

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 relates to a hot-rolled steel sheet with excellent scale adhesion, which 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, 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 oxide) 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, flaking-like scale peeling is a major cause of contamination of a process line, deterioration of surface quality, or deterioration of laser cutting properties. Thus, to improve the adhesion of scale, suppression of flaking-like scale peeling is required.

[0003]

Furthermore, there is a tendency that strain generated in scale of a hot-rolled steel sheet during deformation increases with the thickness of the hot-rolled steel sheet, and the scale is easily peeled off. Furthermore, in forming with a high degree of processing, such as bending or press forming, peeling is more likely to occur. On the other hand, the need for a hot-rolled steel sheet with mill scale with a large sheet thickness has been increasing in recent years and, for example, there is also a strong demand for an improvement in the adhesion of scale to a hot-rolled steel sheet with a thickness of more than 5.0 mm.

[0004]

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 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 microstructure 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 microstructure 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 ($^{\circ}\text{C}$) 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 ($^{\circ}\text{C}$) 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.

[0005]

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 the 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.

[0006]

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

[0007]

PTL 1: Japanese Patent No. 6760425

PTL 2: Japanese Patent No. 4153734

PTL 3: Japanese Patent No. 4061996

Summary of Invention

Technical Problem

[0008]

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 microstructure 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 flaking-like scale peeling is not mentioned.

[0009]

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. There is also a concern that the adhesion of scale may decrease in a hot-rolled steel sheet with a larger thickness. Furthermore, a method for suppressing flaking-like scale peeling is not mentioned.

[0010]

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, there is a concern that flaking-like scale peeling cannot be sufficiently suppressed. There is also a concern that the adhesion of the scale may decrease in a hot-rolled steel sheet with a larger thickness.

[0011]

It is an object of the present invention to solve the above problems and to provide a hot-rolled steel sheet with excellent scale adhesion, particularly with high flaking-like peeling resistance, even when the hot-rolled steel sheet has a larger thickness or is subjected to processing, particularly leveling, under severe conditions and to provide a method for producing the hot-rolled steel sheet. A hot-rolled steel sheet in 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.

Solution to Problem

[0012]

The present inventors first investigated the cause of

flaking-like scale peeling in a known hot-rolled steel sheet. As a result, it is shown that the scale peeled off in a flake shape was peeled off from the interface between the scale and the steel substrate. Thus, to suppress flaking-like peeling, it is important to appropriately control the interface properties between the scale and the steel substrate and increase the contact area between the scale and the steel substrate. Furthermore, since the chemical composition of the steel substrate also affects the contact area between the scale and the steel substrate, it is also necessary to appropriately control the chemical composition of the steel substrate.

[0013]

Scale formed during hot rolling is roughly classified into primary scale formed in a slab heating furnace or in a rough rolling process and secondary scale formed in a finish rolling process. In the related art of a steel sheet, the primary scale is often completely removed by descaling before finish rolling, and the properties of the secondary scale therefore have a great influence on the scale adhesion in the final product. Based on these findings, the present inventors have conducted intensive studies on means for achieving excellent scale adhesion, particularly flaking-like peeling resistance, even in a hot-rolled steel sheet with a larger thickness and have obtained the following

findings.

(i) A steel material with a predetermined chemical composition is heated at a heating temperature of 1150°C or more to once remove scale by descaling and is then subjected to descaling by hot rough rolling and water injection at a pressure of 30 MPa or less. As a result, an uneven scale/steel substrate interface suitable for improving the flaking-like peeling resistance is formed in the final product without completely removing the primary scale formed during rough rolling from the interface with the steel substrate.

(ii) After hot rough rolling, finish rolling is performed at a finish rolling delivery temperature in the range of 800°C to 950°C to appropriately control the scale thickness while maintaining the uneven interface between the primary scale and the steel substrate and to suppress the occurrence of a crack in the scale, which causes a decrease in the flaking-like peeling resistance.

(iii) Cooling is performed at an average cooling rate of 5°C/s or more in the 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 the temperature range of 750°C to a coiling start temperature. This suppresses the deterioration of the flaking-like peeling resistance caused by the excessive growth of scale

at high temperatures.

(iv) Coiling is performed at a coiling temperature in the range of 500°C to 630°C, and holding is performed for 100 minutes or more in the temperature range of the coiling temperature - 50°C or more and the coiling temperature or less. At this time, after coiling, holding in the temperature range of the coiling temperature - 50°C or more and the coiling temperature or less for 100 minutes or more sufficiently advances the eutectoid transformation of wustite and thereby improves the flaking-like peeling resistance of scale.

[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 25 μm or less and has a microstructure containing, in terms of area ratio, magnetite: 20% or more, a eutectoid transformation microstructure of iron and magnetite: 30% or more, wustite: 15% or less, and 90% or more (including 100%) of a total of

the magnetite, the wustite, and the eutectoid transformation microstructure of iron and magnetite, and an interface between the scale and a steel substrate has an arithmetic average roughness of 0.3 μm 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 heating a steel material with the chemical composition according to [1] or [2] at a heating temperature of 1150°C or more, descaling the steel material, then performing hot rough rolling and descaling by water injection at a pressure of 30 MPa or less, performing finish rolling at a finish rolling delivery temperature in the range of 800°C to 950°C, cooling at an average cooling rate of 5°C/s or more in the temperature range of the finish rolling delivery temperature to 750°C, then cooling at an average cooling rate of 1°C/s or more and 30°C/s or less in the temperature range of 750°C to a coiling start

temperature, coiling at a coiling temperature in the range of 500°C to 630°C, and holding in the 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, the method comprising heating a steel material with the chemical composition according to [3] at a heating temperature of 1150°C or more, descaling the steel material, then performing hot rough rolling and descaling by water injection at a pressure of 30 MPa or less, performing finish rolling at a finish rolling delivery temperature in the range of 800°C to 950°C, cooling at an average cooling rate of 5°C/s or more in the temperature range of the finish rolling delivery temperature to 750°C, then cooling at an average cooling rate of 1°C/s or more and 30°C/s or less in the temperature range of 750°C to a coiling start temperature, coiling at a coiling temperature in the range of 500°C to 630°C, and holding in the 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 high flaking-like peeling resistance of scale at low cost and have significant industrial

advantages. The present invention also has the effects of preventing flaking-like peeling of scale 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 also possible to solve problems, such as a decrease in the flaking-like peeling resistance of scale, resulting from an increase in the thickness of a hot-rolled steel sheet and processing, particularly leveling, under severe conditions.

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, a decrease in the contact area between the scale and the steel substrate, peeling of the scale during rolling, and a scale defect, so that the C content is 0.30% or less. From the perspective of the flaking-like peeling resistance of scale, 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 solid-

solution 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 oxide at the interface between the scale and the steel substrate, which causes a decrease in the flaking-like peeling resistance of 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 flaking-like peeling resistance of scale. 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 flaking-like peeling resistance of scale. 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 costs.

[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 sol. Al content is 0.10% or less, preferably 0.06% or less.

[0024]

N: 0.015% or less

N is an element that forms a nitride, BN, AlN, TiN and the same, in steel and is an element that impairs the hot ductility and surface quality of steel. Furthermore, a N content of 0.015% or more results in very low 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 costs. 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 characteristics.

[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 the 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 preferable lower limits, optional elements contained in amounts below their lower limits do not impair the effect of the present invention. Thus, when the optional elements are contained in amounts below the

preferable 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 25 μm or less

When the scale has an average thickness of more than 25 μm , the strain applied to the outermost surface layer of the scale increases while the steel sheet is processed, causes a crack in the scale, and decreases the adhesion at the interface between the scale and the steel substrate. Thus, the scale has an average thickness of 25 μm or less, preferably 20 μm or less, more preferably 18 μm or less. Furthermore, 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 flaking-like peeling resistance of scale. 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, magnetite with an area ratio of more than 70% may decrease the ratio of a eutectoid transformation microstructure of iron and magnetite that contributes to the improvement of the flaking-like peeling resistance of scale and decrease the flaking-like peeling resistance in some cases. 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 microstructure of iron and magnetite.

[0041]

Eutectoid transformation microstructure of iron and magnetite: 30% or more

The eutectoid transformation microstructure 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. This effect cannot be sufficient at less than 30%, so that the eutectoid transformation microstructure of iron and magnetite has an area ratio of 30% or more, preferably 40% or more, more preferably 45% or more.

[0042]

Wustite: 15% or less

In addition to magnetite and the eutectoid transformation microstructure of iron and magnetite, wustite may remain in an untransformed state at room temperature in some cases. In addition to being more brittle than magnetite at room temperature, wustite has a lower compatibility with the steel substrate than magnetite or the eutectoid transformation microstructure 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 microstructure 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 microstructure of iron and magnetite is contained, and the total fraction of magnetite, wustite, and the eutectoid transformation microstructure of iron and magnetite is less than 90%, a surface defect occurs, and the flaking-like peeling resistance is decreased. From the perspective of ensuring the surface quality and the predetermined flaking-like peeling resistance, the total fraction of magnetite, wustite, and the eutectoid transformation microstructure of iron and magnetite is 90% or more.

[0045]

In addition to hematite, a non-ferrous oxide, for example, a Si oxide or a Cr oxide, is contained as a remaining microstructure other than magnetite, wustite, and the eutectoid transformation microstructure of iron and magnetite, and a total of 10% or less of these in terms of area ratio does not decrease 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 hematite described later.

[0046]

Arithmetic average roughness at interface between scale and steel substrate: 0.3 μm or more

When the arithmetic average roughness of the interface

between the scale and the steel substrate is $0.3\text{ }\mu\text{m}$ or more, it is possible to suppress flaking-like peeling probably caused by peeling at the interface. When the interface between the scale and the steel substrate has an arithmetic average roughness of less than $0.3\text{ }\mu\text{m}$, this effect is not sufficient, and the flaking-like peeling resistance is deteriorated, so that the interface between the scale and the steel substrate has an arithmetic average roughness of $0.3\text{ }\mu\text{m}$ or more, preferably $0.4\text{ }\mu\text{m}$ or more. Furthermore, there is no upper limit, but from the perspective of ensuring the stability of the cut surface quality during processing, such as laser cutting, the interface between the scale and the steel substrate preferably has an arithmetic average roughness of $5\text{ }\mu\text{m}$ 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 microstructure 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. Then 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 microstructure 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 $\text{CoK}\alpha$ 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, Fe₂O₃, or Fe₃O₄.

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 microstructure, and wustite are calculated from the remaining area.

[0050]

For the arithmetic average roughness of the interface between the scale and the steel substrate, after the scale on the steel sheet surface is removed by pickling, the three-dimensional shape of the surface of the steel substrate is measured with a laser microscope, and five roughness curves with a reference length of 100 μm parallel to the rolling direction are extracted. The arithmetic average roughnesses of these sections determined in accordance with JIS B 0633: 2001 are then averaged.

[0051]

Next, a method for producing a hot-rolled steel sheet

according to the present invention will be described.

[0052]

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).

[0053]

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.

[0054]

Heating temperature: 1150°C or more

The steel material is heated at a heating temperature of 1150°C or more. This heating is performed for the purpose of performing sufficient solid solution of a steel base material and roughening the interface between the primary scale and the steel substrate. The interface is not

sufficiently roughened at a heating temperature of less than 1150°C, and the heating temperature is therefore 1150°C or more, preferably 1180°C or more, and preferably 1300°C or less. 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.

[0055]

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. Scale formed at the time of heating the steel material is descaled by water injection before rough rolling. This is because the scale formed at the time of heating is very thick, and the final product therefore has lower flaking-like peeling resistance of scale and a surface flaw. The descaling at this time may be performed by a known method as long as the thick scale can be removed. 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.

[0056]

Descaling by water injection at pressure of 30 MPa or less

Before finish rolling, descaling is performed by water injection at a pressure of 30 MPa or less on the entry side of a finish rolling mill. Thus, an uneven interface between the scale and the steel substrate suitable for improving the flaking-like peeling resistance in the final product is formed without completely removing primary scale formed during rough rolling from the interface with the steel substrate. When the pressure of the water injection is higher than 30 MPa, the scale may be completely removed from the interface, thus resulting in insufficient roughness of the interface between the scale and the steel substrate and a decrease in the adhesion at the interface between the scale and the steel substrate. Thus, the water injection pressure is 30 MPa or less, preferably 25 MPa or less. Furthermore, from the perspective of preventing an excessive increase in the scale thickness, the water injection pressure is preferably 5 MPa or more, more preferably 10 MPa or more.

[0057]

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 in some cases. 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.

[0058]

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, which causes a decrease in the flaking-like peeling resistance of scale. This also results in a finer scale microstructure and a decrease in the adhesion at the interface between the scale and the steel substrate due to an increase in the hardness of the scale itself. 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. 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.

[0059]

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 inhibit a decrease in the flaking-like peeling resistance of scale caused by excessive growth of the scale. When the average cooling rate in the 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. Thus, the average cooling rate in the 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 the 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 at the interface between the scale and the steel substrate may therefore be decreased in some cases. Furthermore, a crack may occur due to a decrease in the ductility of the scale, which causes a decrease in the adhesion at the interface between the scale and the steel substrate in some cases.

Thus, the average cooling rate in the 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.
[0060]

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 the 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 inhibit a decrease in the adhesion at the interface between the scale and the steel substrate caused by excessive growth of the scale. When the average cooling rate in the 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. Thus, the average cooling rate in the 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 the 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 from the steel substrate increases. This may cause a crack in the scale and decrease the adhesion at the

interface between the scale and the steel substrate in some cases. Thus, the average cooling rate in the temperature range of the finish rolling delivery temperature to 750°C is 30°C/s or less, preferably 20°C/s or less.

[0061]

Coiling temperature: 500°C to 630°C

After the cooling, the steel sheet is coiled at a coiling temperature in the range of 500°C to 630°C. 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. As a result, the flaking-like peeling resistance of scale is deteriorated due to the brittle nature of wustite at room temperature. When the coiling temperature is higher than 630°C, the scale grows excessively, resulting in a decrease in the adhesion at the interface between the scale and the steel substrate. Thus, the coiling temperature is 500°C or more and 630°C or less, and a preferred lower limit is 530°C or more. A preferred upper limit is 620°C or less.

[0062]

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 the temperature range of the coiling temperature - 50°C or more and the coiling temperature or less is less than 100 minutes or when being held at a temperature lower than the coiling temperature - 50°C, the eutectoid transformation of wustite does not occur sufficiently, and wustite remains excessively at room temperature. As a result, the flaking-like peeling resistance of scale is deteriorated due to the brittle nature of wustite at room temperature. Thus, the holding time in the 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 scale/steel substrate interface, which causes a decrease in the flaking-like peeling resistance of scale in some cases, so that the holding time in the temperature range of the coiling temperature - 50°C or more and the coiling temperature or less is preferably 300 minutes or less.

[0063]

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.

[0064]

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

[0065]

Examples of the present invention will be described below.

[0066]

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 adhesion by the following methods.

[0067]

[Table 1]

Steel No.	Chemical composition (% by mass)											Notes
	C	Si	Mn	P	S	sol. Al	N	Cu	Ni	Cr	Others	
A	0.090	0.10	0.78	0.020	0.0053	0.039	0.0033	-	-	-	-	Conforming steel
B	0.037	0.13	1.91	0.022	0.0028	0.047	0.0037	0.05	0.03	-	-	Conforming steel
C	0.167	0.42	0.62	0.017	0.0044	0.037	0.0042	-	-	0.55	-	Conforming steel
D	0.195	0.21	0.65	0.019	0.0058	0.041	0.0037	0.46	0.32	0.13	-	Conforming steel
E	0.130	0.14	1.32	0.018	0.0033	0.046	0.0032	-	-	-	Mo: 0.63, Nb: 0.03, V: 0.03	Conforming steel
F	0.286	0.31	0.43	0.017	0.0043	0.038	0.0044	0.04	0.02	0.25	Ti: 0.017, B: 0.005, Sb: 0.01	Conforming steel
G	<u>0.327</u>	0.35	0.92	0.021	0.0059	0.041	0.0038	-	-	-	-	Comparative steel
H	0.151	<u>0.70</u>	1.18	0.015	0.0049	0.049	0.0032	-	-	-	-	Comparative steel
I	0.234	0.23	<u>2.22</u>	0.022	0.0062	0.045	0.0040	-	-	-	-	Comparative steel
J	0.093	0.02	1.47	0.017	0.0034	0.029	0.0036	-	-	-	-	Conforming steel
K	0.163	0.01	0.82	0.011	0.0039	0.037	0.0038	-	-	-	-	Conforming steel
L	0.156	0.02	0.86	0.015	0.0043	0.033	0.0032	0.05	0.04	0.15	-	Conforming steel

The underlined values lie outside the scope of the present invention.

[0068]

[Table 2]

No.	Steel No.	Hot-rolling conditions									Scale microstructure							Scale adhesion	Notes
		Slab heating temperature (°C)	Decaling pressure before finishing (MPa)	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 microstructure (%)	Area ratio of wustite (%)	Mass fraction of hematite (%)	Area ratio of magnetite, wustite, and eutectoid transformation microstructure (%)	Arithmetic average roughness at interface between scale and steel substrate (μm)	Flaking-like peeling resistance	
1	A	1240	28	1150	900	6	37	27	510	130	6	32	56	4	8	92	0.6	O	Inventive example
2	A	<u>1140</u>	28	1150	900	12	26	18	530	130	9	32	62	2	4	96	<u>0.2</u>	x	Comparative example
3	A	1240	<u>45</u>	1150	900	18	6	5	550	130	19	39	53	1	7	93	<u>0.1</u>	x	Comparative example
4	B	1160	25	1150	900	16	10	5	570	130	13	46	46	0	8	92	0.8	O	Inventive example
5	B	1240	25	1150	<u>785</u>	16	10	5	590	130	14	28	60	0	<u>12</u>	<u>88</u>	1.2	x	Comparative example
6	B	1240	25	1150	<u>965</u>	16	10	5	610	130	<u>26</u>	39	55	0	6	94	0.7	x	Comparative example
7	C	1240	20	1150	900	16	10	5	620	120	13	51	43	0	6	94	0.5	O	Inventive example
8	C	1240	20	1150	900	16	<u>3</u>	5	510	130	<u>27</u>	48	40	5	7	93	0.6	x	Comparative example
9	C	1240	20	1150	900	16	10	<u>0.2</u>	530	130	<u>26</u>	32	60	3	5	95	0.8	x	Comparative example
10	D	1240	10	1150	900	16	10	5	550	130	11	41	55	1	3	97	1.1	O	Inventive example
11	D	1240	10	1150	900	16	10	<u>36</u>	570	130	12	35	54	0	<u>11</u>	<u>89</u>	0.9	x	Comparative example
12	D	1240	10	1150	900	16	10	5	<u>480</u>	110	10	<u>18</u>	<u>28</u>	<u>49</u>	7	93	0.3	x	Comparative example
13	E	1240	5	1150	900	16	10	5	600	130	9	43	50	0	7	93	0.5	O	Inventive example
14	E	1240	5	1150	900	16	10	5	<u>660</u>	130	<u>28</u>	30	61	0	9	97	0.4	x	Comparative example
15	E	1240	5	1150	900	16	10	5	510	<u>80</u>	12	50	<u>25</u>	<u>23</u>	2	98	0.4	x	Comparative example
16	F	1240	5	1150	900	16	10	5	530	130	10	46	46	2	6	94	0.8	O	Inventive example
17	<u>G</u>	1240	25	1150	900	16	10	5	550	130	11	46	48	1	5	95	0.7	x	Comparative example
18	<u>H</u>	1240	10	1150	900	16	10	5	570	130	10	42	53	0	5	95	0.5	x	Comparative example
19	<u>I</u>	1240	5	1150	900	16	10	5	590	130	10	47	49	0	4	96	0.6	x	Comparative example
20	J	1240	10	1150	900	16	10	5	510	130	8	52	41	3	4	96	0.7	O	Inventive example
21	K	1240	15	1150	900	16	10	5	530	130	11	50	45	1	4	96	0.5	O	Inventive example

22	L	1240	20	1150	900	16	10	5	550	130	10	44	50	1	5	95	0.5	O	Inventive example
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The underlined values lie outside the scope of the present invention.

[0069]

Regarding the area ratios of magnetite, a eutectoid transformation microstructure 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.

[0070]

The integrated intensity of a diffraction peak of each phase in the scale was measured with an X-ray diffractometer using a $\text{CoK}\alpha$ radiation source, and the mass fraction of hematite was determined 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 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.

[0071]

For the arithmetic average roughness of the interface between the scale and the steel substrate, after the scale on the steel sheet surface is removed by pickling, the three-dimensional shape of the surface of the steel substrate is measured with a laser microscope, and five roughness curves with a reference length of 100 μm parallel to the rolling direction are extracted. The arithmetic average roughnesses of these sections were then averaged.

[0072]

The adhesion of scale in the present invention was evaluated in terms of flaking-like peeling resistance. That is, 30 mm x 100 mm test specimens were taken from the hot-rolled sheets after the leveling so that the longitudinal direction was parallel to the rolling direction, and were then bent by a press bending method in accordance with JIS Z

2248, and a tape was attached to the surfaces of the steel sheets on the outside of the bend to peel off the scale. The bending conditions included the ratio r/t of the pressing tool tip radius r to the test specimen thickness t of 4 and a bending angle of 180 degrees. An image of a portion of the steel sheet surface from which the tape was peeled off 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 from which 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%, the flaking-like peeling resistance was judged to be good and was shown as a circle in Table 2. On the other hand, when the area ratio of the steel substrate exposed portion was 10% or more, the flaking-like peeling resistance was judged to be poor and was shown as a cross in Table 2.

[0073]

The examples of the present invention shown in Table 2 had high flaking-like peeling resistance of scale, whereas the comparative examples had low flaking-like peeling resistance of scale.

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 25 μm or less and

has a microstructure containing, in terms of area ratio,

magnetite: 20% or more,

a eutectoid transformation microstructure of iron and magnetite: 30% or more,

wustite: 15% or less, and

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

an interface between the scale and a steel substrate

has an arithmetic average roughness of 0.3 μm 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:

heating a steel material with the chemical composition
according to Claim 1 or 2 at a heating temperature of 1150°C
or more, descaling the steel material;

then performing hot rough rolling and descaling by

water injection at a pressure of 30 MPa or less;

performing finish rolling at a finish rolling delivery temperature in the range of 800°C to 950°C;

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

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

coiling at a coiling temperature in the range of 500°C to 630°C; and

holding in the 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:

heating a steel material with the chemical composition according to Claim 3 at a heating temperature of 1150°C or more, descaling the steel material;

then performing hot rough rolling and descaling by water injection at a pressure of 30 MPa or less; performing finish rolling at a finish rolling delivery temperature in the range of 800°C to 950°C;

cooling at an average cooling rate of 5°C/s or more in

the temperature range of the finish rolling delivery temperature to 750°C;

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

coiling at a coiling temperature in the range of 500°C to 630°C; and

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