

DESCRIPTION

HOT-ROLLED STEEL SHEET AND METHOD FOR PRODUCING THE SAME

Technical Field

[0001]

The present invention relates to a hot-rolled steel sheet with excellent oxide scale adhesion for use in automobiles, home appliances, construction materials, and the like, and a method for producing the hot-rolled steel sheet. The present invention is particularly suitable as a material for a component of construction and industrial machinery to be subjected to processing, such as temper rolling, bending, press forming, or laser cutting. The present invention relates to a hot-rolled steel sheet with excellent scale adhesion including adhesion at an interface between scale and a steel substrate and high powdery peeling resistance, and a method for producing the hot-rolled steel sheet.

Background Art

[0002]

Since a hot-rolled steel sheet is typically hot-rolled at a high temperature in an oxidizing atmosphere, scale (iron oxides) is inevitably formed on the surface. When a hot-rolled steel sheet with mill scale to which the scale remains attached is subjected to processing, such as temper

rolling, bending, press forming, or laser cutting, the scale is partially peeled off. This causes a processing defect, contamination of a process line, a surface defect in a product after processing, or the like. To avoid such a situation, a hot-rolled steel sheet with high adhesion of scale on the steel sheet surface has been demanded, and the demand has become stronger. In particular, powder-like scale peeling is a major cause of contamination of a process line and deterioration of surface quality. Thus, to improve the adhesion of scale, suppression of powder-like scale peeling is required.

[0003]

Various proposals have been made to improve the adhesion of scale. For example, Patent Literature 1 proposes a hot-rolled steel sheet with excellent scale adhesion, characterized in that a steel material having a composition containing, on a mass percent basis, 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 remainder being Fe and incidental impurities, is subjected to rough rolling, descaling, and finish rolling satisfying the following formula (1) at a finish rolling delivery temperature in the range of 800°C to 950°C, followed by cooling at an average cooling rate of 3°C/s or more and 80°C/s or less from the finish rolling to the start

of coiling, and then coiling at a coiling temperature in the range of 430°C to 580°C, and in that the hot-rolled steel sheet has, from a steel substrate side, a magnetite layer and magnetite grains and/or a eutectoid transformation structure of iron and magnetite on an upper layer of the magnetite layer, wherein the average grain size of the magnetite grains and/or the average block size of the eutectoid transformation structure is 3 μm or more and 8 μm or less, and the mass fraction of wustite contained in the scale layer is 10% or less.

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

wherein

T_1 denotes the temperature (°C) of the steel sheet after the finish rolling at a position 30 m from a front end in the longitudinal direction and at the central portion in the width direction,

T_2 denotes the temperature (°C) of the steel sheet after the finish rolling in the center in the longitudinal direction and at the central portion in the width direction, and

T_3 denotes the temperature (°C) of the steel sheet after the finish rolling at a position 30 m from a rear end in the longitudinal direction and at the central portion in the width direction.

[0004]

Patent Literature 2 proposes a hot-rolled steel sheet with excellent scale adhesion characterized in that a slab containing, on a mass percent basis, 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 remainder being Fe and incidental impurities, is heated at 1100°C or more, then hot rolling is finished in a temperature range of 800°C to 950°C, and coiling is performed at 400°C to 650°C, so that the number of roughness heights of 0.5 μm or more per inch of length is 300 or more as the surface roughness of the interface between the steel sheet surface scale and the steel sheet substrate.

[0005]

Patent Literature 3 proposes a hot-rolled steel sheet with mill scale with high blackness characterized in that a hot-rolled steel sheet with a chemical composition containing C: 0.001 to 0.20% by mass, Si: 0.001 to 0.50% by mass, Mn: 0.05 to 2.0% by mass, P: 0.05% by mass or less, S: 0.05% by mass or less, and sol. Al: 0.01 to 0.10% by mass, with the remainder being Fe and incidental impurities, has a scale with a thickness of more than 4 μm on the surface thereof, the scale has a composition containing 50% or more of Fe_3O_4 in terms of volume ratio, and precipitated Fe is not contained in a region from the scale surface to a depth of

at least 2 μm in the thickness direction.

Citation List

Patent Literature

[0006]

PTL 1: Japanese Patent No. 6760425

PTL 2: Japanese Patent No. 4153734

PTL 3: Japanese Patent No. 4061996

Summary of Invention

Technical Problem

[0007]

In the technique described in Patent Literature 1, a steel material with a predetermined chemical composition is used to adjust the finish rolling delivery temperature during hot rolling, the cooling rate after rolling, and the coiling temperature. This optimizes the average grain size of the magnetite grains in the upper layer of the magnetite layer on the steel substrate side and/or the average block size of the eutectoid transformation structure of iron and magnetite in the scale layer. Furthermore, the temperature of the steel sheet in the longitudinal direction immediately after the finish rolling is controlled to improve the adhesion of scale uniform in the longitudinal direction. However, a method for suppressing powder-like scale peeling is not mentioned.

[0008]

In the technique described in Patent Literature 2, a hot-rolled steel sheet with excellent scale adhesion is proposed by hot-rolling steel to which predetermined amounts of Ni, Cu, and Cr are added and controlling the surface roughness of the interface between the steel sheet surface scale and the steel sheet substrate in a predetermined range. However, although the adhesion at the interface between the scale layer and the steel substrate is improved, there is a concern that peeling off of the scale occurs in the scale surface layer or inside the scale and decreases the adhesion. Furthermore, a method for suppressing powder-like scale peeling is not mentioned.

[0009]

In the technique described in Patent Literature 3, a steel slab with a predetermined chemical composition is heated, is then hot-rolled at a finish rolling delivery temperature of 800°C or more, is then cooled to 650°C or less at a cooling rate of 50°C/s or more, and is coiled at 600°C or more. This advantageously realizes blackening of scale while maintaining the adhesion of the scale. However, control is performed to blacken the scale so that precipitated Fe is not contained in a region from the scale surface to a depth of at least 2 μm in the thickness direction, and there is a concern that particularly powder-like scale peeling cannot be sufficiently suppressed.

[0010]

It is an object of the present invention to solve the above-described problems and to provide a hot-rolled steel sheet with excellent scale adhesion including adhesion at an interface between scale and a steel substrate and high powdery peeling resistance and to provide a method for producing the same. A hot-rolled steel sheet in the present invention has a thickness of more than 2.0 mm and 20 mm or less, preferably more than 5.0 mm and 20 mm or less.

Solution to Problem

[0011]

The present inventors first investigated the cause of powder-like peeling of scale in a conventional hot-rolled steel sheet. As a result, it was found that scale peeled off in the form of powder was mainly composed of magnetite and was caused by breakage inside the scale. Thus, it is possible to appropriately control magnetite formed on the surface layer side of scale to suppress powder-like peeling.

[0012]

Scale formed during hot rolling is formed in the order of hematite, magnetite (Fe_3O_4), and wustite (FeO) from the surface layer side at a high temperature. Among these, wustite undergoes eutectoid transformation while being cooled after coiling and forms a eutectoid transformation structure composed of magnetite and precipitated Fe ($4\text{FeO} \rightarrow$

$\text{Fe}_3\text{O}_4 + \text{Fe}$). In the conventional art, a crack occurring at the interface between magnetite formed at a high temperature and the eutectoid transformation structure causes powder-like scale peeling.

[0013]

Thus, the present inventors have conducted intensive studies on means for solving the above problems and achieving high adhesion at the interface between the scale and the steel substrate and high powdery peeling resistance, and have obtained the following findings.

(i) A steel material with a predetermined chemical composition is subjected to hot rough rolling, descaling, and finish rolling at a finish rolling delivery temperature in a range of 800°C to 950°C, thereby appropriately controlling the scale thickness and suppressing the occurrence of a crack in the scale.

(ii) Cooling is performed at an average cooling rate of 5°C/s or more in a temperature range of the finish rolling delivery temperature to 750°C and then at an average cooling rate of 1°C/s or more and 30°C/s or less in a temperature range of 750°C to a coiling start temperature, thereby suppressing excessive growth of scale at a high temperature.

(iii) Coiling is performed at a coiling temperature in a range of 500°C to 650°C, and holding is performed for 100 minutes or more in a temperature range of the coiling

temperature - 50°C or more and the coiling temperature or less. At this time, the steel sheet surface is shielded from the air atmosphere by coiling and is held in a temperature range in which wustite is stably formed, thereby reducing part or all of hematite and magnetite formed on the scale surface layer to wustite. After coiling, holding in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or less for 100 minutes or more allows the eutectoid transformation of wustite to proceed sufficiently and form a eutectoid transformation structure also on the surface layer side of the scale. This can improve the adhesion at the interface between the scale and the steel substrate, decrease the amount of magnetite generated in the scale surface layer, and thereby suppress powder-like peeling.

[0014]

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

[1] A hot-rolled steel sheet having a chemical composition containing, on a mass percent basis, 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 remainder being Fe and incidental impurities, and having a scale on a surface of the steel sheet, wherein the scale has an average thickness of 20 μm or less and has a

microstructure containing, in terms of area ratio, magnetite: 20% or more, a eutectoid transformation structure of iron and magnetite: 40% or more, wustite: 15% or less, and 90% or more (including 100%) of a total of the magnetite, the wustite, and the eutectoid transformation structure of iron and magnetite, and precipitated Fe in a region from an outermost surface layer of the scale to 1/2 of a thickness of the scale in a thickness direction has an area ratio of 2% or more.

[2] The hot-rolled steel sheet according to [1], wherein the chemical composition further contains, on a mass percent basis, one or more of 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, on a mass percent basis, one or more of 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 comprising: subjecting a steel material with the chemical composition according to [1] or [2] to hot rough rolling, descaling, finish rolling at a finish rolling delivery temperature in a range of 800°C to 950°C, cooling at an average cooling rate of 5°C/s or more in a temperature range of the finish rolling delivery temperature to 750°C,

cooling at an average cooling rate of 1°C/s or more and 30°C/s or less in a temperature range of 750°C to a coiling start temperature, coiling at a coiling temperature of 500°C to 650°C, and holding in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or less for 100 minutes or more.

[5] A method for producing a hot-rolled steel sheet, comprising subjecting a steel material with the chemical composition according to [3] to hot rough rolling, descaling, finish rolling at a finish rolling delivery temperature in a range of 800°C to 950°C, cooling at an average cooling rate of 5°C/s or more in a temperature range of the finish rolling delivery temperature to 750°C, cooling at an average cooling rate of 1°C/s or more and 30°C/s or less in a temperature range of 750°C to a coiling start temperature, coiling at a coiling temperature of 500°C to 650°C, and holding in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or less for 100 minutes or more.

Advantageous Effects of Invention

[0015]

The present invention can easily produce a hot-rolled steel sheet with excellent scale adhesion at low cost and have significant industrial advantages. The present invention also has the effects of preventing peeling at the

interface between scale and a steel substrate and greatly contributing to improvement of surface quality of a product, prevention of a processing defect of a product, and improvement of a work environment. Furthermore, it is possible to solve the problem of a decrease in powdery peeling resistance.

Description of Embodiments

[0016]

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

[0017]

A hot-rolled steel sheet according to the present invention includes the following chemical composition. The unit "%" of the chemical composition content refers to "% by mass" unless otherwise specified.

[0018]

C: 0.01% to 0.30%

C is an element useful for ensuring the strength. A C content of less than 0.01% results in a small effect of ensuring the strength, so that the C content is 0.01% or

more. A C content of more than 0.30% results in generation of CO gas at the interface between the scale and the steel substrate, peeling at the interface between the scale and the steel substrate during rolling, and a scale defect, so that the C content is 0.30% or less. From the perspective of the adhesion at the interface between the scale and the steel substrate, the C content is preferably 0.20% or less.

[0019]

Si: 0.50% or less

Si is an element that acts as a deoxidizing agent, and the Si content is preferably 0.01% or more to produce such an effect. However, a Si content of more than 0.50% results in Si concentrated at the interface between the scale and the steel substrate and the formation of a Si oxidized layer. Scale is likely to be peeled off at the interface between the Si oxidized layer and a scale layer formed thereon. Thus, the Si content is 0.50% or less, preferably 0.20% or less.

[0020]

Mn: 0.01% to 2.0%

Mn is an element effective in not only rendering solute S, which causes embrittlement during hot working, harmless as MnS, but also improving the strength. A Mn content of less than 0.01% results in a small effect, whereas a Mn content of more than 2.0% results in a decrease in toughness

and the formation of a Mn oxides at the interface between the scale and the steel substrate, which causes a decrease in the adhesion of the scale. Thus, the Mn content ranges from 0.01% to 2.0%. A preferred lower limit is 0.05% or more. A preferred upper limit is 1.5% or less.

[0021]

P: 0.10% or less

P adversely affects grain boundary embrittlement and is therefore an element that is desirably decreased as much as possible. Furthermore, P forms a very brittle oxidized layer at the interface between the scale and the steel substrate and decreases the adhesion at the interface between the scale and the steel substrate. These adverse effects become large at a P content of more than 0.10%, so that the P content is 0.10% or less, preferably 0.05% or less. Although P is not necessarily contained, the P content is preferably 0.001% or more from the perspective of production costs.

[0022]

S: 0.10% or less

S is an element that significantly decreases hot workability and toughness. Furthermore, S is concentrated at the interface between the scale and the steel substrate and decreases the adhesion at the interface between the scale and the steel substrate. These adverse effects become

large at a S content of more than 0.10%, so that the S content is 0.10% or less, preferably 0.05% or less.

Although S is not necessarily contained, the S content is preferably 0.0001% or more from the perspective of production cost.

[0023]

Sol. Al: 0.10% or less

Sol. Al is an element that acts as a deoxidizing agent. Although the sol. Al content may be 0.00%, to produce such an effect, the sol. Al content is preferably 0.01% or more. On the other hand, a sol. Al content of more than 0.10% results in an increase in the amount of oxide inclusion and a decrease in cleanliness. Thus, the Al content is 0.10% or less, preferably 0.06% or less.

[0024]

N: 0.015% or less

N is an element that forms nitrides, such as BN, AlN, TiN and the same, in steel and is an element that impairs the hot ductility and surface quality of steel. A N content of more than 0.015% results in significant deterioration of surface quality. Thus, the N content is 0.015% or less. The N content is preferably 0.010% or less. Although N is not necessarily contained, the N content is preferably 0.0001% or more from the perspective of production cost. More preferably, the N content is 0.001% or more.

[0025]

The above-described chemical components are essential components of a hot-rolled steel sheet according to the present invention. In addition to the above-described chemical components, a hot-rolled steel sheet according to the present invention may contain one or more of Cu: 1.0% or less, Ni: 0.50% or less, and Cr: 2.0% or less as necessary to improve various properties.

[0026]

Cu: 1.0% or less

Cu is an element that is concentrated at the interface between the scale and the steel substrate to promote grain boundary oxidation, promotes roughening of the interface between the scale and the steel substrate, and increases the adhesion at the interface between the scale and the steel substrate. To produce such an effect, the Cu content is preferably 0.01% or more. However, a Cu content of more than 1.0% may result in molten Cu entering an austenite grain boundary of the steel substrate during heating and degradation of the surface properties caused by hot embrittlement. Thus, when Cu is contained, the Cu content is 1.0% or less, preferably 0.8% or less.

[0027]

Ni: 0.50% or less

Similarly to Cu, Ni is also an element that is

concentrated at the interface between the scale and the steel substrate to promote grain boundary oxidation, promotes roughening of the interface between the scale and the steel substrate, and increases the adhesion at the interface between the scale and the steel substrate. To produce such an effect, the Ni content is preferably 0.01% or more. However, a Ni content of more than 0.50% may result in saturation of the above effects and an increase in cost. Thus, when Ni is contained, the Ni content is 0.50% or less, preferably 0.40% or less.

[0028]

Cr: 2.0% or less

Cr has the effects of increasing strength, hardenability, and corrosion resistance. Furthermore, Cr is concentrated at the interface between the scale and the steel substrate and also has an effect of improving the adhesion at the interface between the scale and the steel substrate by roughening the interface and allowing the scale to bite into the steel substrate. To produce such an effect, the Cr content is preferably 0.01% or more. On the other hand, the above-described effects are saturated at a Cr content of more than 2.0%, and the Cr content is therefore 2.0% or less when Cr is contained. A more preferred lower limit is 0.07% or more. A more preferred upper limit is 1.0% or less. The most preferred lower limit

is 0.12% or more. The most preferred upper limit is 0.8% or less.

[0029]

In the present invention, if necessary, one or more of 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 may be further contained.

[0030]

Mo: 1.0% or less

Mo has the effects of improving strength and hardenability and suppressing softening caused by tempering. To produce such an effect, the Mo content is preferably 0.1% or more. On the other hand, a Mo content of more than 1.0% results in an excessive increase in strength and a decrease in toughness and formability, so that the Mo content is 1.0% or less when Mo is contained.

[0031]

Nb: 0.1% or less

Nb is an element that improves the strength and toughness of the base material and, to produce such an effect, the Nb content is preferably 0.003% or more. On the other hand, a Nb content of more than 0.1% may unexpectedly result in a decrease in toughness. Thus, when Nb is contained, the Nb content is 0.1% or less.

[0032]

V: 0.1% or less

V is an element that improves the strength and toughness of the base material and, to produce such an effect, the V content is preferably 0.003% or more. On the other hand, a V content of more than 0.1% may unexpectedly result in a decrease in toughness. Thus, when V is contained, the V content is 0.1% or less.

[0033]

Ti: 0.03% or less

Ti is an element that improves the strength and toughness of the base material, and is also effective in ensuring toughness in a weld heat affected zone. To produce these effects, the Ti content is preferably 0.001% or more. On the other hand, a Ti content of more than 0.03% may unexpectedly result in a decrease in toughness. Thus, when Ti is contained, the Ti content is 0.03% or less.

[0034]

B: 0.01% or less

B is an element that increases the hardenability of steel, and this effect can increase the strength. To produce such an effect, the B content is preferably 0.0005% or more. On the other hand, this effect is saturated at a B content of more than 0.01%, so that the B content is 0.01% or less.

[0035]

Sb: 0.03% or less

Sb is concentrated in the surface layer when the material is heated, and has an effect of reducing a decrease in the C content of the surface layer during heating. To produce such an effect, the Sb content is preferably 0.001% or more. On the other hand, an Sb content of more than 0.03% results in a liquid metal at the time of heating the material, erosion of a prior-austenite grain boundary, and a decrease in the adhesion at the interface between the scale and the steel substrate. Thus, when Sb is contained, the Sb content is 0.03% or less.

[0036]

The remainder other than the above-described chemical components is composed of Fe and incidental impurities. The incidental impurities may be O: 0.005% or less, Mg: 0.003% or less, Sn: 0.1% or less, and Ca: 0.01% or less.

[0037]

When these optional components are contained in amounts below their respective appropriate lower limits, optional elements contained in amounts below their lower limits do not decrease the advantages of the present invention. Thus, when the optional elements are contained in amounts below the appropriate lower limits, the optional elements are considered to be contained as incidental impurities.

[0038]

Next, the scale microstructure of a hot-rolled steel sheet according to the present invention will be described.
[0039]

Scale with Average Thickness of 20 μm or Less

When the scale has an average thickness of more than 20 μm , the strain applied to the outermost surface layer of the scale or the interface between the scale and the steel substrate increases while the steel sheet is processed, decreases the adhesion at the interface between the scale and the steel substrate, and decreases the powdery peeling resistance. Thus, the scale has an average thickness of 20 μm or less, preferably 18 μm or less, more preferably 15 μm or less. The lower limit of the average thickness of the scale is preferably, but not limited to, 3 μm or more, more preferably 5 μm or more, from the perspective of ensuring the stability of the cut surface quality during processing, such as laser cutting.

[0040]

Magnetite: 20% or more

Magnetite has high compatibility with the steel substrate and contributes to the improvement of the adhesion at the interface between the scale and the steel substrate. This effect cannot be sufficient at less than 20%, so that magnetite has an area ratio of 20% or more, preferably 30% or more. Although there is no upper limit, when magnetite

has an area ratio of more than 70%, the magnetite in the scale surface layer, which is a cause of powder-like peeling, increases, and the powdery peeling resistance may be decreased. Thus, magnetite preferably has an area ratio of 70% or less, more preferably 60% or less. It should be noted that this magnetite can be distinguished from magnetite contained in the eutectoid transformation structure of iron and magnetite.

[0041]

Eutectoid transformation structure of iron and magnetite: 40% or more

The eutectoid transformation structure of iron and magnetite contributes to the improvement of the adhesion at the interface between the scale and the steel substrate due to high compatibility between magnetite and precipitated Fe and the steel substrate. Furthermore, when the eutectoid transformation structure of iron and magnetite is contained on the surface layer side of the scale, it decreases the amount of magnetite in the scale surface layer, which is a cause of powder-like peeling, and thereby contributes to the improvement of the powdery peeling resistance. This effect cannot be sufficient at less than 40%, so that the eutectoid transformation structure of iron and magnetite has an area ratio of 40% or more, preferably 45% or more, more preferably 50% or more.

[0042]

Wustite: 15% or less

In addition to magnetite and the eutectoid transformation structure of iron and magnetite, wustite may remain in an untransformed state at room temperature. Wustite is more brittle than magnetite at room temperature, and a crack in the scale decreases the scale powdery peeling resistance. Furthermore, wustite has a lower compatibility with the steel substrate than magnetite or the eutectoid transformation structure of iron and magnetite, which decreases the adhesion at the interface between the scale and the steel substrate. Thus, wustite has an area ratio of 15% or less, preferably 10% or less, more preferably 7% or less. Wustite may have an area ratio of 0%.

[0043]

In addition to wustite, a hematite layer may be formed in an outermost surface layer portion of a hot-rolled steel sheet and may be contained because the formation of the hematite layer does not decrease the advantages of the present invention. Since the hematite layer causes a surface defect, such as red scale, the mass fraction of hematite is preferably 10% or less. The mass fraction of hematite can be regarded as an area ratio.

[0044]

Total of magnetite, wustite, and eutectoid

transformation structure of iron and magnetite: 90% or more (including 100%)

When a large amount of phase, such as hematite, other than magnetite, wustite, and a eutectoid transformation structure of iron and magnetite is contained, the total fraction of magnetite, wustite, and the eutectoid transformation structure of iron and magnetite may be less than 90%. In such a case, a surface defect occurs, and the adhesion at the interface between the scale and the steel substrate and the powdery peeling resistance are decreased. From the perspective of ensuring the surface quality, the predetermined adhesion at the interface between the scale and the steel substrate, and the powdery peeling resistance, the total fraction of magnetite, wustite, and the eutectoid transformation structure of iron and magnetite is 90% or more.

[0045]

In addition to hematite, non-ferrous oxides, for example, a Si oxide, a Cr oxide and the same, are contained as a remaining microstructure other than magnetite, wustite, and the eutectoid transformation structure of iron and magnetite, and a total of 10% or less of these in terms of area ratio does not impair the advantages of the present invention. Furthermore, the remaining microstructure can be measured by X-ray diffraction analysis in the same manner as

in the method for measuring the mass fraction of hematite described later.

[0046]

Precipitated Fe in region from outermost surface layer of scale to 1/2 of thickness of scale in thickness direction: 2% or more

Part or all of hematite and magnetite formed on the scale surface layer at a high temperature are reduced to wustite by the temperature control described later. After coiling, holding in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or less for 100 minutes or more allows the eutectoid transformation of wustite to proceed sufficiently and form a eutectoid transformation structure also on the surface layer side of the scale. This can improve the adhesion at the interface between the scale and the steel substrate, decrease the amount of magnetite generated in the scale surface layer, and thereby suppress powder-like peeling. Furthermore, the amount of the eutectoid transformation structure on the surface layer side can be represented by the area ratio of precipitated Fe in a region from the outermost surface layer of the scale to 1/2 of the thickness of the scale in the thickness direction. From the perspective of suppressing the powder-like peeling, the precipitated Fe in the region from the outermost surface

layer of the scale to 1/2 of the thickness of the scale in the thickness direction is 2% or more, preferably 3% or more. The upper limit of the precipitated Fe in the region from the outermost surface layer of the scale to 1/2 of the thickness of the scale in the thickness direction is preferably, but not limited to, 50% or less.

[0047]

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

[0048]

Regarding the area ratios of magnetite, a eutectoid transformation structure of iron and magnetite, wustite, and precipitated Fe, a cross section in the thickness direction perpendicular to a steel sheet surface and parallel to the rolling direction is cut out and mirror-polished. Subsequently, the measurement can be performed by observing a backscattered electron image of a cross section of the scale using a scanning electron microscope (SEM) at an observation magnification of 3000 times. In the backscattered electron image of the SEM, magnetite is the darkest, the steel substrate and precipitated Fe are the brightest, and wustite is a region that appears with an intermediate contrast. The average thickness of the scale is determined by measuring the thickness of the scale at

three arbitrary positions with the SEM and averaging the measured values. Furthermore, each area ratio of magnetite, wustite, and the eutectoid transformation structure of iron and magnetite refers to a value when the area of the entire oxidized scale is 100%, and when there is a void in the oxidized scale it is excluded from the calculation of the area ratio.

[0049]

For the mass fraction of hematite, the integrated intensity of the diffraction peak of each phase in the scale is measured with an X-ray diffractometer using a CoK_α radiation source. From the ratio of the integrated intensity of each phase in a standard sample (a mixture of equal weights of Fe, FeO (wustite), Fe_2O_3 (hematite), and Fe_3O_4 (magnetite)) and a test sample, it can be determined using the following formula (2):

$$\text{Mass fraction of phase A} = (I_A/R_A) \times 100 / ((I_{\text{Fe}}/R_{\text{Fe}}) + (I_{\text{FeO}}/R_{\text{FeO}}) + (I_{\text{Fe}_2\text{O}_3}/R_{\text{Fe}_2\text{O}_3}) + (I_{\text{Fe}_3\text{O}_4}/R_{\text{Fe}_3\text{O}_4})) \quad (2)$$

wherein

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

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

A denotes Fe, FeO, Fe_2O_3 , or Fe_3O_4 .

The mass fraction of hematite detected with the X-ray

diffractometer is regarded as an area ratio and is subtracted from 100% of the area of the entire oxidized scale described above, and the area ratios of magnetite, the eutectoid transformation structure, and wustite are respectively calculated from the remaining area.

[0050]

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

[0051]

The temperature specified in each step in the present invention refers to the surface temperature of a slab (steel slab) or a steel sheet and can be measured with a radiation thermometer or the like. Furthermore, unless otherwise specified, the average cooling rate is ((cooling start temperature - cooling stop temperature)/cooling time).

[0052]

In the present invention, a method for producing a steel material with the above-described chemical composition is not particularly limited, and any common method can be applied. For example, it is desirable that a molten steel with the above-described chemical composition be 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 a continuous casting method. An ingot casting and blooming method may be used without any problem. A steel

material is typically heated and then hot-rolled. This heating is only required to achieve sufficient solid solution, preferably by reaching the Ac3 point or higher. More specifically, a typical slab heating temperature range of 1060°C to 1300°C is suitable. A slab produced by a continuous casting method may be subjected to hot direct rolling in which the slab is rolled as it is or while being held for the purpose of reducing a decrease in temperature.

[0053]

A hot-rolling process includes rough rolling and finish rolling. In the rough rolling, provided that a sheet bar with a predetermined dimension is formed, the conditions of the rough rolling are not particularly limited. Furthermore, to perform the finish rolling at a predetermined temperature, the material to be rolled may be heated by a heating means, such as a sheet bar heater, in the middle. Scale formed on the surface of the sheet bar is removed by descaling at a known high water pressure or the like on the inlet side of a finish rolling mill before finish rolling.

[0054]

Next, finish rolling is performed. A finish rolling entry temperature of more than 1100°C may result in an increase in scale thickness and a decrease in the adhesion at the interface between the scale and the steel substrate

and a decrease in the scale powdery peeling resistance. On the other hand, a finish rolling entry temperature of 950°C or less may result in a significant increase in rolling force and a decrease in productivity. Furthermore, as the product sheet thickness increases, the thickness on the finish rolling entry side increases and, for example, a product sheet with a thickness of more than 5.0 mm may require a long time to start the finish rolling, which results in a decrease in productivity. Thus, the finish rolling entry temperature is preferably 1100°C or less, more preferably 1050°C or less. The lower limit of the finish rolling entry temperature is preferably 950°C or more.

[0055]

Finish rolling delivery temperature: 800°C to 950°C

A finish rolling delivery temperature of less than 800°C results in cracking due to a decrease in the ductility of scale. This decreases the adhesion at the interface between the scale and the steel substrate, and a crack promotes reoxidation of the scale to form hematite and thereby causes a decrease in the scale powdery peeling resistance. This also results in a finer scale microstructure and, due to an increase in the hardness of the scale itself, a decrease in the adhesion at the interface between the scale and the steel substrate and a decrease in the powdery peeling resistance. On the other

hand, a finish rolling delivery temperature of more than 950°C results in an increase in the thickness of scale due to excessive growth of the scale and a decrease in the adhesion at the interface between the scale and the steel substrate and a decrease in the scale powdery peeling resistance. Furthermore, as the grain size of each phase in the scale microstructure increases, the scale powdery peeling resistance decreases. Thus, the finish rolling delivery temperature ranges from 800°C to 950°C. A preferred lower limit is 820°C or more. A preferred upper limit is 930°C or less.

[0056]

Cooling at average cooling rate of 5°C/s or more in temperature range of finish rolling delivery temperature to 750°C

Since scale grows faster in a high-temperature region, it is necessary to rapidly cool the high-temperature region immediately after the finish rolling to reduce a decrease in the adhesion at the interface between the scale and the steel substrate and a decrease in the scale powdery peeling resistance caused by excessive growth of the scale. When the average cooling rate in a temperature range of the finish rolling delivery temperature to 750°C is lower than 5°C/s, the scale grows excessively, which causes a decrease in the adhesion at the interface between the scale and the

steel substrate and a decrease in the scale powdery peeling resistance. Thus, the average cooling rate in a temperature range of the finish rolling delivery temperature to 750°C is 5°C/s or more, preferably 7°C/s or more. On the other hand, when the average cooling rate in a temperature range of the finish rolling delivery temperature to 750°C is higher than 80°C/s, the scale microstructure may be refined, and the adhesion of the scale may therefore be decreased.

Furthermore, a crack may occur due to a decrease in the ductility of the scale and promote reoxidation of the scale to form hematite, which causes a decrease in the scale powdery peeling resistance. Thus, the average cooling rate in a temperature range of the finish rolling delivery temperature to 750°C is preferably 80°C/s or less, more preferably 50°C/s or less.

[0057]

Cooling at average cooling rate of 1°C/s or more and 30°C/s or less in temperature range of 750°C to coiling start temperature

The growth of scale is relatively slower in a temperature range of 750°C to a coiling start temperature than in the high-temperature region immediately after the finish rolling, but it is necessary to reduce a decrease in the adhesion at the interface between the scale and the steel substrate and a decrease in the scale powdery peeling

resistance caused by excessive growth of the scale. When the average cooling rate in a temperature range of 750°C to a coiling start temperature is lower than 1°C/s, scale grows excessively, which causes a decrease in the adhesion at the interface between the scale and the steel substrate and a decrease in the scale powdery peeling resistance. Thus, the average cooling rate in a temperature range of 750°C to a coiling start temperature is 1°C/s or more, preferably 3°C/s or more. On the other hand, when the average cooling rate in a temperature range of 750°C to a coiling start temperature is higher than 30°C/s, the scale microstructure becomes finer, and the stress difference between the scale and the steel substrate increases. This causes a crack in the scale and decreases the adhesion at the interface between the scale and the steel substrate, and the crack promotes reoxidation of the scale to form hematite and decreases the powdery peeling resistance of the scale. Thus, the average cooling rate in a temperature range of the finish rolling delivery temperature to 750°C is 30°C/s or less, preferably 20°C/s or less.

[0058]

Coiling temperature: 500°C to 650°C

After the cooling, the steel sheet is coiled at a coiling temperature in the range of 500°C to 650°C. The surface of the steel sheet is shielded from the air

atmosphere by coiling and is held in a temperature range in which wustite is stably formed, thereby reducing part or all of hematite and magnetite formed on the surface layer of the scale to wustite. A eutectoid transformation structure is formed also on the surface layer side of the scale by holding the temperature range of the coiling temperature - 50°C or more and the coiling temperature or less for 100 minutes or more after coiling to sufficiently progress the eutectoid transformation of wustite. This can improve the adhesion at the interface between the scale and the steel substrate, decrease the amount of magnetite generated in the scale surface layer, and thereby suppress powder-like peeling. When the coiling temperature is lower than 500°C, the eutectoid transformation of wustite does not occur sufficiently, and wustite remains excessively at room temperature. This decreases the adhesion at the interface between the scale and the steel substrate and decreases the powdery peeling resistance of the scale. Furthermore, the reduction of hematite and magnetite in the surface layer of the scale to wustite does not proceed sufficiently, the eutectoid transformation of the surface layer of the scale becomes insufficient, and the powdery peeling resistance decreases. When the coiling temperature is higher than 650°C, the scale grows excessively, resulting in a decrease in the adhesion at the interface between the scale and the

steel substrate and a decrease in the scale powdery peeling resistance. Thus, the coiling temperature is 500°C or more and 650°C or less, and a preferred lower limit is 530°C or more. A preferred upper limit is 630°C or less.

[0059]

Holding in temperature range of coiling temperature - 50°C or more and coiling temperature or less for 100 minutes or more

After the coiling, the temperature range of the coiling temperature - 50°C or more and the coiling temperature or less is held for 100 minutes or more to allow the eutectoid transformation of wustite to proceed sufficiently. When the holding time in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or less is less than 100 minutes, the eutectoid transformation structure formed on the surface layer side of the scale becomes insufficient, and the powdery peeling resistance is decreased. Holding at a temperature lower than the coiling temperature - 50°C results in insufficient eutectoid transformation of wustite and wustite remaining excessively at room temperature. This decreases the adhesion at the interface between the scale and the steel substrate and decreases the scale powdery peeling resistance. Thus, the holding time in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or

less is 100 minutes or more, preferably 120 minutes or more. Furthermore, a long holding time may result in excessive progress of internal oxidation at the interface between the scale and the steel substrate, which causes a decrease in the scale adhesion, so that the holding time in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or less is preferably 300 minutes or less.

[0060]

The coil after the coiling is preferably placed in a coil box or covered to suppress oxidation of the outermost periphery and the edge portion.

[0061]

Furthermore, the hot-rolled steel sheet coiled in a coil shape may be deformed with a roller leveler, a tension leveler, or the like for a shape correction treatment. For example, a hot-rolled steel sheet with a thickness of 12 mm is subjected to the shape correction treatment using two upper rolls and three lower rolls of $\phi 250$ mm at a pressing amount of 2 mm.

EXAMPLES

[0062]

Examples of the present invention will be described below.

[0063]

Steels with the compositions shown in Table 1 were melted and cast to produce steel materials. These steel materials were hot-rolled under the conditions shown in Table 2 to form hot-rolled coils with a thickness in the range of 6 to 18 mm. The hot-rolled coils were subjected to shape correction treatment by leveling and were then cut into a predetermined length to form hot-rolled sheets. Test specimens were taken from each portion of the hot-rolled sheets to evaluate the scale microstructure and scale adhesion by the following methods.

[0064]

[Table 1]

Steel No.	Chemical composition (% by mass)											Notes
	C	Si	Mn	P	S	sol. Al	N	Cu	Ni	Cr	Others	
A	0.083	0.01	0.75	0.015	0.0045	0.034	0.0028	-	-	-	-	Conforming steel
B	0.035	0.03	1.84	0.016	0.0023	0.040	0.0033	0.06	0.03	-	-	Conforming steel
C	0.163	0.44	0.55	0.016	0.0038	0.035	0.0035	-	-	0.41	-	Conforming steel
D	0.195	0.15	0.62	0.017	0.0053	0.036	0.0031	0.42	0.31	0.18	-	Conforming steel
E	0.124	0.05	1.23	0.016	0.0023	0.042	0.0025	-	-	-	Mo: 0.61, Nb: 0.04, V: 0.04	Conforming steel
F	0.284	0.22	0.41	0.015	0.0038	0.031	0.0038	0.04	0.02	0.23	Ti: 0.016, B: 0.005, Sb: 0.01	Conforming steel
G	<u>0.320</u>	0.30	0.87	0.016	0.0053	0.035	0.0037	-	-	-	-	Comparative steel
H	0.150	<u>0.63</u>	1.10	0.013	0.0047	0.040	0.0028	-	-	-	-	Comparative steel
I	0.225	0.16	<u>2.18</u>	0.018	0.0052	0.042	0.0033	-	-	-	-	Comparative steel
J	0.087	0.02	1.45	0.014	0.0041	0.037	0.0036	-	-	-	-	Conforming steel
K	0.155	0.01	0.88	0.015	0.0035	0.023	0.0038	-	-	-	-	Conforming steel
L	0.164	0.02	0.81	0.013	0.0044	0.028	0.0032	0.04	0.02	0.21	-	Conforming steel

Underlined portion: outside the scope of the present invention.

[0065]

[Table 2]

No.	Steel No.	Hot-rolling conditions								Scale microstructure							Scale adhesion		Notes
		Slab heating temperature (°C)	Finish rolling entry temperature (°C)	Finish rolling delivery temperature (°C)	Thickness after finish rolling (mm)	Average cooling rate of finish rolling delivery temperature to 750°C (°C/s)	Average cooling rate of 750°C to start of coiling (°C/s)	Coiling temperature (°C)	Holding time of coiling temperature - 50°C to coiling temperature (min)	Average thickness of scale (μm)	Area ratio of magnetite (%)	Area ratio of eutectoid transformation structure (%)	Area ratio of wustite (%)	Mass fraction of hematite (%)	Area ratio of magnetite, wustite, and eutectoid transformation structure (%)	Area ratio of precipitated Fe on scale surface layer side (%)	Interfacial adhesion	Powdery peeling resistance	
1	A	1200	1000	880	6	35	27	520	150	6	34	55	4	7	93	4	O	O	Inventive example
2	A	1200	1000	880	12	24	18	540	150	10	33	60	2	5	95	5	O	O	Inventive example
3	A	1200	1000	880	18	6	5	560	150	18	43	52	1	4	96	3	O	O	Inventive example
4	B	1200	1000	880	14	8	6	580	150	12	49	45	0	6	94	2	O	O	Inventive example
5	B	1200	1000	<u>785</u>	14	8	6	600	150	11	26	62	0	<u>12</u>	<u>88</u>	5	x	x	Comparative example
6	B	1200	1000	<u>965</u>	14	8	6	620	150	<u>22</u>	42	53	0	5	95	3	x	x	Comparative example
7	C	1200	1000	880	14	8	6	640	120	13	50	45	0	5	95	3	O	O	Inventive example
8	C	1200	1000	880	14	<u>3</u>	6	520	150	<u>21</u>	47	42	5	6	94	2	x	x	Comparative example
9	C	1200	1000	880	14	8	<u>0.2</u>	540	150	<u>22</u>	35	58	3	4	96	5	x	x	Comparative example
10	D	1200	1000	880	14	8	6	560	150	11	44	53	1	2	98	4	O	O	Inventive example
11	D	1200	1000	880	14	8	<u>35</u>	580	150	12	35	54	0	<u>11</u>	<u>89</u>	4	x	x	Comparative example
12	D	1200	1000	880	14	8	6	<u>485</u>	<u>90</u>	10	<u>18</u>	<u>35</u>	<u>42</u>	5	95	<u>0</u>	x	x	Comparative example
13	E	1200	1000	880	14	8	6	600	150	9	40	52	0	8	92	4	O	O	Inventive example
14	E	1200	1000	880	14	8	6	<u>660</u>	150	<u>22</u>	40	56	0	4	96	2	x	x	Comparative example
15	E	1200	1000	880	14	8	6	<u>485</u>	150	11	43	42	13	2	98	<u>0</u>	x	x	Comparative example
16	E	1200	1000	880	14	8	6	520	<u>80</u>	12	40	45	13	2	98	<u>1</u>	O	x	Comparative example
17	F	1200	1000	880	14	8	6	540	150	10	45	48	2	5	95	3	O	O	Inventive example
18	<u>G</u>	1200	1000	880	14	8	6	560	150	11	44	49	1	6	94	3	x	x	Comparative example
19	<u>H</u>	1200	1000	880	14	8	6	580	150	10	41	55	0	4	96	4	x	x	Comparative example
20	<u>I</u>	1200	1000	880	14	8	6	600	150	10	44	51	0	5	95	4	x	x	Comparative example
21	J	1200	1000	880	14	8	6	520	150	9	45	45	4	6	94	3	O	O	Inventive example
22	K	1200	1000	880	14	8	6	540	150	12	44	49	2	5	95	4	O	O	Inventive example
23	L	1200	1000	880	14	8	6	560	150	11	38	56	0	6	94	6	O	O	Inventive example

Underlined portion: outside the scope of the present invention.

[0066]

Regarding the area ratios of magnetite, a eutectoid transformation structure of iron and magnetite, wustite, and precipitated Fe, a cross section in the thickness direction perpendicular to a steel sheet surface and parallel to the rolling direction was cut out and mirror-polished. Subsequently, the measurement was performed by observing a backscattered electron image of a cross section of the scale using a scanning electron microscope (SEM) at an observation magnification of 3000 times. In the backscattered electron image of the SEM, magnetite is the darkest, the steel substrate and precipitated Fe are the brightest, and wustite is a region that appears with an intermediate contrast. The average thickness of the scale was determined by measuring the thickness of the scale at three arbitrary positions with the SEM and averaging the measured values.

[0067]

For the mass fraction of hematite, the integrated intensity of the diffraction peak of each phase in the scale was measured with an X-ray diffractometer using a CoK_α radiation source. From the ratio of the integrated intensity of each phase in a standard sample (a mixture of equal weights of Fe, FeO (wustite), Fe_2O_3 (hematite), and Fe_3O_4 (magnetite)) and a test sample, it was determined using the following formula (2):

$$\text{Mass fraction of phase A} = (I_A/R_A) \times 100 / ((I_{Fe}/R_{Fe}) + (I_{FeO}/R_{FeO}) + (I_{Fe2O3}/R_{Fe2O3}) + (I_{Fe3O4}/R_{Fe3O4})) \quad (2)$$

wherein

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

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

A denotes Fe, FeO, Fe₂O₃, or Fe₃O₄.

[0068]

The adhesion of scale in the present invention was evaluated in terms of the adhesion at the interface between the scale and the steel substrate and the powdery peeling resistance. That is, test specimens were taken from the hot-rolled sheets after the leveling, a tape was attached to the surface of each steel sheet to peel off the scale, and the evaluation was performed based on the amount of the steel substrate exposed on the surface of the steel sheet and the amount of the scale attached to the tape. The peeled tape was attached to a transparent sheet and was read by a scanner to measure the peeled amount of the scale by image processing. Regarding the exposure of the steel substrate, an image of the surface of the steel sheet was captured with a camera, and the area ratio of the steel substrate exposed portion, that is, the ratio of the area of the portion where the steel substrate was exposed to the

area of the portion where the tape was peeled off was determined from the captured image. When the area ratio of the steel substrate exposed portion was less than 10% and the area ratio of the scale attached to the peeled tape was less than 10%, the interfacial adhesion and the powdery peeling resistance were judged to be good and were shown as a circle in Table 2. On the other hand, when the area ratio of the steel substrate exposed portion on the surface of the steel sheet was 10% or more, the adhesion at the interface between the scale and the steel substrate was judged to be poor and was shown as a cross in Table 2. Furthermore, when the area ratio of the scale attached to the peeled tape was 10% or more, it was judged to be low powdery peeling resistance and was shown as a cross in Table 2.

[0069]

The examples of the present invention shown in Table 2 had high adhesion at the interface between the scale and the steel substrate and excellent scale powdery peeling resistance, whereas the comparative examples had low adhesion at the interface between the scale and the steel substrate and/or low scale powdery peeling resistance.

CLAIMS

[Claim 1]

A hot-rolled steel sheet having a chemical composition containing, on a mass percent basis,

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 remainder being Fe and incidental impurities,
and

having an oxide scale on a surface of the steel sheet,
wherein the scale has an average thickness of 20 μm or less and has a microstructure containing, in terms of area ratio,

magnetite: 20% or more,

a eutectoid transformation structure of iron and
magnetite: 40% or more,

wustite: 15% or less, and

90% or more (including 100%) of a total of the
magnetite, the wustite, and the eutectoid transformation
structure of iron and magnetite, and

precipitated Fe in a region from an outermost surface
layer of the scale to 1/2 of a thickness of the scale in a

thickness direction has an area ratio of 2% or more.

[Claim 2]

The hot-rolled steel sheet according to Claim 1,
wherein the chemical composition further contains, on a mass
percent basis, one or more of

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, on a mass
percent basis, one or more of

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 with the chemical
composition according to Claim 1 or 2 to hot rough rolling,
descaling,

finish rolling at a finish rolling delivery temperature

in a range of 800°C to 950°C,

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

cooling at an average cooling rate of 1°C/s or more and 30°C/s or less in a temperature range of 750°C to a coiling start temperature,

coiling at a coiling temperature of 500°C to 650°C, and holding in a temperature range of the coiling temperature - 50°C or more and the coiling temperature or less for 100 minutes or more.

[Claim 5]

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

subjecting a steel material with the chemical composition according to Claim 3 to hot rough rolling, descaling,

finish rolling at a finish rolling delivery temperature in a range of 800°C to 950°C,

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

cooling at an average cooling rate of 1°C/s or more and 30°C/s or less in a temperature range of 750°C to a coiling start temperature,

coiling at a coiling temperature of 500°C to 650°C, and
holding in a temperature range of the coiling
temperature - 50°C or more and the coiling temperature or
less for 100 minutes or more.