling method can be employed without any problem. In general, a steel material is hot-rolled after heating. This heating needs only to be sufficient to achieve adequate solid-solution treatment, and the steel material is preferably heated to an A_{c3} point or higher. Specifically, the heating temperature is preferably in a range of 1060°C to 1300°C, which is a normal slab heating temperature range. For a slab produced by continuous casting, hot direct rolling may be employed in which rolling is performed without further treatment or after holding the slab to suppress a decrease in temperature.

[0063]

The hot rolling step includes rough rolling and finish rolling. Rough rolling involves forming a sheet bar having predetermined dimensions, and it is not necessary to limit the rough rolling conditions. The material being rolled may

be heated during rolling by using a heating means, such as a sheet bar heater, in order to perform finish rolling at a predetermined temperature. Before rough rolling and finish rolling, scale formed on the surface of the sheet bar is removed by descaling using high water pressure or the like on the inlet side of a rolling mill.

[0064]

Next, finish rolling is performed. When the finish rolling inlet temperature exceeds 1100°C, the thickness of the scale may increase, and scale adhesion may decrease. When the finish rolling inlet temperature is lower than 950°C, the rolling load may significantly increase, and productivity may decrease. In addition, as the product sheet thickness increases, the finish rolling inlet thickness increases. For example, when the product sheet thickness exceeds 5.0 mm, a long time is required until the start of finish rolling, which may result in a decrease in productivity. Therefore, the finish rolling inlet temperature is preferably 1100°C or lower, more preferably 1050°C or lower. The lower limit of the finish rolling inlet temperature is preferably 950°C or higher.

[0065]

Finish rolling delivery temperature: 800°C or Higher
and 950°C or Lower

When the finish rolling delivery temperature is lower

than 800°C, a decrease in scale ductility causes cracks. These cracks promote scale reoxidation to form hematite, which causes deterioration of scale adhesion and scale blackness. In addition, the scale thickness decreases, and sufficient blackness cannot be obtained. Furthermore, the scale microstructure becomes finer, and an increase in hardness of the scale itself causes a decrease in scale adhesion. When the finish rolling delivery temperature exceeds 950°C, excessive scale growth increases scale thickness, resulting in a decrease in scale adhesion. In addition, an increase in grain size of each phase in the scale microstructure causes a decrease in scale adhesion. Therefore, the finish rolling delivery temperature is set to 800°C or higher and 950°C or lower. The lower limit is preferably 820°C or higher. The upper limit is preferably 930°C or lower.

[0066]

Cooling at Average Cooling Rate of 5 °C/s or Higher in Temperature Range from Finish rolling delivery temperature to 750°C

Scale grows more rapidly in a high-temperature region. For this reason, it is necessary to perform rapid cooling in a high-temperature region immediately after finish rolling in order to suppress a decrease in scale adhesion caused by excessive scale growth. When the average cooling rate in a

temperature range from the finish rolling delivery temperature to 750°C is lower than 5 °C/s, scale excessively grows, which causes a decrease in scale adhesion. For this reason, the average cooling rate in the temperature range from the finish rolling delivery temperature to 750°C is set to 5 °C/s or higher, preferably 7 °C/s or higher. When the average cooling rate in the temperature range from the finish rolling delivery temperature to 750°C exceeds 80 °C/s, the scale microstructure may become finer, and scale adhesion may decrease. In addition, a decrease in scale ductility causes cracks, and these cracks promote scale reoxidation to form hematite. As a result, deterioration of scale adhesion and scale blackness may occur. For this reason, the average cooling rate in the temperature range from the finish rolling delivery temperature to 750°C is preferably 80 °C/s or lower, more preferably 50 °C/s or lower.

[0067]

Cooling at Average Cooling Rate of 1 °C/s or Higher and 30 °C/s or Lower in Range from 750°C to Temperature at Start of Coiling

In a range from 750°C to a temperature at start of coiling, scale growth is relatively slower than in a high-temperature region immediately after finish rolling; however, it is necessary to suppress a decrease in scale

adhesion caused by excessive scale growth. When the average cooling rate in the range from 750°C to the temperature at start of coiling is lower than 1 °C/s, scale excessively grows, which causes a decrease in scale adhesion. For this reason, the average cooling rate in the range from 750°C to the temperature at start of coiling is set to 1 °C/s or higher. The average cooling rate is preferably 3 °C/s or higher. When the average cooling rate in the range from 750°C to the temperature at start of coiling exceeds 30 °C/s, refinement of the scale microstructure progresses, and a stress difference between the scale and the steel substrate increases. As a result, cracks occur in the scale, and these cracks promote scale reoxidation. As a result, hematite is formed, which causes deterioration of scale adhesion and scale blackness. For this reason, the average cooling rate in the range from 750°C to the temperature at start of coiling is set to 30 °C/s or lower, preferably 20 °C/s or lower.

[0068]

Coiling Temperature: 450°C or Higher and 600°C or Lower

After the cooling described above, the steel sheet is coiled at a coiling temperature of 450°C or higher and 600°C or lower. When the coiling temperature is lower than 450°C, eutectoid transformation from wustite does not sufficiently proceed after coiling, and an excessive amount of wustite

remains at room temperature. As a result, scale adhesion decreases since wustite is brittle at room temperature. When the coiling temperature exceeds 600°C, scale adhesion decreases due to excessive scale growth. In addition, at a central portion in the width direction that is shielded from an oxidizing atmosphere after coiling, hematite and magnetite in the surface layer are reduced to wustite. The wustite undergoes eutectoid transformation to cause precipitation of Fe on the steel sheet surface, which causes inhibition of blackening. Furthermore, in the edge portions in the width direction, reoxidation promotes formation of hematite, which causes whitening. Accordingly, the coiling temperature is set to 450°C or higher and 600°C or lower. The lower limit is preferably 470°C or higher. The upper limit is preferably 580°C or lower.

[0069]

After Start of Coiling, Entire Coil Is Cooled Such That Temperature of Edge Portions of Coil Decreases at Average Cooling Rate of 0.5 °C/s or Higher and 6.0 °C/s or Lower from Coiling Temperature to Cooling Stop Temperature of 300°C or Higher and 430°C or Lower

After start of coiling, the entire coil is cooled such that the temperature of edge portions of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling

stop temperature of 300°C or higher and 430°C or lower. This process decreases the temperature of the edge portions of the coil, increases coil rigidity, and prevents coil loosening. The entire coil refers to both edge portions and sheet surface of the coil. The edge portions of the coil refer to regions within 200 mm in the width direction of the coil from both edges in the width direction of the coil. The sheet surface of the coil refers to the surface of the coil in a region other than both end portions. As a result, at a central portion in the width direction of the coil, shielding from an oxidizing atmosphere can suppress hematite formation caused by reoxidation to suppress whitening, and a eutectoid transformation microstructure suitable for improving adhesion can be sufficiently obtained. At the edge portions of the coil in the width direction, complete shielding from an oxidizing atmosphere is difficult; however, cooling of the edge portions suppresses reoxidation, and recuperation from the central portion in the width direction promotes eutectoid transformation, thereby ensuring excellent adhesion and blackness. The temperature of the edge portions can be measured, for example, by using a radiation thermometer. The temperature of the sheet surface is not specified because the temperature of the sheet surface at a specific longitudinal position cannot be measured during coiling; however, the

above effects can be obtained by cooling the entire coil by the same cooling method as that for the edge portions. When the cooling stop temperature at the edge portions of the coil exceeds 430 °C, the above effects cannot be sufficiently obtained. When the cooling stop temperature at the edge portions of the coil is lower than 300 °C, the edge portions undergo overcooling, and a large amount of wustite remains in the scale at the edge portions, which leads to a decrease in adhesion. Therefore, the cooling stop temperature at the edge portions of the coil is set to 300 °C or higher and 430 °C or lower. The lower limit is preferably 320°C or higher. The upper limit is preferably 400°C or lower. When the average cooling rate at the edge portions is lower than 0.5 °C/s, the above effects cannot be sufficiently obtained. When the average cooling rate at the edge portions exceeds 6.0 °C/s, cracks occur in the scale due to refinement of the scale microstructure and an increase in stress difference between the scale and the steel substrate. These cracks promote scale reoxidation to form hematite, resulting in a decrease in scale adhesion and blackness. Therefore, the average cooling rate at the edge portions is set to 0.5 °C/s or higher and 6.0 °C/s or lower. The average cooling rate is preferably 1.0 °C/s or higher and 5.0 °C/s or lower. A method for cooling the coil is not particularly specified; however, for example, the coil is

preferably cooled, during coiling in a coiler, using a cooling device that applies water spray cooling to the sheet surface and both edge portions of the coil.

[0070]

After the cooling, the coil is preferably charged into a coil box or covered with a cover to promote eutectoid transformation from wustite and suppress oxidation of the outermost circumference and the edge portions.

[0071]

Furthermore, the hot-rolled steel sheet coiled into a coil shape may be subjected to shape correction by deforming the steel sheet using a roller leveler, a tension leveler, or the like.

EXAMPLES

[0072]

Examples of the present invention will be described below.

[0073]

Steels having the compositions shown in Table 1 were melted and cast into steel materials. These steel materials were hot-rolled under the conditions shown in Table 2 to obtain mill scale hot-rolled coils having a sheet thickness of 2 mm. Test specimens were collected at respective positions in the width direction of each obtained hot-rolled coil, and the scale microstructure, scale thickness,

adhesion, and blackness were evaluated by the methods described below.

[0074]

[Table 1]

Steel No.	Chemical Composition (mass%)											Note
	C	Si	Mn	P	S	sol. Al	N	Cu	Ni	Cr	others	
A	0.053	0.01	0.28	0.016	0.0088	0.038	0.0027	-	-	-	-	Inventive Steel
B	0.076	0.20	1.48	0.049	0.0118	0.021	0.0033	-	-	-	-	Inventive Steel
C	0.158	0.13	0.75	0.012	0.0182	0.051	0.0028	-	-	-	-	Inventive Steel
D	0.084	0.03	1.95	0.043	0.0120	0.044	0.0062	0.08	0.07	-	-	Inventive Steel
E	0.126	0.46	1.27	0.016	0.0166	0.023	0.0036	-	-	0.42	-	Inventive Steel
F	0.180	0.10	0.83	0.036	0.0137	0.029	0.0030	0.04	0.02	0.25	-	Inventive Steel
G	0.230	0.04	0.74	0.023	0.0132	0.026	0.0032	0.52	0.31	0.14	-	Inventive Steel
H	0.248	0.29	0.93	0.049	0.0068	0.016	0.0059	-	-	-	Mo:0.21, Nb:0.03, V:0.03	Inventive Steel
I	0.284	0.07	0.75	0.032	0.0086	0.039	0.0049	0.18	0.03	0.08	Ti:0.015, B:0.003, Sb:0.02	Inventive Steel
J	<u>0.322</u>	0.13	0.25	0.040	0.0071	0.059	0.0021	-	-	-	-	Comparative Steel
K	0.113	<u>0.63</u>	1.49	0.038	0.0092	0.060	0.0051	-	-	-	-	Comparative Steel
L	0.205	0.22	<u>2.21</u>	0.011	0.0066	0.036	0.0046	-	-	-	-	Comparative Steel

Underlined entries are outside the scope of the present invention.

[0075]

[Table 2]

N o.	Steel No.	Hot Rolling Conditions						Scale Microstructure and Adhesion in Central Portion in Width Direction								Scale Microstructure and Adhesion in Portion at 5 mm from Edge in Width Direction								Note
		finish rolling delivery tempera- ture (°C)	average cooling rate (°C/s) from finish rolling delivery tempera- ture to 750°C	average cooling rate (°C/s) from 750°C to tempera- ture at start of coiling	coiling tempera- ture (°C)	cooling stop tempera- ture (°C) at coil edge portion	aver- age cool- ing rate (°C/s)) at coil edge porti- on	area frac- tion (%) of magn- etite grains	area frac- tion (%) of eutectoid trans- forma- tion micro- struc- ture	area frac- tion (%) of wustite	mass frac- tion (%) of hema- tite	precipit- ated Fe (%) on outer- most surface	scale thick- ness (μm)	scale adhes- ion	L*	area frac- tion (%) of magn- etite grains	area frac- tion (%) of eutectoid trans- forma- tion micro- struc- ture	area frac- tion (%) of wustite	mass frac- tion (%) of hema- tite	precipit- ated Fe (%) on outer- most surface	scale thick- ness (μm)	scale adhes- ion	L*	
1	A	870	10	7	460	420	0.8	59	28	13	0	0	8	B	28	59	23	18	0	0	10	B	32	Inventive Example
2	A	<u>770</u>	70	25	460	400	1.5	56	33	11	<u>6</u>	3	<u>2</u>	<u>C</u>	<u>43</u>	53	34	13	<u>8</u>	1	<u>2</u>	<u>C</u>	<u>44</u>	<u>Comparative Example</u>
3	A	<u>970</u>	6	2	460	370	3.0	60	30	10	0	2	<u>22</u>	<u>C</u>	<u>30</u>	58	28	14	1	0	<u>23</u>	<u>C</u>	35	<u>Comparative Example</u>
4	B	840	20	10	480	340	4.5	57	35	8	0	4	7	A	33	56	34	10	1	1	8	A	33	Inventive Example
5	B	940	<u>3</u>	2	480	310	5.5	55	37	8	1	5	<u>21</u>	<u>C</u>	<u>32</u>	56	35	9	2	2	<u>22</u>	<u>C</u>	35	<u>Comparative Example</u>
6	C	840	25	10	500	420	0.8	57	38	5	2	6	6	A	35	55	40	5	3	1	7	A	37	Inventive Example
7	C	940	6	<u>0.4</u>	500	400	1.5	59	37	4	1	5	<u>22</u>	<u>C</u>	<u>38</u>	55	39	6	2	2	<u>22</u>	<u>C</u>	38	<u>Comparative Example</u>
8	D	810	30	15	520	370	3.0	53	45	2	3	9	4	A	35	51	46	3	4	5	5	B	38	Inventive Example
9	D	810	80	<u>34</u>	520	340	4.5	50	48	2	<u>7</u>	11	5	<u>C</u>	<u>42</u>	52	44	4	<u>9</u>	3	5	<u>C</u>	<u>43</u>	<u>Comparative Example</u>
10	E	860	35	20	540	310	5.5	47	52	1	2	13	8	A	37	49	49	2	2	5	8	A	38	Inventive Example
11	E	880	35	20	<u>430</u>	420	0.8	58	<u>18</u>	<u>24</u>	0	0	9	<u>C</u>	<u>29</u>	70	<u>5</u>	<u>25</u>	0	0	9	<u>C</u>	33	<u>Comparative Example</u>
12	F	880	45	20	560	400	1.5	45	55	0	1	13	10	A	35	47	53	0	2	6	10	A	37	Inventive Example
13	F	940	6	2	<u>620</u>	370	3.0	<u>27</u>	<u>73</u>	0	4	<u>23</u>	<u>23</u>	<u>C</u>	<u>48</u>	33	<u>66</u>	1	<u>12</u>	8	<u>24</u>	<u>C</u>	<u>49</u>	<u>Comparative Example</u>
14	G	900	45	20	580	340	4.5	42	58	0	1	12	11	A	34	42	57	1	3	5	13	A	35	Inventive Example
15	G	900	75	25	580	<u>450</u>	<u>0.3</u>	45	55	0	1	13	14	A	37	50	50	0	<u>10</u>	5	<u>22</u>	<u>C</u>	<u>45</u>	<u>Comparative Example</u>
16	H	920	75	25	590	310	5.5	42	58	0	2	14	14	A	38	45	55	0	4	4	16	A	39	Inventive Example
17	H	920	30	15	590	<u>450</u>	1.0	43	57	0	2	12	15	A	39	44	56	0	<u>8</u>	6	<u>21</u>	<u>C</u>	<u>42</u>	<u>Comparative Example</u>
18	I	940	45	20	480	420	0.8	56	38	6	0	10	18	A	31	53	35	12	2	1	19	B	33	Inventive Example
19	I	940	75	25	500	<u>280</u>	<u>6.5</u>	57	40	3	0	6	16	A	30	39	38	<u>23</u>	1	2	18	<u>C</u>	32	<u>Comparative Example</u>
20	<u>J</u>	830	25	10	520	400	1.5	54	45	1	1	7	6	<u>C</u>	<u>31</u>	56	41	3	2	1	7	<u>C</u>	32	<u>Comparative Example</u>
21	<u>K</u>	850	25	10	540	370	3.0	54	46	0	<u>12</u>	9	8	<u>C</u>	<u>45</u>	54	45	1	<u>15</u>	2	8	<u>C</u>	<u>48</u>	<u>Comparative Example</u>
22	<u>L</u>	870	25	10	560	340	4.5	48	52	0	1	10	11	<u>C</u>	<u>35</u>	55	45	0	3	3	13	<u>C</u>	37	<u>Comparative Example</u>

Underlined entries are outside the scope of the present invention.

[0076]

The area fractions of the magnetite grains, the eutectoid transformation microstructure containing iron and magnetite, and the wustite were measured as described below. Cross-sections in the sheet thickness direction that were perpendicular to the steel sheet surface and parallel to the rolling direction were cut out from a central portion in the width direction of the hot-rolled coil and from a portion 5 mm from an edge in the width direction, and the cross-sections in the sheet thickness direction were mirror-polished. Subsequently, the area fractions were measured by observing a backscattered electron image of each cross-section of the scale using an SEM at a magnification of 3000 $\times$. In the backscattered electron image obtained using the SEM, magnetite appears as the darkest region, the steel substrate and the precipitated Fe in the eutectoid transformation microstructure appear as the brightest regions, and wustite appears as a region having intermediate contrast. The eutectoid transformation microstructure containing iron and magnetite is a region containing magnetite and iron in a layered form.

[0077]

For hematite, the integrated intensities of diffraction peaks of the respective phases in the scale were measured by using an X-ray diffractometer with a Co K α radiation source.

The mass fraction was determined using the following formula (2) from the ratios between the integrated intensities of the respective phases in a standard sample (a mixture of Fe, FeO (wustite), Fe₂O₃ (hematite), and Fe₃O₄ (magnetite) at equal weights) and the integrated intensities of respective phases in a test sample.

$$\text{Mass fraction of hematite (Fe}_2\text{O}_3) = (I_{\text{Fe}_2\text{O}_3}/R_{\text{Fe}_2\text{O}_3}) \times 100 / ((I_{\text{Fe}}/R_{\text{Fe}}) + (I_{\text{FeO}}/R_{\text{FeO}}) + (I_{\text{Fe}_2\text{O}_3}/R_{\text{Fe}_2\text{O}_3}) + (I_{\text{Fe}_3\text{O}_4}/R_{\text{Fe}_3\text{O}_4})) \dots$$

(2)

In formula (2),

I_A: the integrated intensity of phase A in the test sample,

R_A: the integrated intensity of phase A in the standard sample, and

A: Fe, FeO, Fe₂O₃, or Fe₃O₄.

[0078]

The area fraction of precipitated Fe on the outermost surface of the steel sheet was measured by observing the backscattered electron images of the scale surface at a central portion in the width direction of the hot-rolled coil and at a portion 5 mm from an edge in the width direction using an SEM at a magnification of 3000×. The area fraction of precipitated Fe appearing with the brightest contrast was determined by image analysis.

[0079]

The average thickness of the scale in the width

direction of the coil was determined as follows. Cross-sections in the sheet thickness direction that were perpendicular to the steel sheet surface and parallel to the rolling direction were cut out from a central portion in the width direction of the hot-rolled coil and from a portion 5 mm from an edge in the width direction. Next, the cross-sections were mirror-polished, and the scale thickness was then measured at three locations for each cross-section using an SEM, and the measured values were averaged to obtain the average thickness.

[0080]

For scale adhesion, test specimens of 30 mm × 100 mm were collected from a central portion in the width direction of the hot-rolled coil and from a portion 5 mm from an edge in the width direction such that the longitudinal direction of each test specimen was parallel to the rolling direction. Next, a bending test (JIS Z 2248) using a press-bending method was performed, and cellophane tape was applied to and peeled from the surface of each test specimen on the bending outer side, and the amount of scale adhering to the tape was measured by image analysis to perform evaluation. The conditions for the bending test were set such that the ratio r/t of the tip radius r of a pressing jig to the sheet thickness t of each test specimen was 4 and the bending angle was 180°. The evaluation criteria were as described

below, and A and B were regarded as superior adhesion.

A: Almost no peeling was observed (the area fraction of scale-adhered portions was less than 10%).

B: Peeling was observed in some areas, but there was no problem in practical use (the area fraction of scale-adhered portions was 10% or more and less than 50%).

C: Peeling was observed in many areas, resulting in a problem in practical use (the area fraction of scale-adhered portions was 50% or more).

Blackness was measured using a spectrophotometer (CM-700d available from Konica Minolta, Inc.) after the surface of the steel sheet at a central portion in the width direction of the hot-rolled coil and at a portion 5 mm from an edge in the width direction was degreased with alcohol. Blackness was determined by measuring the L^* value in $L^*a^*b^*$ color space (JIS Z 8729), which is generally regarded as being close to human vision. A smaller L^* value means a color closer to black. During measurement, the viewing angle was set to 10° , the main light source was an auxiliary illuminant D65 (daylight, color temperature: 6504 K), and measurement was performed in a specular component excluded mode. An L^* value of 40 or less was regarded as superior blackness.

[0081]

In Inventive Examples shown in Table 2, scale adhesion

and blackness were uniformly excellent both at the central portion in the width direction of the hot-rolled coil and at the portion 5 mm from the edge in the width direction, whereas, in Comparative Examples, adhesion or blackness was inferior at one or both of these positions in the width direction.

CLAIMS

[Claim 1]

A hot-rolled steel sheet comprising:

a chemical composition containing,

in mass%,

C: 0.01% to 0.30%,

Si: 0.50% or less,

Mn: 0.01% to 2.0%,

P: 0.10% or less,

S: 0.10% or less,

sol. Al: 0.10% or less, and

N: 0.015% or less,

with the balance being Fe and unavoidable
impurities; and

a scale on a surface of the steel sheet,

wherein the scale in a width direction of the steel
sheet has a microstructure containing,

in terms of area fraction,

magnetite grains: 30% or more,

a eutectoid transformation microstructure
containing iron and magnetite: 20% or more and 60% or less,

wherein magnetite includes the magnetite grains and
the magnetite contained in the eutectoid transformation
microstructure, and

wustite: 20% or less, and,

in terms of mass fraction, hematite: 5% or less,
an area fraction of precipitated Fe on a surface of the
scale is 15% or less, and

an average thickness of the scale in the width
direction of the steel sheet is 3 μm or more and 20 μm or
less.

[Claim 2]

The hot-rolled steel sheet according to Claim 1,
wherein the chemical composition further contains, in mass%,
at least one selected from

Cu: 1.0% or less,

Ni: 0.50% or less, and

Cr: 2.0% or less.

[Claim 3]

The hot-rolled steel sheet according to Claim 1 or 2,
wherein the chemical composition further contains, in mass%,
at least one selected from

Mo: 1.0% or less,

Nb: 0.1% or less,

V: 0.1% or less,

Ti: 0.03% or less,

B: 0.01% or less, and

Sb: 0.03% or less.

[Claim 4]

A method for producing a hot-rolled steel sheet, the

method comprising:

subjecting a steel material having the chemical composition according to any one of Claims 1 to 3 to:

descaling after hot rough rolling;

finish rolling at a finish rolling delivery temperature of 800°C or higher and 950°C or lower;

cooling at an average cooling rate of 5 °C/s or higher in a temperature range from the finish rolling delivery temperature to 750°C;

then cooling at an average cooling rate of 1 °C/s or higher and 30 °C/s or lower in a range from 750°C to a temperature at start of coiling;

coiling at a coiling temperature of 450°C or higher and 600°C or lower; and

after start of coiling, cooling such that an entire coil is cooled so that a temperature of an edge portion of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling stop temperature of 300°C or higher and 430°C or lower.